Reliability Abstracts and Technical Reviews

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Reliability Abstracts and Technical Reviews

JANUARY 1967

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Number 1

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Reliability Abstracts and Technical Reviews

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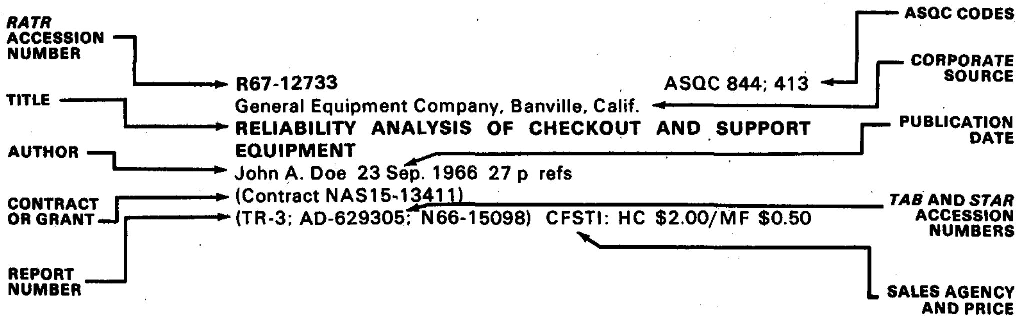
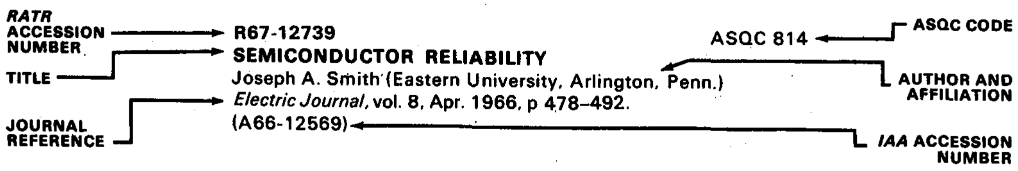
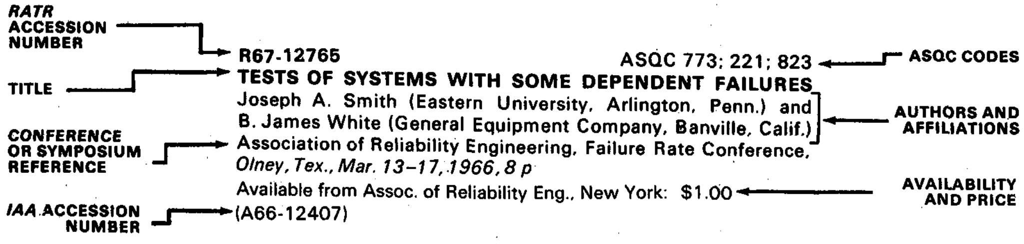


R67-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N66-15098) CFSTI: HC $2.00/MF $0.50



R67-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A66-12569)



R67-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, *Olney, Tex., Mar. 13–17, 1966, 8 p*
Available from Assoc. of Reliability Eng., New York: $1.00
(A66-12407)

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VOLUME 7 NUMBER 1

Reliability Abstracts and Technical Reviews

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January 1967

80 RELIABILITY

R67-12908 ASQC 800

RELIABILITY QUESTIONS AND ANSWERS.

A. J. Bonis (General Motors Corp., AC Electronics Div., Milwaukee, Wis.).

Industrial Quality Control, vol. 22, no. 11, May 1966, p. 606–610.

Reliability engineering effects on the general consumer, the more specialized markets, and the manufacturing processes are described. Definitions of reliability are presented, and distinctions between quality control and reliability are indicated. It is pointed out that an experienced person should be especially designated to perform reliability analyses to follow up on equipment failures, and to operate an effective failure recurrence control system. It is recommended that the reliability chief must be at a sufficiently high level in the organization to participate in management decisions. The necessity of tradeoffs between higher R & D costs and greater reliability is mentioned. A step-by-step description of the reliability function in planning, design, manufacture, and operation is included. N.E.N.

Review: This is both easy and worthwhile reading for beginners and old hands alike. In some ways, it does not say a lot, but the nature of the comments shouts a great deal. Some idea of the differences of opinion in the field is evident; presenting these differences is most helpful. People with different backgrounds can expect to get different things from the paper.

R67-12909 ASQC 801; 844

PROBLEMS DEPARTMENT: PROBLEM 2-66 AND REPLY 2-66.

Richard A. Freund, ed.

Industrial Quality Control, vol. 22, no. 11, May 1966, p. 617–618. 6 refs.

Dimensional units of failure rate are discussed. Definitions and expressions are presented for the failure rate, the average failure rate, and the probability of item failure in a given time interval. It is shown that the proper dimension of the average failure rate or the instantaneous failure rate is (unit time)$^{-1}$, or "per unit time". The distinction is drawn between "failures" and "per unit time" in the expression "failures per unit time". It is emphasized that the term "failure" indicates the types of observation and is not part of the dimension. Illustrations are given, and generalized Poisson process is briefly considered. N.E.N.

Review: The problem posed is essentially "What are the proper units (dimensions) of the average or instantaneous failure rate?" It is adequately discussed here. Non-statisticians can easily be confused by terminology, units, etc. and explanations such as this are helpful. (There is another definition for failure rate that is often used: $h(t) = -dR/dt$ and it is an instantaneous failure rate.)

R67-12910 ASQC 800

RELIABILITY ENGINEERING AND SUCCESS IN SPACE EXPLORATION.

N. E. Golovin (Office of Science and Technology, Washington, *(Western Operations Research Society of America, Annual Meeting, 10th, and International Meeting, 1st, Honolulu, Hawaii, Sept. 14–18, 1964, Paper.)* *Industrial Quality Control*, vol. 22, Mar. 1966, p. 457–464. 10 refs.

(A66-3742)

Attempt to understand the problem of how a spacecraft development and test program is to be conducted so that the operational flight readiness of a manned space system can be assured with a minimum number of flight test mission cycles, with discussion of some of the methods which must be applied if quantitatively justifiable solutions are to be found. Classical reliability engineering concepts are examined critically. It is considered that important advantages may ensue from organizing complex system developments in general and reliability engineering efforts in particular in cybernetic form–i.e., so that the assignments and separations of functions, definitions of the flows of information, and specifications of control relationships provide the optimum practical structure for learning from, and changing because of, new experience. IAA

Review: This is a long essay on the philosophy of reliability engineering and on predictions of reliability. The points are all worth discussing; many generate a valuable controversy. Classical, traditional statistical methods are overenthusiastically designated as being "scientifically established." These methods are mathematically consistent of course, but how useful they are when applied to the treatment of data is something else again. In this latter sense, traditional statistical methods are not scientifically established; no method can be so established–the concept is not applicable. It is easy to get from the text the idea that some procedures are totally quantitative to the exclusion of qualitative assessments. This is not the case. To go from experimental data to engineering conclusions requires many and varied assumption and judgments. Mathematics is often used in this chain, but just because the mathematics is correct (i.e., no violation of the rules) does not mean that the results are useful. Some methods of analysis have the mathematics or statistics near the beginning and some have them near the end; the rest is filled with engineering judgments. There is a grossly unjustified tendency to think that when the mathematics comes at the end, the answer is solid because it is mathematical. Engineering confidence is the only kind of confidence we are ever after in designing spacecraft or anything else. The original setting of reliability goals, of choosing conceptual models for analysis, etc. are all matters of engineering judgment. The results of this judgment may well be the setting of quantitative goals or the establishment of statistical tests. Many factors are not accounted for by our conceptual models; so the results of our analyses must be applied with engineering judgment. It is also easy to infer from the paper that science and engineering approach the problem of predicting/estimating reliability quite differently. There is no place at all for probability in the physics of devices (ignoring wave and statistical mechanics which are not involved here)—thus reliability in its probabilistic interpretation has no meaning at all. Engineering is the discipline that deals in working systems and hence must deal as well with approximation, lack of knowledge, and uncertainties. It creates the mathematical models which, it is hoped, will adequately represent the real situation. Now, rather exact models have several difficulties–they are hard to create, they tend to be quite intractable, and they are almost impossible to evaluate. Practical models that are creatable, tractable, and evaluable have, of course, the unknown approximations which tend to destroy the exactness one was seeking and which introduce uncertainties. While the dilemmas mentioned above are clearly presented in the paper, they are not clearly analyzed. Part of the root of the problem is involved when high reliability is expressed as a probability in the first place. When relative frequency is being modeled by probability, it becomes apparent that it has little meaning unless at least one event is likely. Ten vehicles with a reliability of 0.999 allows only 0.01 failures. What does that mean? Nothing. The program for improving knowledge about part behavior is good, irrespective of philosophic arguments about the meaning of reliability and the proving of it. The article itself serves a useful purpose in bringing this discussion out into the open in a productive way.

R67-12965 ASQC 800; 870

MECHANICAL RELIABILITY RESEARCH IN THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION.

Welfred M. Redler (NASA, Reliability and Quality Assurance Office Washington, D. C.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 763–768. 6 refs.

(A66-37959)

Description of representative research and development projects on reliability to identify their objectives and results. The mechanical failure problem is examined and efforts to eliminate these failures are studied. The need for mechanical reliability improvement is discussed and a reliability demonstration using overstress testing is considered. Other topics discussed include the reliability of structures and components subjected to random dynamic loading, a cumulative fatigue damage survey, the JPL high-impact program-1965, and reliability and design analysis of the brushless dc motor. All the projects mentioned represent the bulk of the NASA efforts in the mechanical research for improved reliability.

IAA

Review: These four papers provide a useful and interesting review of the reliability and maintainability research being sponsored by NASA and DoD. The first paper provides a good summary of NASA efforts aimed at the improvement of mechanical reliability, an area generally considered to be neglected. The Air Force paper is by far the longest, most comprehensive, and has the most references. The comments which put the Physics of Failure program into perspective are very good. (A minor criticism is that the area of overlap of stress and strength distributions is graphically referred to as interference theory. This is misleading since the exact nature of interference theory is more complicated.) The Army paper uses the term "inherent" reliabilitv which is a most elusive concept to pin down; it implies more than exists for it. The Navy paper has an appended bibliography which includes abstracts for many of the references (although some of the sources are not sufficiently identified to enable the reader to find them); the bibliography contains much of the meat of the paper. Only the Air Force paper refers directly to work on Bayesian methods of estimating and demonstrating reliability; several of the references in the Navy paper are on this topic. Some of the references and work summaries refer to items with restrictions on distribution (e.g. DDC documents with AD numbers in the 400,000 series).

R67-12966 ASQC 800; 870

RELIABILITY AND MAINTAINABILITY RESEARCH IN THE UNITED STATES AIR FORCE.

Joseph J. Naresky (USAF, Systems Command, Rome Air Development Center, Engineering Div., Rome, N. Y.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 767–787. 48 refs.

(A66-37960)

This paper describes the USAF reliability and maintainability research program which has as its goal improved understanding, prediction, measurement, control, and correction of failure of component parts, equipment, and systems under the diverse stresses and environmental conditions encountered in USAF operations. It encompasses these efforts which can be classified as either research or exploratory development. A significant portion of the work described is being done at Rome Air Development Center (RADC), the focal point for reliability and maintainability research within the USAF. The paper, however, does not limit itself to RADC's program but includes all of the known reliability and maintainability research being performed. It describes work being done in seven USAF laboratories. Author (IAA)

Review: See R67-12965

R67-12967 ASQC 800; 870

RELIABILITY AND MAINTAINABILITY RESEARCH IN THE U. S. ARMY.

Norman C. Krause (U. S. Army Materiel Command, Washington, D. C.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 788–793. 17 refs.

The broad spectrum of reliability and maintainability research in the U. S. Army is outlined and some examples illustrate the current status of projects in this area. An evolutionary presentation is included to show how changing configuration and mission requirements have influenced the development of reliability and maintainability programs. Among the primary areas of research discussed are testing concepts, instrumentation, and methodology; modeling and statistical methodology; data collection systems; cost considerations; materials research, and reliability engineering. A listing of problems which require attention includes maintainability methodology, failure mechanisms in electromechanical and mechanical subsystems, improvement in quantification methods, self-checkup and automatic diagnostic aids, and materials research that considers both equipment and environments. M.W.R.

Review: See R67-12965

R67-12968 ASQC 800; 870

RELIABILITY AND MAINTAINABILITY RESEARCH IN THE U. S. NAVY

Keith N. Sargent (ARINC Research Corporation, Santa Ana, Calif.) and John W. Stone (Naval Material Command, Washington, D.C.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 794–810. 121 refs.

Analyses of operations, human factors, effectiveness, hardware; and materials, applications, and testing are discussed for the reliability and maintainability research program conducted by the U. S. Navy. It is noted that effective analysis, which includes costs, encompasses about 46% of the total research effort. Investigations are concerned with determination of significant parameters, assignment of criteria, and design evaluation requirements; and much of the effort has been devoted to the compilation of failure rate and mode data. Applicable provisions of two recent documents which establish policy for reliability of naval material are included; and a bibliography, partially annotated, is appended. M.W.R.

Review: See R67-12965

81 MANAGEMENT OF RELIABILITY FUNCTION

R67-12903 ASQC 813

MINUTEMAN MICROELECTRONIC RELIABILITY CONCEPTS.

Donald G. Cummings (North American Aviation, Inc., Autonetics Div., Data Systems Div., Anaheim, Calif.).

Electronics in Transition; Winter Convention on Military Electronics, 6th, Los Angeles, Calif., February 3–5, 1965, Proceedings. Volume 4. Conference sponsored by the Professional Technical Group on Military Electronics of the Institute of Electrical and Electronics Engineers, Los Angeles Section. Los Angeles, Institute of Electrical and Electronics Engineers, Los Angeles District, 1965, p. IID-1 to IID-9.

(A65-23189)

Comparison of the Minuteman I and Minuteman II reliability concepts, stressing the approach being used in Minuteman II to accomplish the reliability objectives. Minuteman II component-reliability requirements differ in concept and mechanics of implementation from those of Minuteman I. Minuteman II has introduced the use of large numbers of microminiature electronic components in the design of the improved guidance and control system. Minuteman I utilized funded Reliability Improvement Programs (RIP's) to effect and verify several-orders-of-magnitude improvement in failure rate on various transistors, diodes, resistors, and capacitors. Minuteman II is using Component Quality Assurance Programs (CQAP's) and stressing a physics-of-failure approach to effect the required failure-rate improvement in the microminiature components. This is in addition to maintaining the Reliability Assurance Program provisions of Minuteman I. The use of integrated circuits in Minuteman II has shifted the responsibility for proper derating to the supplier, whose skill as a circuit designer becomes a major factor in attaining the required reliability. Since Minuteman II utilizes a relatively large number of integrated circuits to replace discrete devices, the reliability of these devices is of paramount importance. Emphasis is therefore placed on the identification of failure modes and the alteration of designs and processes to reduce the effects of these modes to a negligible level. Author (IAA)

Review: This paper reviews the Autonetics Minuteman Reliability Improvement plans for both I and II. The success of these programs and their beneficial impact on the electronics industry is widely acclaimed. The shift in emphasis from Program I to Program II is interesting, showing both a saturation of benefits from the earlier type of program and a trend in the industry toward accelerated testing and physics-of-failure approach. The discussion is general enough for anyone interested to follow and pointed enough to be beneficial. Individual suppliers have also published their experiences with Program II.

R67-12904 ASQC 813; 838; 844

REALIZATION OF THE RELIABILITY POTENTIAL FOR MICROELECTRONICS.

E. B. Gould, III and C. A. Wiley (Hughes Aircraft Co., Semiconductor Div., Newport Beach, Calif.).

National Winter Convention on Military Electronics, 5th, Los Angeles, Calif., Feb. 5–7, 1964, Proceedings. Volume 3. Convention sponsored by the Professional Technical Group on Military Electronics, Institute of Electrical and Electronics Engineers. Edited by R. F. Lander. North Hollywood, Western Periodicals Co., 1964, p. 2–61 to 2–67.

Reliability potential for microelectronic equipment is considered in terms of assessing each step of a production line, and to bridge the gap between various failure mode experiments and quality assurance of the finished product. Methodology employed, team effort, and the importance of training programs are discussed. Basic definitions and levels of redundancy are treated; and attention is given to component, functional, and material redundancy. It is concluded that reliability requirements for military electronics will always be ahead of the state-of-the-art until redundant, microelectronic, self-contained structures are available. It is suggested that the necessary requirements for microelectronic production technology can be met by implementing the reliability research technology; and, specifically, through the use of (1) parallel resistive elements for protection from opens, (2) series capacitive elements for protection from shorts, (3) series active elements for automatic gain, and (4) alloy contacts to package pins. M.W.R.

Review: This is a good short article, except for the part on redundancy. The emphasis on sound engineering analysis during design is good. In the Redundancy part there are several deficiencies, for example: (1) Failure probabilities rather than failure rates must be used. The authors' formula "λ (redundant) = λ^n" is incorrect. This error persists through much of the discussion. (2) Using mean life as a figure-of-merit for improvement by redundancy is not a good idea. Failure probability, for a period short compared to component mean life, is better. This is actually illustrated by the chart. (3) The section on material redundancy is not at all clear when specifics are sought. (4) The definitions given are actually assumptions, and this does make a difference.

R67-12916 ASQC 810; 815; 833; 844

PUT ENGINEERING EFFORTS BACK IN RELIABILITY TECHNIQUES.

Raymond H. Hollis (Sanders Associates, Inc., Nashua, N. H.). *(Institute of Electrical and Electronics Engineers, the 1965 Electronic Components Conference, Washington, D. C., May 5–7, 1965, Paper.) IEEE Transactions on Parts, Materials and Packaging,* vol. PMP-1, Jun. 1965, p. s-297–s-302.
(A65-30837)

Suggestion that reliability-analysis techniques be reoriented so that the statistical methods currently used may by employed in a manner that is meaningful and effective for the design engineer. Standards, specifications, and techniques for ensuring high system reliabilities are discussed, and suggestions are given for further improving reliability-engineering methods. IAA

Review: This is an essay on what is wrong with Reliability and what to do right. It is not always very clear, but most of the assertions appear to be made very positively. It would be foolish to deny that much inadequate, poor, and misleading work has been done in the name of Reliability; but the situation is not as bad as it appears to be painted and there has been an emphasis on engineering. In fact, some spokesmen assert that Reliability should be the responsibility of the designer, just as other requirements are his responsibility. The author draws considerably on his company's procedures as illustrations of the right way to go about Reliability engineering. The adequacy of procedures depends very much on the circumstances, e.g., company organization and peculiarities of the contract. The paper is interesting to read and one gets some kind of feel for the problem and solutions from reading it. Much of the feel will be from the reader's own views on how to implement the title.

R67-12923 ASQC 813; 833; 840

A PRIME CONTRACTOR'S RELIABILITY PROGRAM FOR COMPONENTS/PARTS FOR THE DOUGLAS S-IVB STAGE PROJECT.

R. B. Wilson (Douglas Aircraft Co., Inc., Reliability Engineering Branch, Huntington Beach, Calif.), and N. L. Hug (Douglas Aircraft Co., Inc., Electronics Dept., Huntington Beach, Calif.).
Annals of Reliability and Maintainability, Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 3–11. 1 ref. NASA-sponsored research.
(A66-37880)

Description of the activities of a parallel-reliability program applicable to overall project reliability. In the normal course of development the first major portion of the program is dedicated to achievement of desired design reliability by focusing all available experience on technical development problems. The second part of the program is directed toward the maintenance of the designed level of reliability during manufacture and use of the hardware. IAA

Review: The parts reliability programs which are described in these three papers are representative of those which are now found at missile and space hardware producers, and which have played a significant role in the increased reliability over that which existed in the first few years of the missile and space era. These parts reliability programs are similar to each other, which indicates industry-wide selection of the most effective approaches. Various worksheets are attached, and these as well as the discussions might convey throughts which are useful to the parts specialist.

R67-12924 ASQC 813; 833; 840

SYSTEMS ORIENTED PARTS MANAGEMENT CONSTRAINTS.

Leo W. Geary (Hughes Aircraft Co., Culver City, Calif.).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 12–18. 4 refs.
(A66-37881)

Discussion which considers electronic component part programs from the standpoint of management and a consideration of the basic managerial functions with their relationship to the subject at hand. The application of the five managerial functions—planning, organizing, staffing, directing, and controlling—to a number of parts program (with an analysis of the system-imposed constraints) is examined. IAA

Review: See R67-12923.

R67-12925 ASQC 813; 833; 840

APOLLO CSM PARTS MANAGEMENT—A LEGACY FOR FUTURE SPACE PROGRAMS.

Howard L. Steverson (North American Aviation, Inc., Space and Information Systems Div., Downey, Calif.).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 19–30.
(A66-37882)

Review of the parts management program for the Apollo command service module (CSM). The scope and implementation of the program are discussed and the results achieved are presented. Specified constraints imposed on Apollo CSM parts are presented in terms of design requirements, manufacturing process controls, and qualification test criteria. Apollo technology is discussed in terms of operational and environmental requirements. IAA

Review: See R67-12923.

R67-12936 ASQC 817; 431; 614; 615

RELIABILITY-MAINTAINABILITY COST TRADE-OFF VIA DYNAMIC AND LINEAR PROGRAMMING.

W. J. Reich, D. A. Miller (Conductron Corp., St. Charles, Mo.), and W. A. Flannery
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference, sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 310–329. 8 refs.
(A66-37911)

This paper considers the application of Howard's dynamic programming algorithm to the study of the "cost-reliability trade-off" problem associated with complex repairable systems which are subject to availability constraints. The generalized problem is formulated in terms of states, alternatives within states, transition rates, and expected costs. Each of these factors is discussed in some detail, first in general terms and then in a numerical application. The assumptions and approximations required are stated explicitly, probably the most important of which is the use of the Poisson process and associated exponential probability law; however, even with this restriction, use of the method is shown to possess considerable merit for performing system configuration feasibility studies in the preliminary design stage. In the appendix, the generalized data array and concomitant iteration cycle are presented in terms of Howard's algorithm. The same problem formulated as a linear program is then given along with a brief discussion of the method used for handling the availability constraints and performing sensitivity analyses. The systems considered in the paper are stationary stochastic processes in the sense that the transitional probabilities are a result of the use of the Poisson distribution. Further, by the nature of the physical problems considered, the processes are ergodic; that is, all states communicate (one recurrent chain). IAA

Review: The title of this paper aptly describes it. A well-presented discussion is given of the application of the programming algorithms to system and cost-effectiveness problems. It is not stated whether the aircraft simulator which is analyzed is a hypothetical situation, or a real one where the results of the analyses were actually implemented. In any case, enough detail is presented to make this paper suitable for careful study by those interested in applications. The solution here is not just a matter of a single optimal decision, but rather the results of a number of related analyses which build on previous results, such as bringing in an additional constraint, conducting a sensitivity study, and obtaining numerical values for certain related characteristics which are of interest. This paper does not dwell much on the basics of dynamic and linear programming; suitable references are given. A computer program is attached, but it is not cited in the paper.

R67-12938 ASQC 810; 871

PROGRAM MANAGEMENT AT THE SUBSYSTEM SUBCONTRACTOR LEVEL FOR PRODUCT RELIABILITY AND MAINTAINABILITY.

G. A. Dove, D. P. Mundell, and E. E. Johnson (Texas Instruments, Inc., Dallas, Tex.).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 345–353.
(A66-37914)

Description of a case study of a program management approach in developing the An/APQ-110 terrain-following radar for the F-111A. The F-111A is one of the first major weapon systems to have specified quantitative reliability and maintainability requirements. The description is made from the perspective of the AN/APQ-110 program manager and shows how he coped with the problems of achieving the reliability and maintainability requirements with emphasis on the development portion of the program. A detailed discussion is given of how he organized to use effectively the reliability and maintainability specialists as part of his line organization in meeting overall performance, schedule, cost, and contractual requirements. Considerable use is made of actual data and results from the AN/APQ-110 program to illustrate problems the program manager faced and the full accomplishment of program objectives. IAA

Review: This paper presents a case study which represents a different environment with respect to reliability and maintainability for an equipment contractor than the environment which was prevalent not very many years ago. The paper deals with organizational and management considerations, and, as the discussion is centered about a timely case study, it has a ring of reality. Unfortunately, the real-life motivational factors of many designers versus those of achieving reliability and maintainability are a problem confronting the program manager. In this case there is a fixed price contract with a reliability demonstration and correction of deficiency clause, and management in such a situation must somehow overcome the attitudes of designers who think only of performance. A somewhat unique feature of this reliability program is a full pre-demonstration reliability test, which was quite significant as this test was failed and much improvement was necessary. Somewhat aside from this paper, there is inconsistency between the rigorous tone of the cost effectiveness case study in this paper, which is about the terrain-following radar for the F-111A aircraft, and the reports which have been appearing in the trade magazines to the effect that costs of this aircraft have increased greatly over what was expected.

R67-12941 ASQC 810; 840; 850

THE XB-70A RELIABILITY PROGRAM.

Wj H. Hatton and L. J. Modiest (North American Aviation, Inc., Los Angeles, Calif.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness, Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 380–392.

(A66-37919)

Discussion of the approach used in formulating and implementing the XB-70 reliability program from its inception to the present flight test program. The XB-70 reliability program was unique in that it was one of the first full-scale applications of a reliability program to an aircraft beginning in the initial system design stage. The qualitative and quantitative reliability goals which were established enabled the designers to consider reliability as one of the elements in making design decisions. The XB-70 research program has been highly successful from a reliability standpoint. This success is attributed in part to the early and continued implementation of a planned, comprehensive reliability program.
IAA

Review: Some of the standard reliability techniques are presented in this report about the XB-70A aircraft. It appears that a reasonable effort was made, keeping in mind that this program was experimental and dated back almost a decade. Although not discussed in the paper, the mid-air collision and crash of the XB-70A No. 2 with loss of life provides a costly example of the frustrations of quantitative safety and reliability analysis.

R67-12945 ASQC 813; 770

INDUSTRY–GOVERNMENT RELIABILITY PROGRAM FOR A HIGH-DENSITY WOODEN ROUND MISSILE.

Carl J. Berry (U.S. Army Missile Command, Product Assurance Test Div., Redstone Arsenal, Ala.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 505–514. 3 refs.

(A66-37933)

Definition of a reliability program to insure initial and continued reliability of a weapon system which consists of a noncheckable missile and its associated checkable and repairable launcher-guidance set. The following methods used by the prime contractor for determining reliability are treated: (1) by incremental stress search for reliability margin, (2) by reliability margin verification—large sample, (3) by reliability margin verification—small sample, and (4) by MTBF testing. The Missile Command conducts reliability tests by (1) time testing (MTBF), (2) attribute testing, and (3) testing-to-failure. Failure and test results are exchanged between the prime contractor and the Missile Command to insure that any required design changes are made as early in the program as possible.
IAA

This is a general descriptive paper that gives an idea of the type of tests being performed. (A wooden round missile is not part of a bow and arrow, but is a missile that is fired without preflight check.) The program cannot really be evaluated from this paper, but enough information is given so that those working on other programs can note similarities and differences, then request more information on points of concern.

R67-12946 ASQC 813; 760; 840

THE "ASTRAL" PARTS PROGRAM—A NEW DIMENSION FOR TESTING HIGH RELIABILITY PARTS FOR THE SATURN V INERTIAL GUIDANCE SYSTEM.

Robert F. Unger (Bendix Corp., Eclipse-Pioneer Div., Teterboro, N. J.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 515–527.

(A66-37934)

Discussion of a program for assurance and stabilization trend for reliability by analysis of lots. This program currently operating with full implementation of the most modern techniques available in the field of high reliability is providing realistic information concerning the state-of-the-art performance of parts selected for use on the Saturn V inertial guidance system (ST124M). The purpose for investigating this up-to-the-minute performance of parts is to establish and maintain the highest level of acceptance criteria that will allow the network of components in the system to perform their planned objectives with optimum precision necessary for the success of the mission.
Author (IAA)

Review: Elaborate parts screening tests such as described in this paper are becoming routine on high reliability programs for space systems. Most of this paper is a detailed description of the procedures which are used in this program, and therefore it may contain some ideas for those concerned with the planning of parts screening tests. Little is presented in the way of results of this program, or of an evaluation of its effectiveness.

R67-12947 ASQC 815; 840; 850

RELIABILITY TESTING AND MIL-STD-781A.

Henry R. Thoman (U.S. Navy, Air Systems Command, Washington, D.C.) and Carl G. Wigginton (U.S. Navy, Ammunition Dept., Crane, Ind.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 535–544. 1 ref.

(A66-37936)

Discussion of recent experiences in reliability testing programs applied to aircraft electronics equipment and description of the development of MIL-STD-781A, entitled "Reliability Tests: Exponential Distribution." Several examples of common contractual and specified requirements for reliability testing are presented. The relationship between the reliability prediction and measurement techniques is explored. MIL-STD-781A is described, and background information on the derivation of certain of its requirements is given. Some of the cautions which must be observed in the use of MIL-STD-781A are outlined, and trends in the application of these reliability testing techniques are noted. A typical premium schedule for use in incentive contracting for reliability given. IAA

Review: The discussions of some features of MIL-STD-781A and of general experiences with reliability testing which comprise this paper are timely and readable. The authors are with the government and thereby have the opportunity of a broad visibility. There is little doubt that the authors are enthusiastic proponents of the formal reliability demonstration test. Poor fabrication workmanship is reported here as the main failure cause; this observation coincides with that of others. It is well to keep in mind that when we are lamenting the preponderance of these "quality control" failures, we should be indicting the "manufacturing" department as well as the "quality control" department. "Manufacturing" is committing the poor workmanship and "quality control" is letting them get by. Both of these departments need to become honestly concerned with the reliability implications of their actions before any meaningful improvement can be achieved. In a private communication, the first author has commented as follows. "I am not sure the word "formal" describes our enthusiasm. We believe equipments should have operating time under environmental conditions for a significant period of time. We believe the "test" should be made as soon as possible after the equipment is designed and/or constructed; and we believe that the test should serve to place constant pressure on the producer to do a good job. We have designed formal procedures *only* to make it easier for engineers to use the technique and to provide better analysis and comparison of results."

R67-12964 ASQC 812

RELIABILITY TRAINING–INDUSTRY'S DILEMMA.

J. Frederick Medford (Bell Aerospace Corp., Bell Aerosystems Co., Buffalo, N. Y.)

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 744–753. 9 refs.

(A66-37958)

Description of the problems confronting the aerospace industry in the training of new reliability engineers in view of the critical shortage of this type of engineer. The questions raised by this dilemma are explored and it is indicated where *industry and university contributions will do the most good to* alleviate the problem in the short and long run. The action for the short run will involve training design engineers to become reliability engineers and setting up comprehensive training classes in-house for continuous reliability training of all personnel whose work affects product reliability. The only hope for the long run is that industry must support *universities and colleges in setting up and teaching reliability* courses, institutes and seminars to a greater extent in the future than they have in the past. IAA

Review: "Half of what a graduate engineer knew ten years ago is obsolete today and fully half of what he needs to know for the next ten years is completely unknown today." This dilemma is explored in relation to reliability engineering. In-house training programs provide a temporary solution or part of a solution. Intensive short courses can play an important part. For the long-range solution, Industry and the universities must work together. This paper is a good concise discussion of the problem and its possible solutions; references cited will provide more detail on some points. Some of the same ideas are discussed in the papers found on pp. 894–943 in the same volume. (It should perhaps be pointed out that the statement quoted above is not without its controversy.)

R67-12973 ASQC 812

RELIABILITY EDUCATION—THE STATUS.

Paul H. Zorger (Vitro Labs.; American University, Washington, D. C.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 894–896.

An introduction is presented to a session devoted to the status of reliability educational programs in government, *industry, and universities; and note is made of the reliability* void that exists because of expanding research and development programs. Mention is made of the five papers included in the session that deal with surveys of existing programs, needs that have to be met in future program planning, and proposals to meet the increasing demands of reliability in mission planning. All of the papers are concerned with the contributions of reliability and maintainability disciplines to the optimization of system and cost effectiveness. M.W.R.

Review: Collectively the five papers presented in this session (including the chairman's introductory and concluding remarks) provide a comprehensive and detailed picture of the status of reliability education. They also indicate the needs, and what must be done to meet them. The second paper, based on a Master's thesis by the author, provides a good analysis of reliability engineering education in the colleges and universities. The third paper will be of interest to those concerned with the development of curricula in reliability engineering. The fourth paper makes some reference to a curriculum also, but is concerned mainly with the less formal educational activities—conferences, symposia, etc. The fifth paper is in a more general vein, reviewing the reliability education picture in relation to current needs.

R67-12974 ASQC 812

RELIABILITY ENGINEERING EDUCATION AT COLLEGES AND UNIVERSITIES.

Catherine Dryden Hock (NASA, Office of Manned Space Flight, Washington, D. C.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 897–906. 12 refs.
(A66-37969)

This paper provides an analysis of the current status of reliability engineering at major institutions of higher learning in the U.S. A survey of major colleges and universities training engineers was made to determine the nature and department sponsorship of reliability engineering and related courses, both at the undergraduate and the graduate level. The analysis indicates that approximately 20% of the schools reviewed offer courses designated "reliability," either by course title or description. The preponderance of the courses of interest are in the Industrial Engineering program; whereas, the design engineers, enrolled in programs other than Industrial Engineering, are offered relatively little opportunity to study these subjects. The paper includes a brief review of short courses in reliability, outside the normal curricula for engineering students, taught primarily to update the skills of graduate engineers. It gives recommendations for reliability engineering curricula, both for undergraduate and graduate engineers. An appendix is included, which lists 47 schools offering courses in reliability. Author (IAA)

Review: See R67-12973

R67-12975 ASQC 812
GRADUATE DEGREE CURRICULUM IN SYSTEMS RELIABILITY ENGINEERING.
Thaddeus L. Regulinski (Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 907–910. 37 refs.

Mathematics, engineering, and socio-humanistic sequences are described for the graduate degree curriculum in systems reliability engineering at the Air Force Institute of Technology. Based on a preliminary study of needs for engineering management, the program encompasses such areas as: (1) contract administration, (2) budgetary control, (3) evaluation of contractual reliability programs, (4) systems reliability requirements, and (5) quantitative reliability and maintainability procedures. Both the initial curriculum (adopted in 1962) and the present curriculum are outlined for the six quarter program; and requirements for the thesis are given. M.W.R.

Review: See R67-12973

R67-12976 ASQC 812
RELIABILITY ENGINEERING EDUCATION ACTIVITIES IN THE UNITED STATES AND OVERSEAS.
Dimitri Kececioglu and Joe Mc Kinley (Arizona University, Tucson, Ariz.).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 911–934. 25 refs.
(A66-37970)

Survey of the important contributions of societies, universities, the Department of Defense, and the National Aeronautics and Space Administration, as well as of some companies, to the total reliability education effort in this country. The results are tabulated. These results are analyzed in terms of the total number of such events held, and the specific societies, universities, and other organizations participating. The geographic distribution of these activities and their relation to the engineering population are discussed. The trends in the titles and content of these activities are analyzed, and conclusions on their relative adequacy are drawn. The reliability education activities at the University of Arizona are detailed. Special reliability education aids are mentioned. Developments in reliability education activities in other countries are presented. Recommendations on future needs and educational guidelines are pointed out. IAA

Review: See R67-12973

R67-12977 ASQC 812
AN ANALYSIS OF RELIABILITY EDUCATION.
Dominick Amorelli (North American Aviation, Inc., Space and Information Systems Div., Life Sciences Dept., El Segundo, Calif.).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 937–941.
(A66-37971)

Discussion of the educational aspects of reliability engineering. The terms reliability and probability are defined, and general questions about education are reviewed. The specific levels of education discussed include the policy-making level of management, middle management, technical staff, general labor and clerical force, financial, purchasing, contracting, and materiel personnel, and logistics personnel. The educational influence on reliability is discussed. IAA

Review: See R67-12973

82 MATHEMATICAL THEORY OF RELIABILITY

R67-12921 ASQC 824; 224; 552; 844
A GRAPHICAL SEQUENTIAL WEIBULL LIFE TEST PROCEDURE.
Frank R. Van Wagner (International Business Machines Corp., General Products Div., San Jose, Calif.).

(Institute of Electrical and Electronics Engineers, the 1965 Electronic Components Conference, Washington, D.C., May 5-7, 1965, Paper.) IEEE Transactions on Parts, Materials and Packaging, vol. PMP-1, Jun. 1965, p. s-343–s-351. 12 refs.

Life tests were computer simulated for two sample sizes, five confidence levels, and six shape factors in order to test the joint hypothesis that $\beta=\beta_0$ (Weibull shape factor) and $\theta=\theta_0$ (Weibull scale factor). Graphical plans for this sequential procedure are determined by computing actual bounds that random walks of N devices would make in time vs. failure-count; and twelve graphs are included. Advantages and disadvantages of these plans are cited; and simulating the life test and formulating the sequential graphs are considered. M.W.R.

Review: The text of this paper is very brief, as most of the space is devoted to the graphed sequential tests. While appropriate references are cited for those who wish to go into the background details, there are some deficiencies in the presentation itself. The author implies in the introduction that his procedures will consider truncated plans. However, no further mention is made of truncation throughout the paper; in particular, on the top of page 344, one would like to know what happens if all N items on the test should fail and the observed lifetime, expressed in t/θ units, falls between the limits L_N and U_N. A typographical error exists in the last line of this action-condition table; one would reject the tested lot if $x_i \leq L_i$ It is stated that the procedure tests the joint hypothesis that $\beta=\beta_0$ and that $\theta=\theta_0$. It should be pointed out that the procedure given will not test the above hypothesis against the alternative that $\beta\neq\beta_0$ and $\theta\neq\theta_0$. For example, many combinations of values of β and θ would yield a lifetime distribution function having ordinates less than or equal to those of the hypothesized one for all values of t (time) less than total test time. In practice the procedure given would test the hypothesized distribution against alternative hypotheses determined by combinations of β and θ which yield failure distributions having larger values over a portion of the testing interval. It would also have been useful if the author had provided the results of the simulation studies which he used to obtain the smooth curves given in the figures in the paper. The restriction to specific sample sizes and the fact that "consumer" and "producer" risks must be equal will be important limitations on practical application. The author, in a private communication, has indicated that he presented a completely revised version of this paper at the 1966 ASQC Annual Technical Conference, New York City, June, 1966. (See page 704 in the transactions of that conference, available from American Society for Quality Control, Inc., 161 West Wisconsin Avenue, Milwaukee, Wisconsin 53203, price $6.00.) In the revised paper simulation is replaced by exact numerical computation, and tables replace the graphs. The author suggests that anyone interested in sequential Weibull life test procedures should read the revised paper in preference to the present one.

R67-12926 ASQC 824; 612; 844

PREDICTING BURN-IN TIME BY COMPUTER ANALYSIS.

L. J. Schneider (North American Aviation, Inc., Autonetics, Anaheim, Calif.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18-20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 31–36. 11 refs.

Fundamental terminology and methodology is discussed in relation to the burn-in debugging phase, infant mortality and failure rates, and useful life of electronic components. Two mathematical models are presented which permit the determination of burn-in time by computer analysis. One model assumes a burn-in mode exists at the start of an exponentially-distributed failure pattern. For complex electronic parts, this method is equivalent to replacing the failed unit as soon as failure occurs. Zero slope represents a straight line, and the procedure for determining this constant time point entails sequential fitting of a straight line and testing the slope for significant differences from zero. The second computerized model is considered more useful because it provides estimates of mean life, constant failure rate, and expected number of debugging failures in addition to a least squares estimate of optimum burn-in time. These models can be used with a reliability test plan to detect failure modes, determine hardware conformance to requirements, verify part failure rates, and predict field operational reliability. M.W.R.

Review: This paper has some severe difficulties in the example and derivation which cast doubt on the procedures: (1) Some of the statements are not clear and the notation is not properly explained. For example: "Model (a) assumes that burn-in mode exists at the beginning of an exponentially distributed failure pattern..."; the symbol Y_t is explained only in the Appendix, and there it appears as y_t (a typographical error). (2) The derivation in the appendix is improper: Equations A-2 and A-4 are contradictory. Further, some of the assertions in the derivations appear to follow from a prior knowledge of the answer. It would have been better to hypothesize the answer and then show its properties. (3) A failure-rate (hazard) vs. time curve is plotted as if it were accurately estimated (Figs. 5, 6). There were in fact only eight failures altogether, not a sufficient number to yield the curve. The model fits the data quite poorly and undoubtedly estimates the constant hazard portion even less well since there are very few points in that portion of the curve. (4) Although it is not uncommon to do so, it is poor practice to call the failures "chance failures" during the period of constant hazard.

R67-12937 ASQC 824; 612; 831

IMPORTANCE SAMPLING IN SYSTEMS SIMULATION.

Phyllis Nagel (Boeing Co., Aerospace Group, Seattle, Wash.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18-20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 330–327. 11 refs

(A66-37912)

An application of the Monte Carlo technique of importance sampling has been made to the problem of estimating the probability of occurrence of a rare event in complex systems. The technique depends on biasing the simulation through the use of an importance distribution so that the components, or combinations of components, that can cause the unlikely event are emphasized in the sampling. Details of the technique are presented using the concept of a fault tree as a frame of reference. Two theorems are proved which relate the general theory of importance sampling to fault tree simulation. The method has already demonstrated its effectiveness on systems ranging in size from 30 to over 1200 independent components. On the average the improvement over direct simulation has been about a factor of 100. The most dramatic improvement has been on the larger trees with small probabilities. On a tree of about 1200 inputs this method took about 20 min of machine time to estimate a probability in the range of 10^{-3} with a standard deviation of about 10% of this value. The best preliminary estimate of computer time to simulate this tree directly was about 85 hr. IAA

Review: The technique described in this paper could be a valuable design tool through making possible the relatively inexpensive estimation of the probability of the rare but hazardous event associated with a complex system. The paper is concerned with the technical aspects of importance sampling rather than with failure mode analysis, or the details of application to any specific system. However, it is indicated that this method has been successfully applied to actual systems. The big advantage which it has over direct simulation is that of saving machine time.

R67-12952 ASQC 820; 711; 712; 844

USE OF MAXIMUM ENTROPY IN ESTIMATING THE DAMAGE DISTRIBUTION OF A SINGLE DEGREE OF FREEDOM SYSTEM SUBJECTED TO RANDOM LOADING.

Haresh C. Shah (Pennsylvania University, Towne School of Civil and Mechanical Engineering, Philadelphia, Pa.), and Tsu-Yao Chow

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 598–604. 6 refs.

(A66-37942)

Use of the principle of maximum entropy to predict the probability distribution function of damage of a single degree of freedom system subjected to narrow-band Gaussian excitation. The Palmgren–Miner hypothesis is used for the fatigue failure criterion. From the probability distribution functions obtained, reliability of the vibrating system is derived as a function of the expected number of cycles up to any finite arbitrary time. IAA

Review: The concept of maximum entropy is reasonably well explained. The sample is interesting and done in detail. However—the principle of maximum entropy is not without its controversy. For example, the answer you get depends on the form of the data. Thus if y is the variable, the answer is different if log y is used for the variable. Some of the equations, which appear to be derived specially in the paper, are in fact general.

R67-12953 ASQC 821; 713; 838

ON THE RELIABILITY OF REDUNDANT STRUCTURES.

Masanobu Shinozuka and Hiroshi Itagaki (Columbia University, Dept. of Civil Engineering and Engineering Mechanics, New York, N. Y.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 605–610. 3 refs.

(A66-37943)

For a simple redundant structure of material with statistical yield point, the probabilities that the structure can sustain the applied load even after yielding has occurred to some of its members are obtained. The conditional probability of survival of the structure under the hypothesis that yielding has occurred to at least one of the members is shown to be a quantity of significance in the fail safe design. Numerical example indicates that caution should be exercised to apply the motion of fail safe design to the redundant structure against the failure due to yielding, since the conditional probability of survival is low. Author (IAA)

Review: The problem attacked here is the yielding of all the elements (failure) of a redundant structure wherein a yielded member can sustain no increase in stress and further loading is equally distributed among the as-yet non-yielded members. A set of assumptions is initially made and then a set of probabilistic equations is listed. These equations purport to solve the problem. While the set of equations undoubtedly solves some problem and perhaps the one the authors wanted to solve, the solution to the problem actually assumed appears extremely simple: Assumption (a) states effectively that a yielded member always carries the maximum possible load, viz., the load required to make it yield. Thus the probability is unity that a simple redundant structure which is acted upon by a load (and not failed), can then sustain the same load again. The maximum load the structure can sustain, no matter how often the load is applied, nor how many members have yielded already, is ΣR_i where R_i is the yield load for the *ith* member. (Fatigue is not considered, just the simple stress-strength model for failure.)

R67-12954 ASQC 824; 433

USING BAYESIAN METHODS TO SELECT A DESIGN WITH KNOWN RELIABILITY WITHOUT A CONFIDENCE COEFFICIENT.

J. H. De Hardt and H. D. Mc Laughlin (North American Aviation, Inc., Downey, Calif.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 611–617. 2 refs.

(A66-37944)

The common practice in designing a structure with high quantitative reliability results in the selection of a design whose reliability is said to be high enough with some numerical level of confidence. This often leads to disagreement concerning the level of confidence which should be required and its effect on the reliability. It is demonstrated that with the use of Bayesian methods a practical and precise determination of reliability can be attained without a confidence level attached. Bayesian methods require the existence of an a priori distribution on the reliability of designs. Theoretical and empirical evidence of the existence of this distribution is presented. Finally, formulas for computing the reliability are derived under assumptions often satisfied in structural design. Author (IAA)

Review: This paper makes a reasonable attempt at the problem of selecting a design with a required reliability using Bayesian methods. However, some of the discussion pertaining to the use and interpretation of the confidence interval rule is not correct. The rule is that if, with confidence level *β, the unknown reliability ρ' of the design is greater than the* desired reliability ρ, the design is accepted. This procedure can be applied to different designs with different reliabilities, and the confidence interval approach still has a clear interpretation and is still valid. The confidence interval statement applies to the unknown reliability ρ' and the interval will contain ρ' in the long run a proportion β of the time. On the other hand, the probability that a design will be accepted on the basis of this rule will depend on the unknown reliability ρ', the confidence level β, the number of items tested, and the desired probability ρ. For example, if ρ' is greater than ρ, but only a few items are tested, the confidence interval rule may seldom accept the design. In this case it does not necessarily accept the design with probability 1 as assumed in the example on page 611, near the bottom of the second column. However, the example does indicate that the problem of using a proper rule for accepting designs does exit. The rule proposed by the authors is to accept a design if the conditional probability of success (k or more of m replicates survive) is greater than or equal to the required probability of success given prior observations on strength and load and *a priori* distributions on strength and load. The authors' use of a Bayesian approach should be given consideration in those cases where sufficient prior information exists.

R67-12959 ASQC 822; 844

COMPARATIVE STUDY OF ACCURACIES IN RELIABILITY DETERMINATIONS.

R. K. Hood and E. P. Virene (Boeing Company, Seattle, Wash.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 686–693. 4 refs.

Specific examples of failure frequency distributions are used to compare the accuracy and applicability of normal, exponential, lognormal, and Weibull distributions in determining reliability. While the nonparametric method can give quick and, under many circumstances, good results, these distributions can validly describe failure rate patterns. If the nature of the distribution is unknown, for instance, a Weibull distribution gives the best chance of being correct. Tabulated data indicate that the nonparametric method gives reliability values somewhat lower than values determined by using the distribution that best fitted the data in question; and a loss in statistical efficiency of from 3 to 5% is estimated. The assumption that all time-independent data can be described exponentially results in a low reliability value; results with a normal distribution are erratic; and, although consistent results are obtained, the Weibull analysis is time-consuming and not always as accurate as using the right failure frequency distribution. If sufficient data and time are available, it is considered best to first determine the nature of the distribution which best fits the data on hand. M.W.R.

Review: It is well known that the exponential distribution is often applied in reliability analysis to situations in which some other distribution would in fact provide a more valid description of the pattern of failure times under study. This paper discusses the advantages and disadvantages of this approach, and then shows examples which compare the results of using a number of different distributions, both when valid and when not valid. The results of using a nonparametric method (described in the paper covered by R65-12058) are also shown. A major conclusion is that improper application of the exponential distribution can yield an overly-conservative estimate of reliability. It is also shown that while the Weibull and the nonparametric method generally yield more accurate results, the nonparametric method is quicker and less complicated to use. A final conclusion, and a very good point, is that "Nothing beats finding the actual distribution and using that in your calculations." However, *limitations on time, effort, and available data often preclude* this. While, as the authors have said, this study is subject to limitations due to the specific test data used as examples, it is a good piece of work which calls attention to some important points.

R67-12961 ASQC 824; 541; 831

PRELIMINARY REPORT ON THE RELATIONSHIP BETWEEN PREDICTED FAILURE RATES AND OBSERVED FAILURE RATES.

Herbert Dagen (ARINC Research Corp., Annapolis, Md.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 704–709. 4 refs.

(A66-37954)

Study of the relationship between predicted failure rates and observed failure rates of units when the parts complement is known. How well the predicted failure rates and observed failure rates of units compare depends on many factors which are listed. The author is concerned with one factor—the part composition of the units and part failure rates assumed in the prediction. The mathematical model used for comparing the observed and predicted failure rates is described. A comparison of regression statistics by various unit types for different failure-rate sets is tabulated. It is pointed out that on the basis of this preliminary analysis it should be possible to develop relationships to predict field failure rates with average stress-level predictions. IAA

Review: The essence of this paper is the application of two-variable linear regression techniques to some data on reliability measurements and predictions, with results presented as tables of various statistics. Very little is given in the way of interpretation of results or of conclusions which have some substance. Further, no simple presentation of the basic information is given, such as a family of scatter diagrams or histograms, which would readily convey the substance of the data and of the findings. It appears that there were some good data here, and the references which are cited in the paper may contain these data. In Figure 1 a predicted failure rate should be an observed failure rate, and the two scales are not identical in value as implied by what is shown, but rather there must be a factor of ten difference for compatibility with the equations which are shown on the figure. In the first sentence of the right column on page 707 the "three" should apparently be 13. In a private communication, the author has noted the following: "I submit that there were two basic conclusions I attempted to formulate in the paper: (1) Page 704: Although estimates of failure rates will provide valuable information for use in trade-offs and parts improvements, the above analysis shows that they can be misleading if used as a basis for choosing from among alternate configurations. (2) Page 709: Such a coefficient (correlation coefficient greater than 0.7) was observed only in the regressions run for the diode-type units for the E-2A aircraft, indicating that additional factors might have to be considered to account for a greater number of the variations in the observed failure rates. That is, a predicted failure rate for a unit is, in itself, not a very good indicator of the failure rate that is expected to be observed during operational use of the unit." In regard to the above remarks of the author, the two "basic conclusions" do not stand out in the paper. The first of the basic conclusions is contained in the introductory remarks, where the "above analysis" refers to a hypothetical example, and the part of the second conclusion which was in the paper appears there as another remark about the various statistics. The actual conclusions section in the paper says nothing of these "basic" conclusions, but rather says in essence that it should be possible to predict field failure rates.

R67-12963 ASQC 824; 551

THE RELATIONSHIP OF EARLIEST FAILURES TO FLEET SIZE AND "PARENT" POPULATION.

R. A. Heller (Columbia University, Institute for the Study of Fatigue and Reliability, New York, N. Y.).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 722–728. 14 refs. USAF-supported research.
(A66-39756)

Use of extreme value statistics to determine the reliability of the parent population from its extremes. A method, illustrated by experimental data, is suggested for the utilization of smallest values in grouped samples toward a nonparametric estimation of population distributions. IAA

Review: Some properties of extreme value statistics are reviewed. The main topic is the prediction of population distribution functions from observations of earliest failures in grouped samples. These early failures are considered to be the extremes of the population. It is shown that small samples may be utilized in estimating reliability distribution parameters even when they constitute a small portion of the total population. This paper is applications-oriented with specific reference to structures, but this basic approach to statistical estimation is, of course, potentially applicable to other commodities. Occasionally a reliability publication will treat extreme value statistics, but it has not received the attention which other statistical approaches have. For instance, reliability texts do not typically treat extreme value statistics, an exception being [1] for those who want some further reading.

Reference: [1] Roberts, N. H., Mathematical Methods in Reliability Engineering, pp. 220–233, McGraw-Hill, 1964

R67-12969 ASQC 824

A SURVEY OF SOME RECENT RESULTS ON RELIABILITY OF STRUCTURES.

Z. W. Birnbaum (Washington, University, Seattle, Wash.).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 845–850. 10 refs. Navy-sponsored research.
(A66-37964)

Survey of results which make it possible, in complex structural systems, to make useful statements about the system reliability, such as giving lower or upper bounds or approximate values for that reliability. The evaluation of the reliability of a system when the reliabilities of its components are known is of practical importance, but such evaluation soon becomes prohibitive in the case of complex structures. Binary devices and coherent structures, reliability and life length, and the properties of reliability functions of completely known structures are considered. Bounds on reliability functions, life distributions, and some open problems are investigated. IAA

Review: This paper presents a survey of recent mathematical results (many due to the present author) in obtaining a somewhat unified theory of reliability of structures. The discussion is quite detailed with many references being given. Several of the results depend upon rather stringent assumptions but such assumptions are clearly pointed out. The paper ends by stating some important open problems in the theory.

R67-12970 ASQC 824; 412

A TECHNIQUE FOR ESTIMATING WEIBULL PERCENTILE POINTS.

John S. White (General Motors Corp., Research Laboratories, Warren, Mich.).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 851–855. 1 ref.
(A66-37965)

Consideration of a typical reliability analysis problem involving a set of 30 identical parts which had their intervals to failure recorded, in order to make certain inferences about the population from which these parts are a random sample. If $T_1, \ldots, T_N$ is a random sample of failure times drawn from a two-parameter Weibull population, and if $X_i = \log T_i$, it can be shown that the 100 P percentile point of X may be estimated by $X(P)^* = \overline{X} + S\ Z(P)$, where $\overline{X}$ and S are the sample mean and standard deviation of the X's, and Z(P) is the 100 P percentile point of the reduced log Weibull distribution. The corresponding estimate of the 100 P percentile point of the Weibull distribution is $T(P)^* = \exp(X(P)^*)$. Coefficients $D = D(N,P,C)$ are given such that $X(P)^* \pm D\ S$ is a 100 C% confidence interval for the 100 P percentile point of X. These confidence intervals are then converted to confidence intervals for the underlying Weibull distribution. The techniques are illustrated by a numerical example. IAA

Review: This paper gives a useful method for computing estimates and confidence intervals of percentiles when the underlying distribution is assumed to be Weibull with unknown shape and scale parameters. Little is known, however, about the "goodness" of the procedures. For instance, why were confidence intervals of this particular form chosen? No allowance for censoring of the data is given. Further the "confidence bands" for the population distribution are not strictly correct since in combining individual confidence intervals the overall confidence coefficient is reduced by an unknown amount.

R67-12971 ASQC 824; 412

WEIBULL ESTIMATION TECHNIQUES.

Gerald J. Lieberman (Stanford University, Stanford, Calif.). *Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers.* Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 856–860. 6 refs.
(A66-37966)

The paper is concerned with methods for finding lower confidence bounds on the reliability of an item. It briefly reviews the results for items whose life times follow an exponential distribution and an underlying Weibull distribution with known shape parameter. It discusses in detail a new simple method for obtaining exact lower confidence bounds for reliabilities for items whose life times follow a Weibull distribution where both the shape and scale parameters are unknown. The paper also presents a method for obtaining exact lower confidence bounds on the operating time required to insure a prescribed reliability for items whose life times follow a Weibull distribution where both the shape and scale parameters are unknown. Author (IAA)

Review: This paper is essentially a review of the applicability of a previous paper on which the present author was a joint author. However, the problem considered is of sufficient importance to warrant further discussion. The one here is excellent and a worked numerical example is given. It is also pointed out how the method may be used to obtain exact lower confidence bounds on the operating time required to insure a prescribed reliability.

83 DESIGN

R67-12905 ASQC 838

A COMPARISON OF TWO PRACTICAL REDUNDANCY METHODS.

Reginald A. Allen (Arthur D. Little, Inc., Santa Monica, Calif.).
National Winter Convention on Military Electronics, 5th, Los Angeles, Calif., Feb. 5–7, 1964, Proceedings. Volume 3. Convention sponsored by the Professional Technical Group on Military Electronics, Institute of Electrical and Electronics Engineers. Edited by R. F. Lander. North Hollywood, Western Periodicals Co., 1964, p. 10–2 to 10–11. (A64-21604)

Comparative study of the triple redundancy with majority voting technique and the quadded components approach. Different methods of mechanizing the redundant circuits are described; state-of-the-art limitations are discussed; failure rates, costs, and component count are given for each method. The effect of the increase in connections is considered in the calculation of failure rate, and a method of predicting the availability of the system is derived. The conclusion is reached that when system availability, economic, and production aspects are considered, triple redundancy is superior. IAA

Review: This is a paper study of flip-flops using quadded logic vs. triple majority-voting logic. The analysis goes into quite a bit of practical detail such as required current gain for transistors and thus is farily complete (except for experimental verification). Separate components, in a cordwood or printed-circuit board package, are assumed; the author points out that with integrated circuits the analysis would have to be redone. The analyses were not followed through in detail, but appear to be competent, except for one thing. In redundancy calculations for failure rate (λ) the λ depends on the mission time; therefore, failure probabilities must be used from the start, not failure rates. Since the author quotes failure rates in "per 1000 hr.," his redundant failure rates are actually failure probabilities for a 1000-hr mission. It should be emphasized that where failure is due to uncertain environmental conditions, much of the redundancy benefit is lost.

R67-12906 ASQC 838

THE APPLICATION OF REDUNDANCY TECHNIQUES TO INTEGRATED CIRCUITS FOR IMPROVEMENT IN RELIABILITY.

N. B. Metteer (Motorola, Inc., Military Electronics Div., Scottsdale, Ariz.).
National Winter Convention on Military Electronics, 5th, Los Angeles, Calif., Feb. 5–7, 1965, Proceedings. Volume 3. Convention sponsored by the Professional Technical Group on Military Electronics, Institute of Electrical and Electronics Engineers. Edited by R. F. Lander. North Hollywood, Western Periodicals Co., 1964, p. 10–12 to 10–22.
(A64-21605)

Discussion of design considerations in the application of redundant techniques to integrated circuits of the analog type. Particular emphasis is on a cascaded amplifier chain. Reliability improvement through redundancy is discussed. Design compromises are considered in detail. Design performance which substantiates theoretical results is demonstrated in the form of an integrated circuit redundant IF amplifier. This amplifier is part of a feasibility demonstration model of a command transceiver for the Office of Naval Research. It is shown that the relative improvement in amplifier reliability is considerable when using a redundant pair amplifier cascade as compared to an equivalent gain nonredundant amplifier cascade. IAA

Review: This is a good practical paper; however, its scope is much more limited than the title implies—it deals largely with parallel redundancy of analog amplifiers. The part on general redundancy and failure rates is quite standard and probably longer than necessary. The problem of deciding that all elements are operating properly to begin with is well brought out since it can be a real problem. The benefits of redundancy are appreciably reduced if there is a possibility of encountering very severe environments.

R67-12920 ASQC 833; 814; 815

RELIABILITY COST EFFECTIVENESS THROUGH PARTS CONTROL AND STANDARDIZATION.

L. P. Michaelis (General Dynamics/Fort Worth, Tex.). *(Institute of Electrical and Electronics Engineers, the 1965 Electronic Components Conference, Washington, D. C., May 5–7, 1965, Paper.) IEEE Transactions on Parts, Materials and Packaging*, vol. PMP-1, Jun. 1965, p. s-327–s-331.

Preferred parts lists, specification control drawings, and the team approach are discussed in relation to the F-111 Parts Control and Standardization (PC&S) Program for use with electronic and electrical–mechanical equipment. Main benefits of the program are: (1) standardization is obtained with a minimum number of common part types to accomplish the same function, (2) specification control drawings are written as a team effort to provide the highest reliability in terms of dollars spent, and (3) exchange of information piece parts information and program problems. It is noted that the PC&S program constitutes 5% of the cost of the total reliability program. Standardization achieved for transistors, diodes, resistors, and capacitors is tabulated. M.W.R.

Review: The idea of increasing reliability and decreasing costs by standardizing on parts and their specifications is a very good one. This paper is a rather general description of a program which is connected with the F-111 aircraft. The many benefits of such a program are well listed, although there was no mention of complaints from design engineers. Generally it is they who resist such standardization programs. Some of their complaints, such as some design penalties, are justified on a narrow viewpoint, but perhaps not on the overall view. With such apparently effective means in use, it is difficult to see how the F-111 program is now receiving such unfavorable publicity.

R67-12928 ASQC 832; 524

A METHODOLOGY TO ANALYZE AND EVALUATE CRITICAL HUMAN PERFORMANCE.

M. A. Barone (Brown Engineering Coj, Inc., Human Factors Branch, Special Programs Section, Huntsville, Ala.).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 116–122. 3 refs.
(A66-37893)

Presented in this paper is a methodology to evaluate, analyze, and predict critical human performance. The methodology is a novel approach towards evaluating potential human error. The aim of the Critical Human Performance and Evaluation (CHPAE) Program is to develop a methodology to control and minimize the natural subjectivity associated with evaluation programs. The typical approach of the CHPAE Program is: (1) analyze the system or task, (2) select evaluation factors, (3) establish and prevalidate a rating manual of check list, (4) perform an analysis and evaluation, (5) estimate potential error probabilities, and (6) perform critical comparison studies. Much work still remains to be done towards a complete and final validation of the program—partly because there is a variety of methods both computerized and manual that can be applied to quantify the evaluations and partly because of the need of large population statistics, other than experimental or selected source data to validate the error potential prediction of the plan. Regardless of the early limitations of the metric, the plan will perform a valuable human factors evaluation of a group of tasks, subsystems or systems. Author (IAA)

Review: A methodology for evaluating critical human performance could make an important contribution to the improvement of systems reliability. The program discussed in this paper may be good, but the description of it leaves a lot to be desired. Perhaps the most important lack is that of a good case-history type of description which would answer a lot of questions on the specifics of application. For example, where does one get the numbers in the body of the matrix in Table II? A variance analysis model is given without any reference to the underlying assumptions essential to the validation of the usual tests of hypotheses, or any discussion of whether data typically available will satisfy these assumptions. In the glossary at the end of the paper, the definition of "Analysis of Variance" is so poorly worded as to be virtually meaninglessj The term "Critical Factor" is defined as "a performance factor which ... has the greatest adverse effects .....," yet the discussion in the body of the paper implies degrees of criticality—not one single critical factor. The term "Statistical Parameter" is defined as an estimator—contrary to standard statistical termininology which makes a clear distinction between a parameter and an estimator. Four words are misspelled in the glossary. In short, one would need a more careful and detailed description in order to make a proper evaluation of the program.

R67-12929 ASQC 832

HUMAN RELIABILITY IN THE OPERATION OF V/STOL AIRCRAFT.

Richard de Callies (North American Aviation, Inc., Los Angeles Div., Life Sciences Group, Los Angeles, Calif.).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 133–145. 24 refs.
(A66-37895)

Study of V/STOL requirements for displays and controls for several modes of operation, including hover and transition, low-altitude high-speed, and all-weather conditions. Display concepts such as "head-up" and the "contact analog" are examined for their capability in maintaining response constancy. The results of tests using a "workspace analyzer" to investigate cockpit subsystem parameters are cited. IAA

Review: Human reliability in a man–machine environment is of importance in the planning for man's role in the operation of future aerospace systems. This paper is concerned with displays and controls in the man–machine interface of V/STOL aircraft. It serves as a useful summary/review of recent and current work in this field, and gives an indication of needed future effort.

R67-12933 ASQC 837

DESIGN FACTORS FOR STRUCTURAL RELIABILITY.

Innes Bouton, Donald J. Trent, and Halsey B. Chenoweth (North American Aviation, Inc., Space and Information Systems Div., Downey, Calif.).
Annals of Reliability and Maintainbility. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainbility Conference, 5th, New York, N.Y., July-20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, The Society of Automotive Engineers, and the American Society of

Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p 229–235. 4 refs
(A66-37905)
(Contract NASw-1052)

Development of a system of structural design factors to achieve a desired level of reliability and correct testing criteria. A standard reliability objective for a space vehicle structure of 0.9999 is proposed. This objective is implemented by defining two discrete levels of operational usage—limit and ultimate. It is shown that the desired reliability can be obtained indirectly if a very low probability of failure is achieved at the limit condition and if the ultimate condition has a very low probability of occurrence. Design factors are proposed that will result in these required low probabilities and, indirectly, in the desired reliability levels. Some examples are given of the application of the design factors to some actual structural design situations. IAA

Review: This paper is difficult to read and even more difficult to analyze. This system of reliability requirements apparently has three classes. Class 1 is an overall reliability requirement. Class 2 breaks it down into reliability requirements for environments of varying severity, and Class 3 breaks those down even further into factors of safety. Environments, called vehicle operational conditions (VOC), are split in the paper into two groups. These are shown in Figure 1.

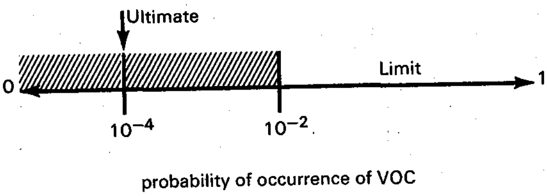


Figure 1

A limit condition has a probability occurrence of 10^{-2} or greater; an ultimate condition has a proability of occurrence of 10^{-4}. The shaded region is not discussed at all and thus the authors' analysis is incomplete. A more adequate breakdown of the environment is shown in Figure 2.

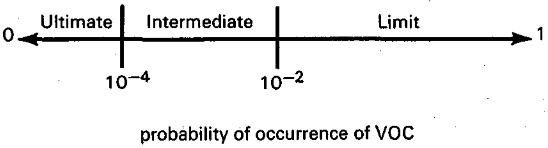


Figure 2

Here the VOC are broken down into three categories according to their probabilities of occurrence. It is seen that these three groups are both mutually exclusive and exhaustive. Limit conditions have a probability of occurrence of 10^{-2} or greater. Ultimate conditions have a probability of occurrence of 10^{-4} or less, and it is necessary to add the Intermediate group which has a probability of occurrence between 10^{-4} and 10^{-2}. The probability of failure can be expanded easily in terms of conditional probabilities where the conditions are a mutually exclusive and exhaustive set of events. (In the equations that follow, the notation will be reasonably conventional and the abbreviations used are indicated by an underlining on some of the words.) One set of conditions the authors introduced is that of a Right guess and a Wrong guess. These will be considered a mutually exclusive and exhaustive set. The other mutually exclusive exhaustive set is Limit, Ultimate, Intermediate. Then the probability of Failure is given by equation (1). In the expansion of equation (1) it has been assumed that the probability of a right guess is virtually unity and that the probability of failure given a wrong guess is also virtually unity.

$$\begin{aligned} P(F) &= P(F \mid R) \cdot P(R) + P(F \mid W) \cdot P(W) \qquad (1) \\ &\approx P(F \mid R) + P(W) \\ &= P(F \mid R \cdot U) \cdot P(U) + P(F \mid R \cdot I) \cdot P(I) + P(F \mid R \cdot L) \cdot P(L) + P(W) \end{aligned}$$

The inequality (2) is obtained by inserting the maximum probability, denoted by P_x.

$$\begin{aligned} P(F) \leq {} & P_x(F \mid R \cdot U) \cdot P_x(U) + P_x(F \mid R \cdot I) P_x(I) \qquad (2) \\ & + P_x(F \mid R \cdot L) \cdot P_x(L) + P_x(W) \end{aligned}$$

Using the standard risk as an example of how the authors' treatment might be modified to be more complete according to inequality (2), we prepare the following table.

VOC's	Ultimate	Intermed.	Limit	$P_x(W)$	P(F).
$P_x(VOC)$	1	10^{-2}	10^{-4}	– –	
$P_x(F \mid R \cdot VOC)$	10^{-6}	10^{-4}	10^{-2}	– –	
product of above (Class 2 Goals)	10^{-6}	10^{-6}	10^{-6}	10^{-6}	$\approx 10^{-6}$ (Class 1 Goal)

The maximum probability of being wrong has been included in the table and has been set at 10^{-6} to be in conformity with the other partial products which also are 10^{-6}. Since these are all maximum probabilities, we can presume that the sum will not exceed 10^{-6}. This was the desired Class 1 goal. The above table differs appreciably from the authors' table in that it is more complete. In particular, it contains the intermediate group and the probability of being wrong, and is more explicit about some of the other probabilities. It shows that in order to achieve the Class 1 goal, the probability of being wrong may well be the limiting factor. The Class 2 goals can be made reasonable extensions of the Class 1 goal, but just as the Class 1 goal is incapable of direct proof, so are the Class 2 Goals. Therefore, the authors have introduced the Class 3 goals. The specific factors of safety presented for Class 3 goals may well be adequate but the rationale for them certainly is not. Perhaps due to length requirements on the paper, the authors have not explained the source of the curve used to derive these goals. In the paper, conventional factor of safety programs are apparently denigrated as being arbitrary and difficult to administer. It is difficult to see that the Class 3 goals are less arbitrary than the traditional ones. It seems that the authors' procedure could easily be criticized by their own words which criticized other such attempts: "In recent years there have been many attempts to rationalize the choice of structural design factors by the use of structural reliability concepts. In general, these attempts have been considered to be unacceptable by the majority of those concerned with the problem. . . . Therefore, any analysis of this type inevitably includes assumptions or estimates in one form or another. Since these are judgment decisions. . . differences of opinion on these judgments will sometimes occur. . . . The present need in structural design criteria is for easily administrable procedures that can take into account the desired reliability level of the structure and practical methods of achieving it." It is worth repeating that the arbitrary factor of safety program discussed in this paper may in fact be very good. However, the justification actually presented for it in the paper is incomplete and difficult to understand. By dint of further work such as given in the tables and equations above, it may be possible to express the program in a satisfactory form. The key will lie in how well the factors of safety can be asserted to correspond to the Class 2 goals. It is extremely difficult, if not impossible, to relate margins of safety to probabilities when the probabilities are on the order of 10^{-6} Details of underlying probability density functions are just not that well known out in the region of 10^{-6}. Since probabilities of 10^{-6} cannot be demonstrated, there is a growing body of opinion which questions the usefulness of specifying those goals, at least in this present form. In a private communication, the authors have indicated that they were restricted in the length of the paper, that they did not intend to denigrate conventional factor of safety programs, and that their method is based on considerable practical experience.

R67-12934 ASQC 830; 720; 844

ULTRA HIGH RELIABILITY MEDIUM POWER TRAVELING-WAVE TUBES.

R. A. Brenan and N. A. Greco (Hughes Aircraft Co., Electronic Products, Div., Microwave Tube Div., Los Angeles, Calif.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 236–246.

(A66-37906)

Description of an approach to the design of an ultrahigh-reliability, lightweight, medium-power traveling-wave tube for use on board spacecraft. The failure modes and mechanisms of the device are pinpointed in detail with their method of control. Emphasis is placed upon a mechanical configuration which couples reliability to excellent performance, the incorporation of a long-lifetime cathode-heater design, and the selection of materials and manufacturing techniques, each capable of supporting ultrahigh reliability and longevity achievement. Data from various medium-power traveling-wave-tube test programs are cited to illustrate the success of this approach. IAA

Review: This is a well-written paper which describes the reliability effort in the TWT design. It is useful as an example of successful design and production efforts—above and beyond the TWT itself. The emphasis on failure modes and effects and on materials are good. Most such development programs have their ups and downs. None of the downs, if they occurred, are mentioned in the paper so that it reads like a success story, not like an engineering effort.

R67-12935 ASQC 831; 838; 844

RELIABILITY IN DESIGN: SOLAR-ELECTRIC PROPULSION SYSTEMS.

R. L. Seliger and J. H. Molitor (Hughes Aircraft Co., Research Laboratories, Malibu, Calif.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966. p. 256–273. 3 refs.

(A66-37908)

Study of the effect of reliability considerations on solar-powered electric-propulsion system design. An extension to the classical formulation of general reliability theory is developed for application to modularized ion thrustor arrays and power conditioning systems. The reliability of standby redundant modularized engine systems, where the number of operating models and the number in standby vary in some known manner with time, is determined. A computer program is developed which, for a given desired system reliability, determines a set of operating and standby modules which minimizes system weight. It is shown that once the number of operating engines is determined, the optimum thrustor module size can be defined. The results of a parametric study carried out with the aid of this computer program are cited to illustrate the effects of individual component weight and failure rate on overall system design and performance. IAA

Review: This is a good kind of analysis to perform on a system, but some details in the paper are cloudy or overstated. The most serious problem arises from splitting the system into two parts: one is independent of engine size and the other is linearly dependent on engine size. Equations 10, 11 do not appear to follow from the assumptions regarding dependence on engine size, and Equations 23, 24 have the same difficulty. The detail results, of course, are correct only insofar as these equations are correct. There are positive unqualified statements made which are not complete enough. For example: (1) "It is well known that the reliability of a system can be increased to any desired level (assuming highly reliable switches and monitors) if enough standbys are employed." This may well require statistical independence of failures and the presumption of no increased complications (ignoring switches and monitors) due to adding standbys. (2) The definitions of wearout and chance failures are poor. It is incorrectly stated that wearout times are normally distributed and incorrectly implied that chance failure times have a negative exponential distribution. (3) The derivations for redundancy are true only for statistically independent events. It is not obvious on its face that these failures will be statistically independent. (4) Standbys are presumed to have a negligible failure rate. Much of the analysis is not affected by these criticisms. The exploring of various possibilities is a vital part of design and should be encouraged. This paper is an example of such a process.

R67-12940 ASQC 831; 817

IDENTIFICATION OF CRITICAL ELEMENTS AS A CRITERION FOR SYSTEM DESIGN TRADE-OFFS.

Harvey G. Ryland (ARINC Research Corp., Huntsville, Ala.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Insitute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 372–379.

(A66-37916)

The paper discusses the use of critical elements (parts and components) as criteria for performing system design trade-offs. A critical element is defined as a single part (or component) which, if it failed in a specified failure mode, would result in significant degradation of system operation. The paper outlines a procedure for identifying critical elements from an FMEA at the system and circuit levels. This procedure has been successfully utilized in the selection of specific designs for space systems. The procedure presents the positive contribution to system design resulting from the identification of critical elements. Situations in which this procedure is most useful and those to which it contributes least are also discussed. Examples of the application of the procedure at the system and circuit levels are given. They illustrate the selection of the optimum system or circuit design (from a reliability standpoint) on the basis of the critical elements contained in the respective designs and the modes of operation which they affect. Author (IAA)

Review: The material in this paper is good, and at least partly tutorial in nature. Designers are concerned about the critical nature of failures and if the FMEA in use by them does not include some measure of criticality, it should. None of the examples use any failure probability knowledge in the decisions—presumably it would be lacking. One can often make guesses about the relative unreliability of elements and these guesses are better than assuming "no knowledge at all" (or more exactly, that the failure mode probabilities are similar). As this paper suggests, it is important that a designer use what information he has, even though it may not be the ultimate in completeness.

R67-12942 ASQC 836; 810

DESIGN REVIEW—PROFIT OR LOSS?

John T. Deden (TRW, Inc., TRW Systems Group, Redondo Beach, Calif.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 393–397. 10 refs.
(A66-37918)

Consideration of examples demonstrating that the primary reason for design reviews is that they have proven to be a worthwhile technique for achieving end products. It is pointed out that design reviews can and have resulted in both profit and loss. Loss-type reviews occur primarily as a result of inattentive top-line management or project management, ineffective placement of an assignment of authority to the design review function, or through failure of the review program to fulfill specified requirements. Secondary loss occurs when reviews (1) are held on an untimely basis, (2) lack the control authority over design releases, and (3) are improperly managed, staffed or conducted. Profit-type reviews occur when up-to-date and dynamic management is applied, when positive activities with data retention, evaluation, and control are applied, and when the design review activity performs both monitoring and control functions fulfilling its reason for being. IAA

Review: This is a good succinct presentation on design reviews which will be worthwhile reading for anyone having responsibility in connection with this phase of a reliability program. The points are presented, for the most part, in an enumerated format which makes for easy acquisition of the ideas. A number of good references are cited as sources of detail on acceptable design review approaches. In answering the question posed in the title of the paper, the author makes a very good point which is, in essence, that design reviews can result in a "profit" if they are well managed or a "loss" otherwise.

R67-12943 ASQC 831; 824

SYSTEMS ESTIMATION FROM PERFORMANCE PARAMETERS.

S. Demskey (General Electric Co., Missile and Space Div., Re-Entry Systems Dept., Philadelphia, Pa.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 398–409. 26 refs.
(A66-37919)

Description of the VAEP (variables/attributes/error propagation) method for providing system estimates at high confidence levels with economical sample sizes. The procedure uses the critical variables, performance parameters, to overcome the large sample size associated with application of the binomial analysis. Although this analysis is somewhat more complex than a binomial attribute analysis, the advantages outweigh the disadvantages. IAA

Review: Some of the ideas in this paper are worthy of consideration; however, the author does not express the basic concepts clearly. In some cases errors occur in the presentation. In Section 4.1 the procedure is stated for the special case in which the system success probability is expressed as a product of six probability estimates for six performance measures or parameters. At this point one questions the fact that no consideration is given to the lack of independence among the performance measures and the effect on the overall probability. This point is discussed in Section E.3.2, but incorrectly. It is concluded in that section that the effect of dependency is negligible. This should have been a clue to the author that the analysis was wrong. If the performance measures were completely dependent, such that if one performance parameter satisfied its requirements, then the remaining ones would satisfy their respective requirements, the resulting success probability for the system would be expressed simply as the probability of success for one performance measure. On the other hand, if the performance parameters were independent the system success probability would be equal to the product of the individual probabilities. In practice neither one of these cases would occur. One error in the analysis is in the formula for C_c^2 at the bottom of page 406 in which the coefficients of variation for the individual performance parameters are in error. In Section 4.1 (2) the author uses 50 percent confidence level as equivalent to the mean. He apparently has in mind the 50th percentile or median and this usage would be correct only when the distribution is symmetrical. In the application described in the paper the probability estimates for the performance parameters would not be symmetrically distributed for values of the probabilities near unity. This leads to a third point of consideration, namely, the use of an equivalent attribute sample size. The need or use for this notion is not at all clear. The tolerance intervals used in the paper are based on sampling from a Normal distribution. One needs to use only the sample size, the sample mean and standard deviation to obtain a tolerance interval for the performance parameter of interest. In summary, the paper might be read with caution in order to gain some insight into problems that need to be solved, but it should not be assumed that the solution presented is adequate. A private communication from the author indicates that a corrected version is to be made available in the near future.

R67-12951 ASQC 830; 711; 712; 844

RELIABILITY DESIGN CRITERIA FOR MECHANICAL CREEP.

Raymond Mesloh (Battelle Memorial Institute, Mechanical Engineering Dept., Applied Solid Mechanics Div., Columbus Laboratories, Columbus, Ohio).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18-20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 590-597. 5 refs.

(A66-37941)

A generalized but formal procedure is outlined for establishing creep design reliability functions for the creep-rupture and critical creep-strain modes of structural-element failure both singularly and combined or bimodally. Fundamental consideration and conditions are discussed for treating the creep data and which the creep data in general must satisfy before the formal procedure is applicable for deriving the several reliability functions. These considerations and procedures are illustrated by application to an engineering alloy, Hastelloy R-235, and its creep properties from the raw creep curves through statistical treatment to final reliability functions. Finally a brief example is presented to illustrate the use of such functional curves. Author (IAA)

Review: The idea behind the paper is good, but its implementation and the details of the treatment are doubtful. The universal curve aspect is not necessary, just more convenient than separate curves; the amount of raw data needed would be the same in either case. Some factors which are inadequately handled are the following: (1) The variations around each curve may not transform to be the same. (This is a different problem than considered in the text.) (2) For the strain vs. time data, the hypothesized log-Normal distribution of times seems to have ignored the fact that two parameters must be specified for the distribution. (3) It would be interesting to note whether the creep rupture treatment is consistent with the Larson–Miller method which is rather popular. (4) The term bimodal is apparently not used in its statistical sense, but refers to two modes of failure. (5) It seems most unlikely that failure by rupture and failure by exceeding the critical strain are statistically independent (contrary to the text). Rupture time is the vertical asymptote of each strain-time curve and obviously the critical strain must be passed before the asymptote is reached. Thus "Rupture" and "Critical Strain Reached" are not even physically independent, much less statistically independent.

84 METHODS OF RELIABILITY ANALYSIS

R67-12902 ASQC 844; 775

HARMONIC TESTING PINPOINTS PASSIVE COMPONENT FLAWS.

Wilhelm Peterson and Per-Olof Harris (L. M. Ericsson Telephone Co., Long Distance Div., Component Laboratory, Stockholm, Sweden).

Electronics, vol. 39, Jul. 11, 1966, p. 93-100. 9 refs.

(A66-35020)

Description of a fast nondestructive testing method that saves time and money in analyzing a wide variety of nonlinearities in all types of passive electronic components. The method employs filters to suppress the fundamental frequency. The test specimen is connected to the circuit, the test voltage is applied, and the results are available in less than a second. This test can uncover uneven film depositions, base material flaws, bad grindings, and unreliable contacts in resistors, as well as imperfect dielectrics and unreliable contacts in capacitors. It also determines the hysteresis dissipation factor and hysteresis loss coefficient in magnetic components and materials. IAA

Review: Just how effective this method is in screening out potential defectives is not given, but it certainly appears to be worthy of consideration. The title and subtitle of the article appear overly ambitious, but the method seems to have merit. Apparently the effects in poor contacts are due to semiconducting compounds that form there, and carry part of the current. The expression for the third harmonic content vs. current density is asserted without derivation or reference (presumably it derives from experience). A large part of the article is concerned with circuit properties of the tester itself (standard ac circuit analyses). The third harmonic method is compared to current noise techniques and is asserted to be as good or better in some cases. Since the method has received such acclaim in Europe, extensive trial of it here is worthwhile to see if the hopes are fulfilled. The paper was severely shortened for publication; the authors may be able to provide the complete test for those who are interested.

R67-12907 ASQC 844; 831; 843

MECHANIZED RELIABILITY ANALYSIS.

W. Thomas Weir (General Electric Co., Re-Entry Systems Dept., Philadelphia, Pa.).

National Winter Convention on Military Electronics, 5th, Los Angeles, Calif., Feb. 5-7, 1964, Proceedings. Volume 3. Convention sponsored by the Professional Technical Group on Military Electronics, Institute of Electrical and Electronics Engineers. Edited by R. F. Lander. North Hollywood, Western Periodicals Co., 1964, p. 10-23 to 10-38.

(A64-21606)

Presentation of a technique for reliability system analysis which has proven its value in demonstrating contractually required reliability on critical defense systems. Procedures for system analysis techniques covering apportionment, mission profile, trade-off, and logistics are presented. The automated system using this technique along with test data accrued during qualification, acceptance, and field and flight testing provides failure rate data, predicted reliability values, capability indices, and other useful logistics parameters for the various components, subsystems, and systems early in the development program. Reports containing these indices have been used throughout the development cycle. The system, using the 7094 Electronic Data Processing Machine, requires 14 min to take 10,000 input records and generate all the reports discussed. IAA

Review: This paper gives a general view of the analysis in use in the Re-entry Systems Department of the General Electric Company and a more detailed description of each part. The general view will be of interest to the casual reader and the detailed description will probably interest only those who are closely involved with a similar analysis. It is difficult to evaluate a program such as this from the description in the paper. It does appear that much thought has gone into it. Whatever criticisms might be made can probably be countered on the basis of engineering judgment.

R67-12911 ASQC 844

IMPROVE DEVICE RELIABILITY AND PHYSICS-OF-FAILURE TECHNIQUES.

S. M. Skinner, E. R. Pemsel, W. J. Lytle, J. W. Dzimianski (Westinghouse Electric Corp., Aerospace Div., Baltimore, Md.), and Alex E. Javitz

Electronic Design, vol. 13, Sep. 13, 1965, p. 70–72, 74, 75. 4 refs.

The application of physics-of-failure techniques to the development of silicon devices is reviewed, emphasizing specialized measurement techniques. The industry trend to apply precise testing methods is mentioned, and examples of the types of testing and the methods used for recognizing and studying failure mechanisms are outlined. Problems arising in the fabrication and manufacture of silicon microelectronic devices are identified. A failure in the study on a silicon amplifier is outlined, and the failures in the diffusion stage are discussed. The key measurements are identified as being concerned with the characteristics of the oxide coating, the resistivities, concentration of impurities, breakdown, and photoresponse characteristics. N.E.N.

Review: This is an illustrative paper, in that the title subject is discussed largely by examples in the field of semiconductors. The examples are good and are generally taken from the literature (as shown by the references). The article is apparently intended more to interest people in the subject than to give intensive information on it. (It may be easy for some readers to get the idea that more is known about detailed design of semiconductors than is the case; there is much empiricism in the art of making and designing good devices. Likewise, it is easy to get the idea that the obvious faults are not longer made by manufacturers; papers such as some by RADC personnel show that this also is not so.)

R67-12913 ASQC 844; 720

RELIABILITY IMPROVEMENT IN PULSE TRANSFORMERS.

Martin Perl (Space Technology Laboratories, Inc., Redondo Beach, Calif.).

(Institute of Electrical and Electronics Engineers, the 1965 Electronic Components Conference, Washington, D. C., May 5–7, 1965, Paper.) IEEE Transactions on Parts, Materials, and Packaging, vol. PMP-1, Jun. 1965, p. s-103–s-108. 1 ref.
(A65-30823)

Investigation of failure mechanisms in miniature pulse transformers, a type commonly used for drive pulse coupling in low-power digital circuitry. The resulting corrective action methods are useful for reliability improvement in other similar magnetic devices and components. Failures were traced to breaks in small diameter magnet wire. Examination showed two possible causes of failure: (1) mechanical stressing of material during assembly and (2) metallurgical stressing of the fine copper wire during soldering. Preventive action was taken to eliminate accidental mechanical stress. To avoid metallurgical changes during soldering, a process specification was developed to prevent gross solution of the solder. This was accomplished by close control of soldering temperature, wider distribution of heat at the joint, and control of the length of time the material is held at soldering temperature. Tests verified the effectiveness of these process improvements. No failures have been experienced in subsequent manufacturing. Author (IAA)

Review: This is a good case history which illustrates the attention to detail which is necessary for high reliability. It also illustrates that some designs (if not most) are insufficiently detailed, so that the term "inherent reliability" has little if any meaning. The paper is well written and easy to read. Unfortunately, in a way, it all sounds so simple after-the-fact that designers can get the feeling it all was not really terribly critical anyway. So many reliability problems are of this kind—design and manufacturing gross insufficiencies—and they keep getting repeated (as illustrated by papers on failures in aircraft) that more attention needs to be paid to retention of experience. Perhaps then, this paper will not need to be regiven by someone else in two or three years.

R67-12915 ASQC 844

FAILURE MECHANISM OF HIGH ENERGY SURGE RESISTORS.

L. H. Hardy (Carborundum Co., Research Branch, Niagara Falls, N.Y.).

(Institute of Electrical and Electronics Engineers, the 1965 Electronic Components Conference, Washington, D.C., May 5–7, 1965, Paper.) IEEE Transactions of Parts Materials and Packaging, vol. PMP-1, Jun. 1965. p. s-136–s-142. 3 refs.

Thermal shock propagation caused by the discharge of large amounts of stored energy in a short time interval is found to be the fundamental cause of failure in high power non-inductive ceramic resistors in high energy and high voltage surge applications. Magnitude of surge current, as determined by change in resistance, is not a primary failure cause; and extremely high peak currents and voltages as high as 445 kV can be tolerated if the energy in the discharge is maintained at a low surge level. The average energy causing failure is shown to be a function of the physical dimensions of the resistor and the time duration of the pulse (or R–C time constant); and stress due to thermal shock is an inverse function of the mass. Test data and the approximate theoretical expression for stress of a ceramic matrix resulting from thermal shock indicate that the failure mechanism is a function of the (1) joules of energy stored in the discharge capacitors, (2) physical geometry of the resistor, (3) physical properties of the ceramic body, and (4) resistance of the body. M.W.R.

Review: This is a physics-of-failure paper and treats the subject well. The part played by inhomogeneities in the ceramic is not discussed at all; one might guess that it could be important. The author in a private communication has indicated that plans have been made to investigate more completely, in the future, this probable cause of failure. The investigation described in the paper seems to have largely stopped at the point where the cause of failure was isolated from the two possible causes, although one design criterion—large mass of the resistor—is given. High reliability demands many talents on many fronts; the work in this paper illustrates some of the ways in which attention must be paid to detail.

R67-12917 ASQC 844; 833

COMPONENT RELIABILITY AT LOW STRESS LEVELS AND THE SIGNIFICANCE OF FAILURE MECHANISMS.

Arnold Simoni (Precision Electronic Components, Ltd., Toronto, Canada).

(Institute of Electrical and Electronics Engineers, the 1965 Electronic Components Conference, Washington, D.C., May 5–7, 1965, Paper.) IEEE Transactions on Parts, Materials, and Packaging, vol. PMP-1, Jun. 1965, p s-303—s-308 12 refs.
(A65-30838)

Discussion of failure in modern electronic equipment, where many components operate at stress levels much below their rated values. The factors governing failure—and therefore reliability—may be quite different at these levels from those that apply at the higher levels at which testing is usually performed. The importance of considering low stress phenomena is pointed out, with electrical contacts and dielectric materials as examples. The need for more investigation is stressed. Author (IAA)

Review: This is an interesting and informative paper. As the author suggests, little has been published on this subject, although several authors have given summaries of their literature searches on nonoperating failure rates. The examples of electrical contacts and dielectric materials well illustrate the problems of life at low stress levels. The relay manufacturers have been fighting a similar "derating" battle for several years. Many questions are raised by the paper for which there are no answers. Physics-of-failure studies, intelligently applied to each specific case, are a means of generating useful information, as the author suggests. As the paper illustrates, the use of usual reliability data, extrapolated down to low stress levels can be very misleading for some kinds of components.

R67-12918 ASQC 844; 522; 541; 817

ELECTROMAGNETIC RELAY RELIABILITY PREDICTIONS BY DESIGNED LIFE EXPERIMENTS AND WEIBULL ANALYSIS.

William J. Fontana (U. S. Army Electronics Labs., Fort Monmouth, N. J.).

(Institute of Electrical and Electronics Engineers, the 1965 Electronic Components Conference, Washington, D.C. May 5-7, 1965, Paper.) IEEE Transactions on Parts, Materials and Packaging, vol. PMP-1, Jun. 1965, p. s-309—s-319 3 refs.

A mathematical model was developed for use in life testing of an electromagnetic relay as a function of its most significant operating variables. Data from this statistically designed procedure is used in combination with Weibull and linear regression analyses to provide life expectancy profiles. The method is applied to a newly-designed relay; and the life quality and life tradeoff characteristics are described in terms of contact load, ambient temperature, and operating speed over the useable range of these parameters. While the technique includes only these three factors, it can be expanded to include other factors or combinations of factors to provide an economical means of obtaining reliability estimates that are unattainable by conventional life testing. The factorial design and the second degree quadratic model equation are described along with the experimental test plan and actual test program on the relay. Applications of the model equation are presented. M.W.R.

Review: Relays are traditionally difficult to fit into the electronic reliability framework. This paper provides a method for estimating the two Weibull parameters of the life distribution for a range of three operating parameters (contact current, ambient temperature, operating frequency). This approach is a good one and should be encouraged. The temptation should always be avoided to extrapolate any polynomial which has been fitted to data; beyond those end points lies the abyss of total self-delusion. (This statement is in contrast to the author's "...may not be entirely valid...and may be used cautiously..."). It would also have been wise to get a measure of the uncertainties in the two Weibull parameters and to translate these into life or failure probability. These uncertainties may well be a factor of two or more. This presumes that the parameters used as data in the analysis were exact; they were not, of course, and this contributes further uncertainties to the answer. (Ignored altogether is the fact that no failure probabilities below 10% were ever measured.) The exact statistical treatment: going from the data to the probabilities would probably be rather complicated, but perhaps quite worthwhile.

R67-12919 ASQC 844; 773

GARD—A NEW ERA OF COMPONENT TESTING.

Donald D. Vanous (Dale Electronics, Inc., Advanced Engineering Div., Columbus, Nebr.).

(Institute of Electrical and Electronics Engineers, the 1965 Electronic Components Conference, Washington, D. C., May 5-7, 1965, Paper.) IEEE Transactions on Parts, Materials and Packaging, vol. PMP-1, Jun. 1965, p. s-320–s-326. 3 refs.

Test theory, procedure, instrument, and verification are described for the GARD (Graphic Analyzer of Resistance Defects) concept, which is proposed as a reliable replacement for presently-used burn-in screening tests of resistive components. The test, which requires approximately five seconds and is applicable to all types of resistive components, identifies any failure modes that exist in a resistive system and could cause or contribute to component failure. The GARD testing concept consists of continuously monitoring the dynamic resistance change of a resistor whiile it is being subjected to a controlled pulse of maximum nondestructive power. During the 5-sec test, the test instrument determines the resistance stability of the resistor as well as the temperature coefficient of resistance characteristics of the test unit. M.W.R.

Review: This is the somewhat expanded version of the paper which was mentioned in R65-12056. If the test continues to live up to the expectations for it, it can be a big help in improving the reliability of resistors. Perhaps similar concepts can be used for other components.

R67-12922 ASQC 844; 522; 541; 817

Army Electronics Labs., Fort Monmouth, N. J.

LIFE EXPECTANCY OF A NEW MINIATURE POWER RELAY

William J. Fontana Mar. 1966 56 p refs

(ECOM-2672; AD-632340; N66-29956) CFSTI: HC $3.00/ MF$0.50

Estimation of the life expectancy of electromagnetic relays under usage conditions is a difficult, expensive process. Because of the wide variety of circuit conditions in which a particular relay design might be used in its many applications, extensive test programs involving the same relay design are often conducted under widely variant load conditions. Such test programs, which have little applicability to other potential uses, are ineffective in developing the total picture and contribute substantially to the total product cost to the Military. This report describes a Laboratory-conducted program wherein a new miniature power relay design, developed under an ECOM sponsored contract, was subjected to a series of life tests to develop its life expectancy profile under a broad range of electrical operating conditions. The principle of factorial experimentation was applied to develop a test program which, over the relay's design range of resistive load conditions, operating temperatures, and operating rates, would provide useful data at minimum cost. From the resulting statistical analysis, a series of functional relationships between the relay life expectancy and the operating stress levels were developed. Mathematical and graphical representations of these relationships are given for use by design engineers in estimating the life expectancy, or reliability, of the relay under specific operating conditions. In addition, the curves can be used to estimate the effect which "trading off" specific operating parameters can have on the expected reliable life of the relay. Author

Review: This report is similar in content to the paper by the same author published in IEEE Transactions on Parts, Materials and Packaging, vol. PMP-1, Jun. 65 (1965 Electronic Components Conference issue), p. 309–319.

R67-12927 ASQC 840; 851; 870

METHODS OF PREDICTING ELECTRONIC FAILURES.

Robert A. Kirkman (TRW, Inc., TRW Systems Group, Redondo Beach, Calif.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 75–83. 6 refs.

(A66-37887)

Consideration of failure-prediction procedures for outlining an optimal failure prevention strategy applicable to the testing of an aerospace system or a checkout program. The ambiguities inherent in the use of the term "failure" are explained; the terms "defect," "fault," or "flaw" are used to refer to the actual source or cause of the system breakdown, whereas "failure" is used in the generalized conventional sense. The specific definitions given to many terms describing undesirable equipment states are listed in a table. It is shown that the most important failure prediction techniques are those based upon the detection of embryonic defects by suitable testing methods. The application of a number of such failure prediction procedures to failure determination and timely repair or replacement is described. IAA

Review: This is a good paper; it reviews the philosophy of four prediction methods (detection of defects, use of failure-sensitive parameters, marginal tests, historical data) rather than going into intensive specifics for any one situation. Examples are sprinkled throughout the text to make understanding easier. The points are well and carefully made so as not to be more exuberant than sensible. Some minor comments on the text are the following. (1) One must have a way of being reasonably sure that the replacement is less defective than the removed part. (2) In some cases, the cure of preventive maintenance can easily be worse than the disease. This situation should not be treated lightly, especially if prevention involves pawing over the gear. In this connection the author, in a private communication, has expressed an opinion that the point where the cure becomes worse than the illness is a variable. It depends heavily on the situation, i.e., the kind of equipment, its demonstrated reliability, skill of the maintenance personnel, etc. He has referred to the paper covered by R63-11034 as containing fundamental data on typical field cases.

R67-12930 ASQC 844; 711; 712; 713

THE MATERIALS PROBLEM IN STRUCTURAL RELIABILITY.

A. A. Mittenbergs (Battelle Memorial Institute, Columbus Laboratories, Mechanical Engineering Dept., Columbus, Ohio).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 148–158. 18 refs. Research sponsored by the Batelle Memorial Institute, the General Electric Co., the Hughes Aircraft Co., and the Lockheed Aircraft Corp.

(A66-37897)

The paper considers problem areas associated with engineering materials from the viewpoint of incorporating reliability criteria into the design of a structural part, before test and service data on the part are available. The subjects covered include load and strength distributions, modes of failure, variability of material properties, nature and availability of material-property data, material-property degradation, and some other relevant considerations. The present difficulties in utilizing material-property data in reliability predictions are assessed, and the future needs are outlined. IAA

Review: This is a good paper covering a broad range of topics, but it is rather long for the message. The section on Statistical Nature of Material Properties is especially good—the emphasis on the behavior far out on the tails of the distribution is excellent. Beginners should probably read the whole paper, long though it is; those more knowledgeable will skim many parts. The Military Handbook No. 5 which is referenced as a good source of material-property data is described in the paper immediately following this one in the same volume. The article on the Handbook is good. It deals with everyday problems; this paper deals more generally and philosophically with the subject.

R67-12931 ASQC 844; 711; 712; 713

USE OF STATISTICAL CONSIDERATIONS IN ESTABLISHING DESIGN ALLOWABLES FOR MILITARY HANDBOOK 5.

Donald P. Moon, Donald A. Shinn, and Walter S. Hyler

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 159–172. 4 refs.

(Contract AF 33(616)-10076)

(A66-37898)

In the paper, the authors discuss the use of statistical considerations in the establishment of design mechanical properties of materials, or "design allowables," and describe briefly several of the analytical procedures employed. In addition, they discuss some of the considerations that lead to the lowering of design allowables for certain service conditions. Several examples of data analysis are presented to illustrate the definition of a material and its properties and the computational procedures most widely used to determine minimum property values. All illustrations have been taken from the history files of Military Handbook 5, which is used extensively by the aerospace industry as a source of reliable mechanical-property data for airframe and missile design. Author (IAA)

Review: Reliability papers on the subject of mechanical strength are so often just plain trash, that this one stands out in welcome contrast. It is an excellent paper—certainly one of the best to appear on the subject. The theoretical and practical problems are juggled with great skill and understanding. The naive designer is certainly in for a shock when he reads this because many of the ubiquitous simple-minded concepts are here laid to rest. Obviously, this material is well known to some people, but to many—especially in the electronics business—the ideas will be new. (The use of the Chi Square test to test for Normality does leave something to be desired. The test often has somewhat low discriminating power—thus, if the null hypothesis is accepted, it may just mean that there were not enough data to show the difference.) In a private communication the first author of this paper has called attention to a new document: MIL-HDBK-5, Guidlines for the Presentation of Data. These Guidelines present, in much greater detail, the intricacies of analyzing data and presenting the results in a form useful to the designer. They are expected to be published as an AFML Technical Report in November 1966.

R67-12932 ASQC 844; 770

METALLIZATION FAILURES IN SEMICONDUCTOR DEVICES.

Joseph M. Schramp (USAF, Systems Command, Research and Technology Div., Rome Air Development Center, Griffiss AFB, N. Y.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 177–181. USAF-sponsored research.

(A66-37900)

The metallizing systems used to provide interconnections and electrical contacts to semiconductor devices constitute one of the principal problem areas contributing to the degradation of the performance of these devices. Solid state reactions such as diffusion and compound formation which occur in the contact metal systems can result in out-of-tolerance operation or catastrophic failure. By monitoring the resistance of thin film structures, information concerning the activation energy and reaction kinetics of solid state reaction occurring in metal systems was obtained in relatively short times. By permitting sensitive measurements to be made at relatively low stress conditions, the potential hazard of extrapolating high stress data is avoided. Metal–metal, metal–semiconductor, and metal–oxide systems were studied at temperatures ranging from 150 up to 20°C below the solidus temperature of some of the systems. Data were obtained on interactions in various ohmic contact systems, including Au–(Sn–Sb), Ag–Sn, Au–Cr, Au–(Ni–Cr), Al–Si and $Al–SiO_2$. Author (IAA)

Review: The description of the "test vehicle" employed in these experiments leaves some unanswered questions: (1) Were the metallurgical systems evaporated as bimetallic films or as intimate mixtures of the constituents? (2) In either event what proportions were employed? It is the former, containing some sort of an interface, that would seem to be most meaningful in predicting the performance of a metallurgical combination as an intraconnection or an electrical contact on a practical semiconductor device. In a private communication the author has confirmed that the metal films were sequentially deposited, each being 0.1 μm in thickness. The measurements of film resistance were made by nulling methods so as to eliminate series contact resistance. The text does not explicitly state this and is confusing in its explanation of the pattern illustrated in Fig. 1. The photographs showing aluminum film degradation on silicon integrated circuits are worthy of note. The existence of such failure potential should be made known to both users and manufacturers. More complete descriptions of this work are available from Rome Air Development Center.

R67-12939 ASQC 844; 831; 836

FAILURE MODE AND EFFECT ANALYSIS: A POWERFUL ENGINEERING TOOL FOR COMPONENT AND SYSTEM OPTIMIZATION.

Harry E. Arnzen (Grumman Aircraft Engineering Corp., Bethpage, N. Y.).

Annals of Reliability and Maintainability. Volume 5–Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 355–371. 11 refs.

(A66-37915)

Description of the application of the failure mode and effect analysis (FMEA) technique to each stage of system development. The following aspects are treated: (1) how information is generated, (2) suggested procedure for preparing FMEA, (3) use of completed FMEA in the development cycle, (4) the decision for remedial action to prevent catastrophic failures, and (5) a summary of benefits and major uses of FMEA in implementing the overall reliability program. Two typical aerospace systems examples are given to demonstrate the effective use of FMEA by comparing the initial system configuration and related FMEA with the final system configuration. Detailed tabulations of accumulated benefits and reliability improvements for each system are provided. IAA

Review: Failure mode and effect analysis (FMEA) is quite important as an aid in designing reliable equipment (components, assemblies, subsystems, and complex systems). This paper is a rather detailed treatise on the subject as applied to both aircraft and spacecraft systems, with specific examples of application to dynamic- and static-type systems included to demonstrate appropriate use of the technique. Some of the detail rules are for those types of systems only, but the general concepts and methods of FMEA are applicable to any kind of component or system. The detail is sufficient to give designers and program managers a firm grasp of the subject and its application in various phases of a system development program.

R67-12944 ASQC 844; 837

NUMERICAL EVALUATION OF ACCIDENT POTENTIALS.

Willie Hammer (USAF, Missile and Space Safety Div., Washington, D. C.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 494–500. 2 refs.

(A66-37931)

The paper discusses methods for quantitative evaluation of accident potentials, principally as related to missile and space systems. It indicates methods which have been used to rate safety numerically, and provides additional procedures. It indicates that a complete system should involve both probability of a mishap and the degree of loss which might result. IAA

Review: While the primary concern in this paper is with the numerical evaluation of safety as related to missile and space systems, it will be of interest to reliability engineers also. Reliability and safety are closely related functions and use some of the same concepts. However, it must not be assumed that adequate achievement in either one automatically ensures the same in the other. The author gives some examples which support this point. His discussions of failure effects analysis, fault tree analysis, and time sequencing are brief but adequate for the purpose of the paper.

R67-12949 ASQC 840; 831

VARIABLES ANALYSIS APPLIED TO SOLID PROPELLANT ROCKET MOTORS.

R. C. Meyer (Thiokol Chemical Corp., Wasatch Div., Brigham City, Utah).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 555–562. 5 refs.

Reliability estimates, based on variables data from design verification testing of subsystems and a single static test of a full-scale motor are described for a full-scale, flightweight solid propellant rocket motor. A methodology is outlined which permits a meaningful reliability estimate on the basis of three or more static motor tests. Ground rules for identifying parameters to be used in the model are listed, a stress vs. strength analysis is discussed, statistical tolerance limits are treated, and the combining of probability statements with confidence coefficients is mentioned. Applications are discussed for a 156-in dia motor with a monolithic fiberglass case, submerged nozzle, liquid injection, and thrust vector control. These data deal with (1) ignition design, (2) igniter performance, (3) motor case design and performance, (4) propellant grain design, (5) insulation, liner, and bladder design, (6) nozzle design and performance, and (7) thrust vector control design and performance. Equations are given for estimating reliability of the various subsystems of the motor. M.W.R.

Review: The basic principles involved here are good. Getting as much information as feasible from a test is always a good idea and permits more accurate decisions. Some of the nomenclature is not too easy to follow, but understanding the details is not essential to the main points. The mathematical treatment in the paper is too sketchy to be useful; in fact it contains some errors. The probability of success in the stress versus strength analysis is incorrectly referred to as the area of no overlap of the load and strength distributions. There is a misprint in equation 1 which defines the standard normal deviate. Reference is made in the text to an equation 5, but there is no equation 5 in the paper. It is suggested that readers interested in the mathematical aspects of this work refer to (1), which is cited by the author as his source of this information. The author in a private communication has indicated that the design and test data could not be included in the paper while retaining its non-security classification. Removal of these data and illustrative calculations detracted from the value of the paper since it now appears more conceptual than descriptive.

Reference: (1) Lloyd, David K. and Lipow, Myron: *Reliability: Management Methods, and Mathematics,* Prentice-Hall, Inc., Englewood Cliffs, N. J., 1962

R67-12950 ASQC 840; 775; 831

MECHANICAL SIGNATURE ANALYSIS—A NEW TOOL FOR PRODUCT ASSURANCE AND EARLY FAULT DETECTION.

Bjorn Weichbrodt (General Electric Co., Research and Development Center, Schenectady, N. Y.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 569–581. 4 refs.

(A66-37939)

Discussion of mechanical signature analysis, a technique for using external measurement of sound and vibration signals to diagnose internal condition or malfunctions of machinery components and to detect incipient failures. The development of mechanical signature analysis is outlined, and its application to active and passive systems is considered. A method for early detection of ball bearing damage is discussed, and some possible future applications of mechanical signature analysis are mentioned. IAA

Review: This paper conveys a general understanding of Mechanical Signature Analysis, a technique which has potential for increasing the reliability and maintainability of a variety of equipment. Nondestructive methods for the early detection of unusual operation can be extremely valuable in production and development, as well as in the monitoring of operating equipment. As the author has indicated, the use of sound and vibration analysis to evaluate internal conditions of structures and operating machinery involves many different methods, and the most effective one for the specific application must be selected. This will call for a sound and detailed knowledge of the equipment under study, including its failure mechanisms and its signal generation and propagation characteristics. This paper will serve a useful purpose for those interested in the development of nondestructive diagnostic techniques.

R67-12955 ASQC 843; 844; 864

RELIABILITY APPLICATION OF AFM 66-1 MAINTENANCE DATA.

Wendell W. Harter (Northrop Corp., Northrop Norair, Hawthorne, Calif.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 626–631. 3 refs.

(A66-37945)

The prime contractor for the USAF T-38 supersonic jet trainer aircraft employs electronic data processing to analyze AFM 66-1 maintenance data for reliability monitoring purposes. The program includes the analysis of approximately 300,000 reports each month representing three months of service. The result is a monthly readout of the top ranking reliability problem items, a monthly listing of measured component failure rates for the last three months of Air Training Command flying experience, and a quarterly assessment of current reliability for the complete aircraft system and its major subsystems. The paper describes key elements of the data analysis program, including the logic used for discrimination of system failures from maintenance actions, the criterion used for establishing the problem ranking index, and the method for assessing mission reliability for comparison with established reliability goals. Analysis costs are also discussed. Author (IAA)

Review: The utilization of USAF AFM 66-1 maintenance data for reliability monitoring purposes is described in this paper. The aircraft system contractor developed a computer program for the reliability analysis of USAF maintenance reports received in punched card form. This program not only provides problem identification and reliability status, but component failure rates for reliability prediction as well. Enough description of the analysis method is given to make the paper useful to those with a detailed interest in how AFM 66-1 or similar maintenance data can be used for reliability monitoring. Computer equipments and operating costs for the monthly analysis of data from more than 600 aircraft are identified.

R67-12956 ASQC 844; 841

ATTACKING UNRELIABILITY.

George E. Knudsen (Bell Aerospace Corp., Bell Helicopter Co., Reliability Data Group, Fort Worth, Tex.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 632–638. 5 refs.

(A66-37946)

Demonstration that a data acquisition, analysis, and corrective action program, properly planned and implemented, can reduce unreliability occurrences and produce a significant savings in logistics and maintenance funds for the customer. An unreliability program is described which is modeled on the UH-1D helicopter and the environment in which it operates. The data forms used in the program are discussed and illustrated, and the analysis program is evaluated. IAA

Review: While this paper is concerned with a particular model of helicopter, it serves to illustrate the value of an adequate program of data acquisition, analysis, and corrective action as a means of reducing unreliability. For the implementation of such a program, there must be a statistically adequate sample of the equipment operated under realistic environmental conditions. An effective system of reporting and recording appropriate data on failure events is another essential. In the situation described in the paper, these key elements were present. Under such conditions, a program of this kind can be worth many times its cost.

R67-12957 ASQC 845

A SUGGESTED CONCEPT FOR THE ACQUISITION AND PROCESSING OF PARTS, MATERIALS, AND COMPONENTS INFORMATION.

Lewis J. Dollman (Brown Engineering Co., Inc., Systems Development and Applications Dept., Huntsville, Ala.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 639–647. 1 ref.

(A66-37947)

A concept for an information center which can acquire, and process reliability testing and failure data, and can furnish to users the reliability and maintainability information needed in the accomplishment of their tasks is presented in the paper. The concept is a combination of both the "formal" and "informal" information centers in which the center assumes the role of a "knowledgeable colleague." The center is designed to furnish users accurate, current and meaningful information in response to their requests. It allows them to explain, clarify, and possibly modify these requirements with a minimum of effort on their part. Author (IAA)

Review: A complete data system encompasses the data sources, the data center, and most important of all, the user. This paper concentrates on the center and presents a system concept for implementation of the storage and retrieval function. It does not consider the reduction, analysis, or conversion of data. Some possible worthwhile features of the system discussed are a video file for "hard copy" storage and reproduction of some data and the flexibility of input format and storage. The description, however, is very idealistic with few working details presented. For example, the only estimate of requirements represented for the effort is 15 people for initial staffing of an Inquiry Service. Much effort and many revisions would obviously be required to implement the system described. The presentation is lengthy and could have been greatly assisted and shortened by the use of figures. None were presented; however, reference was made to a Figure 5 in the latter part of the paper. There is also an allusion to some previous documents which were not identified. Experience with the many data systems in existence has revealed that more consideration of the user is needed. The reader is referred to the paper covered by R65-12013 for a data center which has received considerable attention from the user viewpoint. More detailed descriptions are also presented in [1].

Reference: [1] Goldberg, M. E., et. al. (1965). Development of a Detailed Plan for a Reliability Central, Vols. I and II, Illinois Institute of Technical Research, Chicago, Illinois (AD-623195 and AD-623196)

R67-12960 ASQC 844; 543

RELIABILITY PREDICTION BY FUNCTION FOR AVIONIC EQUIPMENT.

H. Balaban, R. Plotkin, and G. Harrison (ARINC Research Corp., Annapolis, Md.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 694–703. 4 refs.
(Contract AF 30(602)-3387)
(A66-37953)

Description of a study currently being conducted to develop a technique for the prediction of avionic equipment in the early design stage. The most common prediction procedures are reviewed. Two basic sets of equations are to be developed: one set applicable to predictions at the equipment level and the other set applicable to predictions at the "line replaceable unit" (LRU) level. An LRU is defined. The classification criteria used for this study are given. Other topics discussed include LRU classification, parameter selection, and multiple regression procedure. Prediction equations are developed and the validity of the technique described is discussed. IAA

Review: The work described in this paper is a continuation of that discussed in the paper covered by R66-12670. It is concerned with the development of two sets of equations for use in reliability prediction—one set applicable at the equipment level and the other applicable at the line-replaceable-unit level. The steps in the approach are concisely described. Multiple linear regression, which is the basis for the development of the actual equations, is sketched. Some prior familiarity with the technique will be desirable for those wishing to apply it—even though the actual calculations are computerized. Among its other good features, the paper includes a frank discussion of the limitations of the technique, some of which will be alleviated as further work is done.

85 DEMONSTRATION/MEASUREMENT

R67-12912 ASQC 851; 770; 782; 844

LIFE TESTING OF ELECTRONIC POWER TRANSFORMERS.

Thomas W. Dakin (Westinghouse Research and Development Center, Pittsburgh, Pa.), and E. Newman Henry (Westinghouse Aerospace Division, Baltimore, Md.).
(Institute of Electrical and Electronics Engineers, the 1965 Electronic Components Conference, Washington, D. C., May 5–7, 1965, Paper.) IEEE Transactions of Parts, Materials and Packaging, vol. PMP-1, Jun. 1965, p. s-95–s-102. 8 refs.

A specialty transformer life test procedure is found to be usable for the evaluation of life-temperature characteristics of a typical low voltage electronic power transformer insulation system; and life values are obtained which follow the Arrhenius life-temperature relation. Elimination of vibration, cold shock, or humidity cycling phases of the procedure produce little effect on the life of the insulation system studied; but it is recommended that these features be retained in the procedure for testing of other systems which might be sensitive to environmental cycling. Tests of the transformer insulation system, made up of many materials and encapsulated and impregnated with a stable resin, indicate a longer functional life for the system as a whole than for the individual components. Transformer construction, circuitry, and life testing procedures are discussed; and a tabulation of transformer life test values indicates a slight trend toward longer life with the less severe thermal and environmental cycling conditions. M.W.R.

Review: This paper is more restricted than the title implies since it treats essentially one test procedure (having several modifications) on one transformer. It does treat that subject rather well. The comments on having to treat the insulation system as a whole are well taken; the system performed better than did its weakest link when the parts were tested separately. (A minor point is that the life values do not necessarily follow the Arrhenius model since there were only three and the curvature is obvious. Rather, the points are not inconsistent with that model). The discussion of failure modes and mechanisms is good.

R67-12914 ASQC 851; 770; 844

ENVIRONMENTAL AND LIFE TESTING OF HIGH RELIABILITY MAGNETIC COMPONENTS.

F. B. Colby and R. R. Ursch (Raytheon Co., Waltham, Mass.).
(Institute of Electrical and Electronics Engineers, the 1965 Electronic Components Conference, Washington, D. C., May 5–7, 1965, Paper.) IEEE Transactions on Parts, Materials and Packaging, vol. PMP-1, Jun. 1965, p. s-109–s-114.
(A65-30824)

Description of a testing program for high-reliability magnetic components manufactured for missile and space programs. Reasons for testing are discussed. The testing program described consists of (1) a final manufacturing electrical test and mechanical inspection; (2) 100% screening tests, including burn-in; (3) a qualification test; and (4) an acceptance test. These four aspects of the program are described in detail. Results of the program are discussed, as are its effects on the manufacture of the tested components. IAA

Review: This paper illustrates the importance of good failure analysis and failure mechanisms study. It deals largely with the insulation system of magnetic components rather than with the magnetic properties themselves. High-reliability systems are very dependent on the attention to detail illustrated by this paper. As is usual in this sort of program, engineering judgment is used extensively in deciding among the various possibilities for testing in view of the many constraints imposed by time, money, and people. The use of the term "random" to describe a particular kind of failure in this paper is perhaps a euphemism for "we figured this wasn't very likely to happen again" or for "there doesn't seem to be much we can do about it anyway."

R67-12958 ASQC 851; 771; 824

RELIABILITY TESTING IN THE SATURN S-II STAGE PROJECT.

Donald L. Roelands (North American Aviation, Inc., Space and Information Systems Div., Downey, Calif.).
Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 672–677.
(A66-37951)

Testing in the Saturn S-II Stage Project was planned to achieve high statistical confidence in high reliability through comprehensive ground testing of a flight vehicle. This required apportionment of the required test cycles among test facilities with different capabilities. New statistical approaches to reliability assessment were devised to provide confidence that the maximum allowable failure rate would not be exceeded under the mission conditions. These include use of chi-squared values for evaluating probabilities in the worse cases, the application of hazard rate concepts in various test phases, and the development of truncated normal distributions for evaluating life-length distributions under wearout conditions. Author (IAA)

Review: Well-planned and well-executed integrated testing approaches can greatly benefit the reliability effort in a system program. This paper is an expository discussion of one approach and presents sound evidence of intelligent planning to insure that each test contributes additional confidence to reliability. The first part of the text, discussing test planning is well written and will interest all persons concerned with system reliability testing and demonstration. As a reminder, however, small samples, even though they may represent a large percent of the total production, are not *necessarily* representative of the total population. Further discussion on confidence measurement techniques later in the paper provides only a cursory treatment. The statistical techniques and assumptions appear to be basically sound; however, there is a lack of adequate depth for the unfamiliar reader to fully understand the concepts discussed. The author states that rigorous mathematical treatment of the statistical techniques is contained in contract reports to NASA but does not explicitly identify them. No references are cited.

R67-12962 ASQC 851; 770; 837

RELIABILITY DEMONSTRATION SHILLELAGH MISSILE SUBSYSTEM.

Delbert W. Parsons (Philco Corp., Aeronutronic Div., Reliability Dept., Newport Beach, Calif.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Insitute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966. p. 710–721. 3 refs.

(A66-37955)

The paper summarizes the integrated reliability test program that has been applied to the Shillelagh guided missile subsystem. The various test and analysis techniques, with particular emphasis on test-to-failure, are described in detail. A complete summary of the test results, including safety margin data and success/failure/retest history, is provided for all testing completed to date. General observations regarding the usefulness and problems associated with test-to-failure programs are presented. The use of test-to-failure techniques has uncovered design weaknesses which might not have been detected with small sample size tests at the specification level, or "reliability boundary." For this reason, and in view of the highly successful flight test reliability record achieved in development, the author concludes that a properly administered test-to-failure program can be a key ingredient in the development of high-reliability equipment. Author (IAA)

Review: The emphasis in this paper is on the test-to-failure method for estimating safety margins of system components. To avoid confusion for some readers in the meaning of the test-to-failure method, it is briefly described as follows. In simplest concept a reusable item is tested at increasing stress levels with a *fixed* test duration at each stress level until a stress level is reached where failure occurs. With sufficient items tested in this manner a frequency function for stress levels at which failure occurs could be obtained. For the applications described, repairable items are repaired after failure and retested at slightly lower stress levels to determine the item strengths. The first stress level applied is that representing a reliability boundary or the maximum stress level specified for the operational profile. The safety margin is estimated as simply the number of standard deviations that the mean strength is greater than the reliability boundary. Safety margins of "one-shot" items are similarly obtained; however, a different scheme is used for selecting stress levels whereby the level selected for each test is influenced by the results of previous tests. In a private communication the author has indicated that the different scheme is used for "one-shot" items to achieve results more efficiently with small sample sizes. The concepts in the paper are readily comprehended and will interest those persons concerned with reliability test planning. The assumptions involved in the method appear reasonable. More elaboration on the use of the operating characteristic curves for selection of sample size would have been welcomed.

R67-12972 ASQC 850; 433; 824

BAYESIAN RELIABILITY DEMONSTRATION PLANS.

Austin J. Bonis (General Motors Corp., AC Electronics Div., Milwaukee, Wis.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 861–873. 15 refs.

(A66-37967)

Review of present reliability demonstration difficulties. The author continues Bayesian researches begun in earlier reliability and maintainability transactions. A practical way of acquiring confidence that a desired reliability has been achieved is provided. It is possible to demonstrate high reliability by combining (mathematically) engineering judgment and experience with limited test data. IAA

Review: This is a good readable paper on the subject. It is clear enough to be understandable with relatively little statistical background. The reasons for the use of Bayesian "proofs" of reliability are cogent and well explained. There are many possible sets of assumptions which one can make beforehand (a priori) and this paper deals with only one or two of them. They are not unreasonable ones, nor are many others that are made. (This framework is not neglected in the paper, but it is worthwhile emphasizing here.) One thing not brought out explicitly is that a statement to be made with confidence C in this Bayesian system is not the same statement to be made with confidence C in traditional single-sample plans, nor is either the same as in multiple-sample (sequential) plans. This has importance in writing contracts wherein the statement may be so narrow as to preclude flexibility in the kind of proof. (Not all the algebra in the paper was checked, but it appears quite competent. In Corollary II on p. 864, the explained consequence is incorrect since there are circumstances wherein π *cannot* always be improved upon, viz., there is no guarantee that the quantity on the right of the inequality is always non-negative. Yet it must be for the corollary to have physical meaning, i.e., r is never negative.)

86 FIELD/CONSUMER ACTIVITY

R67-12948 ASQC 863; 814; 872

OPERATIONAL FACTORS IN SYSTEM RELIABILITY PREDICTION.

F. D. Pace (Boeing Co., Aerospace Group, Missile and Information Systems Div., Seattle, Wash.).

Annals of Reliability and Maintainability. Volume 5—Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N.Y., July 18–20, 1965, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 549–554.

(A66-37937)

Discussion of a valid set of quantitative spares and maintenance requirements necessary to develop a cost effective logistics support system for complex weapon systems. Data from a recent major weapon system are discussed to show the relationship between predictions of design reliability and the consumption of spares and of required maintenance actions.

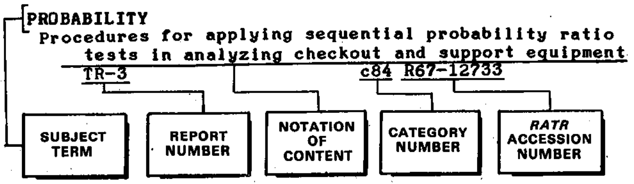
IAA

Review: Logistics and maintenance are important elements in overall system effectiveness and are strongly dependent upon the reliability, among other factors, of the equipment. The models for spares consumption and maintenance demands presented in this paper are very simple but provide much insight into the real-world problems of operational support for complex systems. This is a well-written paper and will be of interest to personnel engaged in practically all areas of systems effectiveness. It emphasizes the importance of not relying primarily on predicted equipment failure rates in logistics and maintenance planning but considering also factors such as induced failures, actual failure rates, and unwarranted repair action. This argument is supported by some very interesting field data from operational Minuteman systems. Such a study can obviously lead to improvements in the logistics and maintenance policy for the operational system which was studied and to improved design for reliability and maintainability of future systems employing hardware of similar type. The author cautions, however, against general application of the data to other programs since the design approach, degree of fault isolation, and maintenance concepts may differ. The concepts in the paper alone, however, warrant consideration of similar studies of other systems to generate data of the generic type presented here. A couple of minor errors noted are that the unit, "number of spaces," in the first equation should be "number of spares per unit of time" and that the term, "percentage," in the definition of symbols throughout should be "proportion."

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 1

Typical Subject Index Listing

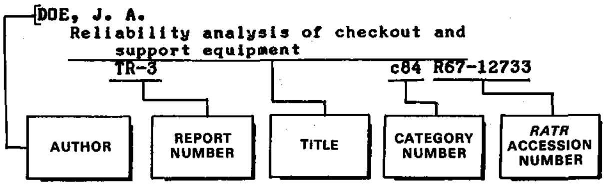


The Notation of Content, rather than the title, is used to provide a more exact description of the subject matter. The category number and *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

PERSONAL AUTHOR INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 1

Typical Personal Author Index Listing



The category number and the *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

REPORT AND CODE INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 1

List of Report Numbers

This may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number preceded by the category number for locating the abstract-review in the abstract section of *RATR*. For purposes of this index, AD, N, and A numbers (accession numbers from *TAB*, *STAR*, and *IAA*, respectively) and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

ACCESSION NUMBER INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 1

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This list of *RATR* accession numbers may be used to identify the category in which a numbered abstract-review appears in the abstract section of this journal. Accession numbers are arranged in ascending order. Preceding each accession number is the category number for locating the abstract-review in the abstract section of *RATR*.

c84	R67-12902
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NASA-Langley, 1967

Reliability Abstracts and Technical Reviews

FEBRUARY 1967

Volume 7
Number 2

R67-12978–R67-13026

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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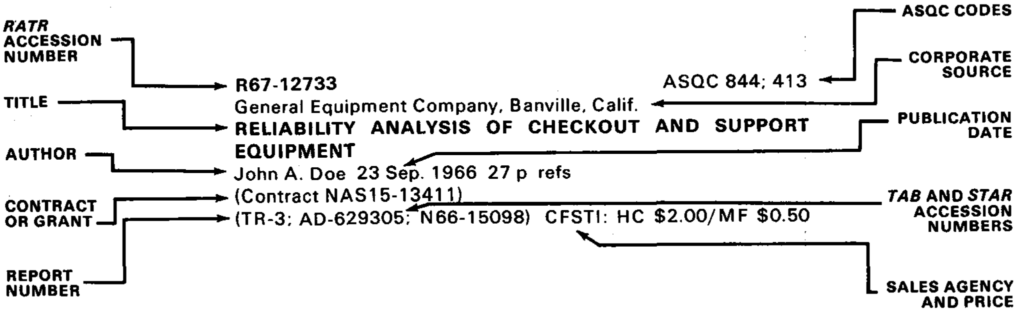
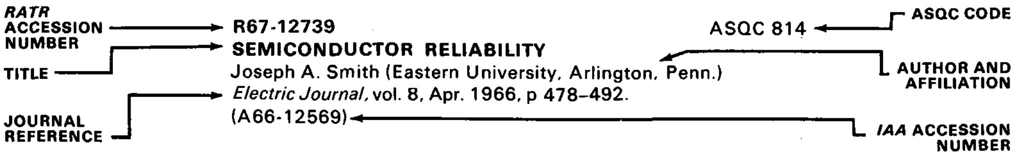
The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

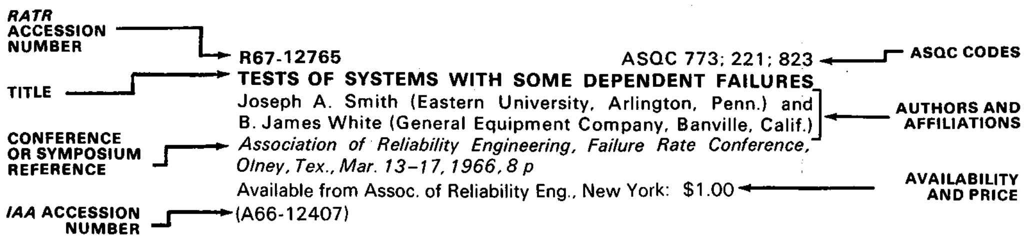
EXAMPLES OF CITATIONS IN *RATR*



R67-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N66-15098) CFSTI: HC $2.00/MF $0.50



R67-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478-492.
(A66-12569)



R67-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13-17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A66-12407)

VOLUME 7 NUMBER 2

Reliability Abstracts and Technical Reviews

A Monthly Publication
of the National Aeronautics and Space Administration

February 1967

80 RELIABILITY

R67-12991 ASQC 800
RELIABILITY AND ECONOMIC PROGRESS.
Daniel J. Haughton (Lockheed Aircraft Corp., Burbank, Calif.).
(1966 Symposium on Reliability, San Francisco, Calif., Jan. 25–27, 1966, Paper.) IEEE Transactions on Reliability, vol. R-15, Aug. 1966, p. 51–54.

Problems in reconciling the outlooks of the economist and the reliability specialist are discussed with emphasis upon the issue of "quantification" for analytical purposes. The approach to reliability and quality issues through economic motivations is viewed as constructive for industries as well as for nations, making the long-term reliability requirements appear even more necessary than those experienced thus far.
Author

Review: These five papers (R67-12991–R67-12995) discuss the subject of Reliability vs. Economics only in a very general way; the last four are quite brief. They assert that improvement in reliability is one means of attaining economic progress, but point out that there are short-term ceilings on the reliability that the customer is willing to pay for. In the case of some monopolies (electric utilities, for example) the customer has little direct choice; it is interesting to note that over half the papers mentioned the recent large power blackout in the Northeast. The second paper has little to say on the subject theme. The third one suggests that service is a good concept that combines economics, reliability, and performance; it takes a rather sophisticated buyer and/or seller, however, together with an appropriate product (or service), to make this concept a useful and effective one. These papers are interesting more for who the authors are than for their tutorial or technical content.

80
R67-12992 ASQC 800
RELIABILITY AND ECONOMIC PROGRESS.
Eugene T. Ferraro (Department of the Air Force, Washington, D. C.).
(1966 Symposium on Reliability, San Francisco, Calif., Jan. 25–27, 1966, Paper.) IEEE Transactions on Reliability, vol. R-15, Aug. 1966, p. 54–55. 4 refs.

Reliability and economic progress are treated generally on the basis of the author's experience.
Author

Review: See R67-12991.

R67-12993 ASQC 800
RELIABILITY IN ECONOMIC PRODUCTIVITY.
Jack A. Morton (Bell Telephone Laboratories, Inc., Murray Hill, N. J.).
(1966 Symposium on Reliability, San Francisco, Calif., Jan. 25–27, 1966, Paper.) IEEE Transactions on Reliability, vol. R-15, Aug. 1966, p. 55–56.
See R67-12992.

Review: See R67-12991.

R67-12994 ASQC 800
RELIABILITY AND ECONOMIC PROGRESS.
John E. Condon (National Aeronautics and Space Administration, Washington, D. C.).
(1966 Symposium on Reliability, San Francisco, Calif., Jan. 25–27, 1966, Paper.) IEEE Transactions on Reliability, vol. R-15, Aug. 1966, p. 56–57.
See R67-12992.

Review: See R67-12991.

R67-12995 ASQC 800
RELIABILITY AND ECONOMIC PROGRESS RELATIONSHIP.
Robert L. Wells (Westinghouse Electric Corp., Pittsburgh, Pa.).
(1966 Symposium on Reliability, San Francisco, Calif., Jan. 25–27, 1966, Paper.) IEEE Transactions on Reliability, vol. R-15, Aug. 1966, p. 57–58.
See R67-12992.

Review: See R67-12991.

R67-13018 ASQC 802
Stevens Inst. of Tech., Hoboken, N. J.
QUALITY CONTROL AND RELIABILITY
Norbert Lloyd Enrick (Kent State Univ., Ohio). New York, Ind. Press, 1966 245 p 2 refs

While this updated practice-oriented text deals primarily with quality control applications and methods, it includes a section on reliability evaluation, assurance, and design. Topics in the chapter on evaluation of reliability include types of failure, analysis of wear-out failures, chance failures, repairable and nonrepairable failures and survival probability. The standardized exponential curve is discussed, as is the practical value of reliability information. Reliability assurance covers testing, sequential sampling plans, the application of the sampling table, and practical reliability assurance procedures. Under the design heading, attention is given to redundant structures and procedures, single and double limit operations, conversion of time procedures, and component reliability data. Sampling plans, control charts, tolerance systems, and life testing are considered; along with the economics of quality control and reliability. M.W.R.

Review: This review is concerned with the section of the book dealing specifically with reliability, which is approximately the last 15 percent of the text. The author's purpose, according to the foreword, was to provide a simplified but valid presentation of the subject for managers, inspectors and engineers. The three short chapters, covering evaluation of reliability, reliability assurance, and reliability design, could serve to introduce the manager or inspector to the basic concepts of reliability. The content of these chapters is quite elementary; they contain nothing which should be new to those whose training or experience has given them an acquaintance with the technical aspects of the reliability discipline. However, the author in a private communication has expressed the opinion that the preceding sentence is optimistic, as he has come across reliability engineers and a reliability manager who had far less than is contained in the book. Quoting the author: "The fact is he may *not* find the reliability chapters in QC & REL old stuff—sadly as this news may be received." It is indeed sad news, and also is a contributor to the ill feelings toward reliability which many persons have. The individual reliability worker must decide how much he has acquired or how much his experience has given him on the technical aspects of reliability in determining whether this book would be helpful to him. It is not the intention to imply that anyone with "reliability" in his job title, including those so titled for some years, is honestly qualified for the title.

81 MANAGEMENT OF RELIABILITY FUNCTION

R67-12980 ASQC 813; 840; 850
Naval Ordnance Test Station, China Lake, Calif.
EX POST FACTO RELIABILITY CONSIDERATIONS
Herbert H. Blackschleger Oct. 1965 17 p refs
(NOTS-TP-3716; AD-633428; N66-15757) CFSTI: HC $1.00/MF $0.50

This report describes the basic considerations of an effective and comparatively low-cost reliability program for an exemplary airborne missile. It covers cases where expediency precludes full reliability considerations prior to production go-ahead and where the manufacturer has accepted a contractual requirement to demonstrate reliability at the systems level. It apportions reliability requirements, delineates important procedures that will provide worthwhile reliability assurance at reasonable cost, and fits the program into the quality assurance provisions of a typical manufacturer oriented to military contracts. The program is intended for missiles that are produced in small quantities. Author (TAB)

Review: A brief coverage of elementary aspects of reliability prediction, programs, and measurement is presented in this report. It is suitable for initial orientation of those without prior familiarity with reliability. As is typical with this sort of presentation, there is a tendency to generalize excessively the pertinence of material which is presented. Several illustrations of this from the report follow: Reliability is defined in terms of the exponential distribution and the prediction and measurement material which is presented is based on this distribution. As the orientation here is missiles, which contain such sub-systems as a rocket motor and a wing assembly, other distributions may also be appropriate. The discussion of achievement of reliability lists several approaches, such as failure reporting. Many other approaches in addition to those cited are possible. The discussion of reliability demonstration features the statistical considerations of the approach of accumulating operating time on several missiles. This sort of reliability testing may or may not have a predictable relationship with the actual reliability of a missile during captive aircraft flight and firing. The dominant failure modes which occur during flight and firing may not appear during tests which are accumulating operating time in another environment. The implication of this generalization, as illustrated above, is that anyone contemplating the application of any of this material should look elsewhere and considerably deeper before deciding on a course of action. In a private communication the author questions whether or not this report is elementary, as he has found that the scope of the paper is beyond the comprehension of most reliability engineers. He says the report was written for the reorientation of these persons. This comment from the author is disturbing, as it indicates that people are continuing to be classified as reliability engineers even though they lack knowledge of the most basic technical and analytical reliability considerations.

R67-13003 ASQC 810; 345
A RELIABILITY AUDIT IN MILITARY AND SPACE ELECTRONICS.
J. E. Mills (Westinghouse Electric Corp., Atomic Defense and Space Group, Aerospace Div., Product Reliability Dept., Baltimore, Md.).
Industrial Quality Control, vol. 23, Sep. 1966, p. 123–126. (A66-42714)

Description of a reliability audit which is applied throughout the plant, irrespective of the separate contracts and their particular conditions. Its function is to examine the activities that culminate in delivery of the finished product to the customer. Its purpose is to identify areas of deficiency in controls, procedures, inspections, tests, procurement, and programs, and to bring them to the attention of management. Author (IAA)

Review: A rather general description is given of a management tool for the monitoring and evaluation of all of the activities that affect reliability and quality during the entire life cycle of a product. The ideas presented will be of interest to management in the aerospace industry. Specifics of implementation will have to be worked out to meet the needs of particular situations, and much will depend on the resourcefulness of the people concerned. Broadly speaking, the idea is to achieve that over-all attitude of attention to detail which is essential to reliability.

R67-13011 ASQC 813
MANUFACTURERS EFFORTS AND COST OF OBTAINING A HIGH RELIABILITY FROM ELECTRONIC EQUIPMENT FOR MILITARY PURPOSES.
F. Baumgartner
Microelectronics and Reliability, vol. 4, 1965, p. 157–161.

Efforts and costs of an "average size" European manufacturing firm in obtaining highly reliable mobile electronic equipment for military purposes are discussed. The equipment, which weighs between 1 and 5 tons and is pulled by a vehicle, contains about 340 valves and semiconductors and about 6000 fixed units such as relays, trips, and switches. Numerous photographs of the unnamed equipment as well as the testing facilities are included, and the type of installation and operating staff difficulties are considered. M.W.R.

Review: This is a very qualitative paper. It does show pictures of environmental facilities which are interesting. The emphasis on human factors in design and or, poor incoming quality are good. The paper is useful for those who want a nontechnical brief discussion of a foreign program and facility.

R67-13017 ASQC 813; 844

SEMICONDUCTOR DEVICE RELIABILITY EVALUATION AND IMPROVEMENT ON MINUTEMAN II CQAP.

D. R. Fewer, W. L. Gill and J. R. Tomlinson (Texas Instruments Inc., Dallas, Tex.).

In: Electronic Components Conference, Washington, D. C., May 4–6, 1966, Proceedings. Conference sponsored by the Institute of Electrical and Electronics Engineers, and the Electronic Industries Association. New York, Institute of Electrical and Electronics Engineers, 1966, p. 389–406. 4 refs.

Stress testing and resultant improvements in semiconductor devices used in Minuteman II were evaluated as part of a Component Quality Assurance Program (CQAP). While such a program highlights device weaknesses and permits improvements, it is of limited value in determining device reliability since it cannot extrapolate the unique acceleration features or other conditions during actual usage. The program does provide an engineering estimate of low failure rates, using known failure rates at the beginning of the program as a reference point. This relative reliability approach may be useful in estimating performance expectancy of highly reliable devices; and an approach coupled with data analyses is considered to be increasingly necessary as more and more devices approach a reliability level comparable to the overall reliability of the available stressing, measuring, and handling techniques. Conventional statistical methods approach the upper limit of their usefulness at a failure rate of 10^{-8} at the 60% confidence level; an upper limit imposed by stressing, measuring, and handling errors of both equipment and personnel. M.W.R.

Review: This is a good review of the program and is suitable for someone previously unacquainted with it. Many of the improvements are prosaic in that they apply known engineering techniques to solve the problems that have been uncovered—no dramatic scientific breakthroughs were needed. An interesting comment was to the effect that the CQAP speeded up the improvements (appreciably) rather than uncovering needed improvements which likely would never have been made. Other manufacturers have also given their experiences under the Minuteman II program out of Autonetics. The emphasis on failure modes and engineering estimates reflects both the success of earlier programs of getting and measuring low failure rates and the exhaustion of the fruitfulness of that approach in some areas. No mention is made of the "goof failures" discussed by RADC and others, of how to prevent them, or of how they fit into a high-reliability program. For the most part it is the customers who discuss this problem, rarely the manufacturers.

R67-13020 ASQC 814

Joint Publications Research Service, Washington, D. C.

THE RELIABILITY OF COMMUNICATIONS EQUIPMENT FROM AN ECONOMIC VIEWPOINT

H. Weiher 21 Jun. 1966 18 p refs Transl. into ENGLISH from Nachrichtentechnik (E. Berlin), v. 16, no. 2, Feb. 1966 p 46–49

(JPRS-36120; T-66-32554; N66-29561) CFSTI: $1.00

Investigation of the requirements to be met by electronic equipment and installations indicated that reliability and economy in industrial and commercial electronics will be the decisive criteria for evaluating future installations. Mutual relations between reliability and economy in the German Democratic Republic were studied to ensure maximum reliability for optimum economy. Fundamental economic viewpoints were derived for reliability calculations from mathematical formulas. It was pointed out that increase in reliability corresponds to decrease in failure frequency and decrease in failure time. The annual costs are considered as a measure for reliability evaluation and are treated as a function of initial costs, maintenance costs, apparatus lifetime, and optimum average failure rate. L.E.W.

Review: An elementary cost-function approach to the problem of finding the optimum failure rate for minimum annual costs is presented in this paper. The general reference is to electronic equipment and systems but no specific example is given. In fact the author mentions the need to test the theoretical relations with the aid of appropriate data. Some of the conclusions cited in the paper appear rather naive. The discussion is not very clear in places (perhaps a result of translation); and not all of the notation is clearly defined. For example, if m_i and p_i are related as one would infer from equation (2a), then equation (2b) is incorrect.

82 MATHEMATICAL THEORY OF RELIABILITY

R67-12978 ASQC 821; 872

Rand Corp., Santa Monica, Calif.

STATISTICAL ANALYSIS OF SPACECRAFT REPLENISHMENT

G. E. Modesitt Mar. 1966 34 p refs Also published in Proceedings of the IEEE, Vol. 53, Dec. 1965, p. 1989–1993.

(Contracts ARPA SD-79; ARPA Order 189-61)

(RM-4739-ARPA; AD-631942; N66-29894) CFSTI: HC $2.00/MF $0.50

This memorandum discusses the number of launches required to establish and maintain a spacecraft system. The mean and dispersion in number of launches are derived for a system consisting of an arbitrary number of exponentially decaying spacecraft and with a constant probability for successful replenishment launches. The report shows the dependence of these results on the spacecraft mean lifetime, the launch success probability, and the number of spacecraft per launch. The results are useful in estimating the probable costs of various spacecraft systems and should be of assistance in comparing such systems. The memorandum was prepared as part of the Advanced Research Projects Agency's VELA analysis study. An abridged version of this memorandum was published in the Proceedings of the IEEE: Special Issue on Nuclear Test Detection, December, 1965. TAB

Review: This is a mathematical paper which presents the solution to a specific problem. While the author's preface refers to uses of the results in estimating the probable costs of various spacecraft systems, the paper does not deal with applications. Thus it will be of interest to theoreticians rather than reliability or design engineers. The model is very simple, being based on assumptions of exponentially-distributed spacecraft lifetimes and constant probability for successful launches. Not all of the mathematical details were checked, but the work appears to be of high quality.

R67-12981 ASQC 824; 433
RAND Corp., Santa Monica, Calif.

A BAYESIAN APPROACH TO RELIABILITY ASSESSMENT

B. L. Fox Aug. 1966 27 p refs
(Contract NASr-21(11))
(NASA-CR-77910; RM-5084-NASA; N66-36262) CFSTI: HC $2.00/MF $0.50

Bayesian analysis was used to specify prior distribution parameters for the reliability of a unit that performs satisfactorily or not throughout an Apollo mission, and for the failure rate of a unit that fails according to exponential distribution. Prior distribution is based on analogous components and engineering estimates, and testing data are merged with the prior distribution via Bayes rule to obtain the reliability assessment. Tables of the computed prior distribution parameters are appendixed. G.G.

Review: One of the major problems in applying a Bayesian analysis is to specify the prior distribution. A particular feature of this paper is that it gives a procedure and includes a listing of computer programs for estimating the parameters when the prior distribution is of the beta or gamma form. It also includes a table of these parameters based on information concerning the most likely and/or the mean value of the estimate and the odds that the error in the prior estimate is less than a given percent. This is a well-written mathematical paper, and, to one familiar with or interested in Bayesian techniques, the reading of it will be straightforward and very worthwhile.

R67-12982 ASQC 824
RAND Corp., Santa Monica, Calif.

STATISTICAL ESTIMATION PROCEDURES FOR THE "BURN-IN" PROCESS

Richard E. Barlow, Frank Proschan, Ernest M. Scheuer, and Albert Madansky Sep. 1966 21 p refs
(Contract NASr-21)
(NASA-CR-78131; RM-5109-NASA; N66-37212) CFSTI: HC $1.00/MF $0.50

In this process, items whose failure rate is assumed to decrease with time are put on test (burnt-in) until a fixed amount of time has elapsed (truncated sampling) or until a fixed number of failures have occurred (censored sampling). The purpose is to identify and eliminate poor-quality or defective items. For both of the modes of observation described, we provide a conservative upper confidence bound for the failure rate at the time the burn-in process ends, and the maximum likelihood estimate (MLE) of the failure-rate function. These results are valid under quite general conditions. In particular, we do not require that the form of the life distribution be known. The MLE is obtained under the sole assumption that the failure-rate function is decreasing. The confidence bound is obtained under the even weaker assumption that the failure rate of the time observation ends is no larger than the failure rate throughout the period of observation. Author

Review: This is a concise mathematical paper concerned with estimating the failure rate in situations involving a "burn-in" process. Both truncated and censored sampling are considered, and maximum likelihood estimators and confidence bounds are given. The only underlying assumption is that the failure-rate function is decreasing. While the paper is primarily mathematical, application of the results is facilitated through the inclusion of numerical examples and the presentation of a computer program for the computation of a confidence limit for the failure rate in the truncated sample case.

R67-12987 ASQC 824; 512

LAMBDA AND THE QUESTION OF CONFIDENCE (Letter to the Editor).

J. M. Groocock (Standard Telephone and Cables, Ltd., Transistor Div., Sidcup, England).
Microelectronics and Reliability, vol. 5, May 1966, p. 191–192.

Tables of confidence levels for attribute testing that were published in the June 1965 issue of this journal are discussed, and discrepancies between these and abbreviated tables that appeared in the same issue are noted. These tables, based on Poisson distributions, are equally applicable to binomial distributions. It is suggested that the lower confidence limits for zero failures be deleted from the tables. The two articles on which this letter to the editor is based deal with lambda and confidence levels, and reliability testing and assurance of electronic components. M.W.R.

Review: This paper correctly points out errors in the tables in [1], viz., a 2.83 should be 2.43 (90% table) and the 0.00 should be deleted for all zero failures (in "Lower" column). A basic explanation for the latter is that when the true mean is zero the only probability levels which have meaning are 0% and 100%. Thus one cannot "go backwards" for parameter estimation with any other confidence level except 0% or 100%. The correct way of expressing the confidence limits when the random variable is discrete (as in this Poisson case) involves "the confidence is at least. . ." or "the confidence is at most. . ." depending on the situation. In a paper by Meuleau [2] there is confusion between tests in which the time and in which the number of failures is the random variable. (In a private communication Meuleau has indicated that he uses the Bayesian philosophy in which the distinction is ignored.) It is then no wonder that the table in [2] does not agree with that in [1]. (The latter is correct except as noted above.) The author's final comment on making statements about the true mean from a sample is too limited. A good discussion of how to make the proper confidence statement on the interval which is asserted to contain the true mean is found in [3].

References: [1] Lambda and the question of confidence, by J. Honeychurch, *Microelectronics and Reliability,* vol. 4, p. 123–130, Jun. 65 (R67-13010). [2] High-reliability testing and assurance for electronic components, by Charles A. Meuleau, *Microelectronics and Reliability,* vol. 4, p. 163–177, Jun. 65 (R67-13012). [3] *Biometrika Tables for Statisticians, Volume I,* edited by E. S. Pearson and H. O. Hartley, Cambridge University Press, 1956, Introduction, Section 22.

R67-12996 ASQC 821; 431

RELIABILITY PREDICTION TECHNIQUES FOR COMPLEX SYSTEMS.

L. Tin Htun (Raytheon Co., Advanced Development Laboratory, Wayland, Mass.).
(National Aerospace Electronics Conference, 17th, Dayton, Ohio, May 10–12, 1965, Proceedings, p. 444–458) *IEEE Transactions on Reliability,* vol. R-15, Aug. 1966, p. 58–69. 9 refs.
(A66-39341)
See R67-13008.

Review: This paper is the same as that in Proceedings National Aerospace Electronics Conference, 10–12 May 65, Dayton, O., p. 444–458, except that the formulation for the variance of the mean time to first system failure is included. The reference to the earlier publication is given.

R67-13001 ASQC 823

INFERENCE FROM THE THIRD FAILURE IN A SAMPLE OF 30 FROM A WEIBULL DISTRIBUTION.

John I. Mc Cool (SKF Industries, Inc., King of Prussia, Pa.).
Industrial Quality Control, vol. 2, Sep. 1966, p. 109–114. 3 refs.

Properties of the third-order statistic in samples of 30 rolling bearings are used to estimate the tenth percentile of the Weibull distribution; and statistical estimation and testing procedures are given which can be applied to the third smallest failure. While the specific problem directly concerns only the rolling bearing industry, the results illustrate how distribution theory may be applied to transform a so-called rule of thumb into an exact inferential technique. The expected agreement between the third-order statistic and a full-sample is demonstrated, and distribution of this statistic for samples of size n is discussed. Bias of the third-order statistic is considered, and some bias correction values are given. The 80, 90, and 95% confidence levels given for values of the Weibull shape parameter can be used in hypothesis testing of the L_{10} life of groups of ball bearings. Distribution of the quotient of third-order statistics from independent samples of size 30 is discussed in terms of analysis of endurance tests. M.W.R.

Review: The specific problem treated in this paper is of direct concern to the rolling bearing industry. The results are of interest in a broader context, however, since they illustrate the use of distribution theory in transforming a "rule of thumb" into an exact inferential technique. It would be worthwhile to subject other rules of thumb and short-cut methods of analysis to this type of study before using them in making important decisions. The result would be a greater awareness of potential pitfalls and sources of wrong decisions.

R67-13002 ASQC 824; 510

METHODS OF ESTIMATING RELIABILITY.

Thomas M. Drnas (Hughes Aircraft Co., Aerospace Group, Space Systems Div., Systems Reliability Dept., Reliability Analysis Group, El Segundo, Calif.).
Industrial Quality Control, vol. 23, Sep. 1966, p. 118–122. 21 refs.
(A66-42713)

Description of a number of methods whereby a reliability estimate may be determined by contrasting test data with one- or two-sided assigned specification limits. Methods for calculating one- and two-sided confidence intervals are also discussed. The methods require that the test data (samples) be randomly selected from populations which are normally distributed. Author (IAA)

Review: Known statistical methods are applied to a series of textbook-type problems in reliability estimation. The presentation is clear and adequate references are cited. The paper will be of value as tutorial material for those who are learning to apply statistical methods in reliability estimation. In practice, the limitation imposed by the assumption that the performance characteristic is Normally distributed should be noted.

R67-13004 ASQC 821; 872

FAILURE PROBABILITY FORMULAS FOR SYSTEMS WITH SPARES.

D. R. Wilken and E. S. Langford (North American Aviation, Inc., Anaheim, Calif.).
Operations Research, vol. 14, July–Aug. 1966, p. 731, 732.
(Contracts AF 04(694)-923; AF 04(694)-247)
(A66-40516)

Consideration of n systems operating independently, with each system demonstrating an exponential failure pattern with MTBF equal to $1/\lambda$. It is supposed that all systems are "up" at time $t=0$ and that s spare systems are provisioned. When a system fails it is instantaneously replaced by a spare. The expression P(i; s, n, t) is derived for the probability of exactly i failures in a time period of length t. IAA

Review: This short paper gives a mathematical derivation of the probability of i failures in a time period of length t for systems with spares. The result is correct and may be useful in calculating the failure probability for such systems.

R67-13007 ASQC 824

QUERY 18: LIFE TESTING AND EARLY FAILURE

Norman L. Johnson, ed. and A. Clifford Cohen (Georgia University Statistics Department, Athens, Ga.).
Technometrics, vol. 8, Aug. 1966, p. 539–545. 10 refs.

Estimating distribution parameters is discussed for the case during life testing in which some full-term spans are observed, but the operation of other test specimens is discontinued for reasons unrelated to the normal failure mechanism. Derivation of the maximum likelihood estimating equations is given for the exponential, normal, and Weibull distributions; and examples are included to show how the problem can be solved using each of these distributions. M.W.R.

Review: The problem to which this paper is addressed is that of parameter estimation from censored samples of a type resulting from life tests in which some of the items fail for reasons unrelated to the normal failure mechanism. This is a not uncommon problem which can occur, for example, due to accidental breakage of a test specimen. The solution is provided by an author who has published much on parameter estimation based on censored and truncated samples. The material is concisely and clearly presented, and adequate references are cited. The paper constitutes a worthwhile contribution to the literature on statistical estimation procedures applicable to life testing.

R67-13008 ASQC 821; 431

RELIABILITY PREDICTION TECHNIQUES FOR COMPLEX SYSTEMS.

L. Tin Htun (Raytheon Co., Wayland, Mass.).
In: National Aerospace Electronics Conference, 17th, Dayton, Ohio, May 10–12, 1965, Proceedings. Conference sponsored by the Professional Group on Aerospace and Navigational Electronics, Dayton Section of the Institute of Electrical and Electronics Engineers, and American Institute of Aeronautics and Astronautics. Dayton, Institute of Electrical and Electronics Engineers, Dayton Section, 1965, p. 444–458. 9 refs.
(A65-29281)

Development of reliability predictions for repairable systems composed of units with constant failure and repair rates. The use of transition-rate diagrams for describing the dynamic behavior of such a system is explained. A methodology is established for writing the appropriate set of equations, relating the state probabilities of a system, for predicting the reliability, pointwise availability, steady-state availability, and mean time to first system failure. IAA

Review: This report is more limited than is implied by the title. It deals with arbitrary systems composed of units with constant failure and repair rates and uses the Markov chain/flow-graph approach. Much of the text deals with an elementary derivation of the hazard function and flow-graph techniques for analytical solutions. Not all the mathematics was checked, especially in the examples, but it appears to be good. The discussion of flow-graphs and associated equation-solving is clear enough to be understood by engineers with no previous background in them. (The same paper is found in *IEEE Transactions on Reliability*, vol. R-15, Aug. 66, p. 58–69 and this publication is referenced there.)

R67-13009 ASQC 824; 512; 612; 831

EXTENSION OF MONTE CARLO TECHNIQUE FOR OBTAINING SYSTEM RELIABILITY CONFERENCE LIMITS FROM COMPONENT TEST DATA.

Albert H. Moore (USAF, Air University, Institute of Technology, Wright-Patterson AFB, Ohio).

In: National Aerospace Electronics Conference, 17th, Dayton, Ohio, May 10–12, 1965, Proceedings. Conference sponsored by the Professional Group on Aerospace and Navigational Electronics, Dayton Section of the Institute of Electrical and Electronics Engineers, and American Institute of Aeronautics and Astronautics. Dayton, Institute of Electrical and Electronics Engineers, Dayton Section, 1965, p. 459–463. 20 refs. (A65-29282)

Discussion of the Monte Carlo technique for obtaining approximate system confidence levels from component or subsystem test data when the distribution of the estimators of the parameters of the failure models for the components is known. Estimator techniques for the parameters of life distributions are summarized. In general, maximum-likelihood or minimum-variance unbiased estimation is discussed. The components are assumed to have been subjected to a life or truncated test (Type I or Type II censoring). The technique of obtaining system-reliability confidence limits at any specified level is extended to cases where the distribution (joint distribution) of the estimators for the parameters is unknown. Author (IAA)

Review: This is largely a review paper although it is difficult to tell to whom it is directed. Statisticians will know most of it anyway, and engineers are not likely to understand crucial parts. The portion of the paper that is an extension "... to cases where the distribution ... of the estimators is unknown" is not clear. The example does not seem to use this extension. There are many references to the literature which may be of help in the review portion of the paper.

R67-13010 ASQC 824; 512

LAMBDA AND THE QUESTION OF CONFIDENCE.

J. Honeychurch (Texas Instruments Ltd., Bedford, England).

Microelectronics Reliability, vol. 4, 1965, p. 123–130. 3 refs.

Poisson and chi square methods are described for determining the degree of confidence that can be placed on the results of life testing of various components. Applying confidence limits to the failure rate (λ) of a sample and to the mean time between failure is considered, and three tables present the upper and lower confidence limits for confidence intervals between 99.9 and 40% for zero to 50 failures. Examples describe the method for using the tables, and theoretical aspects of the Poisson and chi square distributions are discussed. M.W.R.

Review: This paper has serious disadvantages which limit its usefulness. Most of the equations are actually correct but the explanations tend to be poor. For example: (1) The definitions of confidence limits and confidence interval are not the traditional ones. They appear to pertain to tolerance limits and intervals instead. (2) If the failure rate (hazard) is not constant, and in places the text implies it need not be, some of the equations must be treated with great care; others are wrong. (3) The confidence limits are not on d, the number of failures (since that is observed), but on a, the estimated value of the true mean. Further, in this case where the random variable is discrete, confidence values are expressed as "at lease 95%" or "at most 95%" (depending on the situation) rather than as exact values. For a further explanation of this see [2]. (4) The explanation of the factor (number of failures plus one) in the degrees of freedom for χ^2 (in one of the limits) is poor. The reason is not that "we take the pessimistic view..." but that "the equation for the sum of Poisson terms comes out that way when the χ^2 identity is used." (5) It is implicitly assumed that total test time is fixed and the number of failures is the random variable. In [1] this article is critically discussed. A misprint in the table is pointed out and the entries for zero failures, Lower (they are all listed as 0.0) are shown to be meaningless. Those entries should be deleted with the note: "Not applicable". (This arises because the χ^2 distribution is readily defined only for degrees of freedom greater than zero.) The adverse discussion about confidence limits on parameter estimation is refuted if the correction in #3 above is made.

Referenc;es: [1] Lambda and the question of confidence, by J. M. Groocock, *Microelectronics and Reliability*, vol. 5, no. 2, p. 191–192, May 66 (Letter to the Editor) (R67-12987) [2] *Biometrika Tables for Statisticians, Volume I*, edited by E. S. Pearson and H. O. Hartley, Cambridge University Press, 1956, p. 74–77.

R67-13013 ASQC 824; 512

MULTIPLE FAULTS AND CONFIDENCE LEVELS.

N. J. Briggs and J. Yarnell (Hawker Siddeley Dynamics, Ltd., Hatfield, Herts., England).

Microelectronics and Reliability, vol. 4, Sep. 1965, p. 235–240. (A65-35401)

Study of two general cases of interest to those concerned with the confidence levels associated with the probabilities of more than one event, necessarily based on incomplete statistics. The first part discusses the confidence levels at which one can assess the probability of simultaneous occurrence of several independent random events and shows that the situation is more favorable than would be implied by a less sophisticated view. The numerical advantage to be gained by recognition of this fact is plotted for 2- and 3-fault cases (the events of interest are faults in complex electronic systems). The second part considers the same kind of question but deals with alternative faults. That is to say that it asks what maximum rate of events F_1 or F_2 can be associated with a given confidence level when only a small number of events of each kind have been observed. The simplifying assumption is made that they have each been observed over equal periods, and in this case it is shown that an unwelcome conclusion appears to follow from an extension of the argument to multiple fault cases. Author (IAA)

Review: The framework for the development in this paper is not completely defined. It appears, however, that the following formulation is intended. The n_i, representing the number of faults of type i occurring in time T_i, are independent Poisson processes, process i having failure rate λ_i, $i = 1, 2, \ldots, k$. This does not "follow easily" from the assumptions given, as claimed; further assumptions are required. See, for example, [1]. A case of "k joint events" is one in which disaster occurs only after at least one of each of the k types of faults occurs. The case of "two alternative events" is one in which disaster occurs whenever either one of the two systems fails. The definition of confidence interval given on page 235 in the paper is that of a fiducial interval, as defined by Wilks [2]. The multivariate extensions proposed are neither explicitly defined, nor, more seriously, is an interpretation given of what "α% confidence" means when one uses these bounds. With ordinary interpretations of confidence, and on the basis of reasonable assumptions, the theory in the paper is valid. However, the authors' applications are incorrect in the sense that the parameters for which bounds are established do not measure what the authors think they do. In the case of k joint events, the authors would have an analog of equation (5) to represent disaster probability. However, from the implicit assumptions mentioned above, equation (5) is not valid but must be replaced by:

$$P(T) = f(T) \prod_{i=1}^{k} (\lambda_i + o(T_i)).$$

That the form of equation (5) is not valid for large T_i is evident from the fact that, for large λ_i values, the probability P in equation (5) can exceed unity. The product $\Pi\lambda_i$ does not generally measure disaster probability and hence is not generally of interest in confidence bounding. In this case, the probability of disaster is actually:

$$\prod_{i=1}^{k} (1 - e^{-\lambda_i T_i}),$$

for which bounds are available using standard classical or Bayesian methods. Since computations for the case of k joint events were done for parameters which are presumably not of interest, discussion of "conclusions" drawn from those computations is unnecessary. For a correct treatment of this problem in the case of k joint events, see [3].

References: [1] Gnedenko, B. V. (1962) *The Theory of Probability* (translated from the Russian by B. D. Seckler), Chelsea, New York, [2] Wilks, S. S. (1962), *Mathematical Statistics*, Wiley, New York, [3] "Bayesian confidence limits for the reliability of cascaded exponential subsystems," by Melvin D. Springer and William E. Thompson, presented at the Western Regional Meeting, I.M.S., Los Angeles, California, 15–17, Aug. 66 (abstracted in *Ann. Math. Stat.*, vol. 37, no. 5, Oct. 66, p. 1420–1421)

R67-13022 ASQC 821; 711; 712; 844

Aeronautical Research Inst. of Sweden, Stockholm.

ANALYSIS OF THE PROBABILITY OF COLLAPSE OF A FAIL-SAFE AIRCRAFT STRUCTURE CONSISTING OF PARALLEL ELEMENTS

S. Eggwertz and G. Lindsjo Wright-Patterson AFB, Ohio, AF Flight Dyn. Lab., Feb. 1965 59 p 2 refs
(Contract AF 61(052)-573)
(RTD-TDR-63-4210; AD-431826; N64-17150)

A study is made of the probability of collapse of a fail-safe structure, consisting of a number of parallel members, subjected to a random load spectrum. In the individual members a fatigue crack is first initiated and failure of the members occurs due to a heavy load on the weakened members. The probability of element failure is obtained by a combination of the probabilities of crack initiation and of meeting a load exceeding the residual strength of the member. The probability of consecutive element failures is deduced from the probability of failure of the individual members. Collapse occurs when all members are broken, or, in practice, after a critical number of element failures. The probability of collapse of the assembly during the whole service life is the sum of the probabilities of all the inspection intervals. A numerical procedure for calculating the probability of collapse has been developed and evaluations have been made for an assembly of six identical, parallel members. Diagrams of the probability of collapse P versus the service life time T_L have been plotted in figs. 3–8 for various lengths of regular inspection intervals, assuming different values of the crack initiation and strength reduction parameters introduced. Some preliminary fatigue testing of assemblies with six members has been carried out in order to study the validity of basic assumptions in the theoretical investigation. Author

Review: The main portion of this report is the analysis of a simple structure, consisting of several parallel elements. Much of the work is concerned with substituting hypothetical distributions in the mathematical structure derived for the general case. While not all of the mathematics was checked, it appears to be of good quality. It is worth quoting one of the comments of the authors, "The results obtained in this report are of importance, mainly because they prove that the probability of collapse of a fail-safe structure consisting of parallel elements can actually be calculated taking into account rather detailed conditions regarding service and structure behavior." (p. 29). The authors emphasize that this is a preliminary effort and that many approximations have been made which need to be tested in practice. The problem being attacked here is an important one since if an aircraft is to have fail-safe design it is necessary to be able to find a crack during an inspection and to have a low probability of failure even with cracks in between inspections. The report is of value largely to engineers who are considering doing further theoretical work in this subject. It will be of little direct use to engineers in their design work.

R67-13024 ASQC 824; 431; 782

Technik, Inc., Jericho, N. Y.

LIFETIME EVALUATION PROCEDURES FOR RANDOM SHOCK AND VIBRATION

M. Zaid and P. Marnell *In* NRL The Shock and Vibration Bull., No. 35, Pt. 3 Jan. 1966 p 125–147 refs (See N66-24020 13-32) CFSTI: HC $6.00/MF $1.50
(N66-24033)

This paper presents procedures for evaluating the lifetime of a structure subjected to random vibration and random shock. As a specific example, a filament lamp structure is treated in detail. The random vibration procedure obviates extensive analysis through the introduction of a unique concept relating fatigue life to filament deflection. For a random shock environment, the lamp filament is analyzed as an elastic–plastic system subject to step-shock inputs of random intensity. A cumulative damage concept for shock is introduced, which leads to a straightforward evaluation of the average number of random shocks to failure. In both cases, a combination of theoretical and experimental techniques is utilized to obtain dependable evaluation procedures with minimal expenditures of time and effort. Specific examples are included for purposes of illustration and verification of the methods. Author

Review: This is a well-written paper which describes concepts and procedures used in predicting the adequacy of an incandescent lamp design under random mechanical environments. Numerical examples and experimental results add to the clairty of the presentation. In addition to the intrinsic value of the results, the paper serves to illustrate the use of combined theoretical and experimental techniques in predicting the lifetime of a structure.

R67-13025 ASQC 824; 770
Naval Missile Center, Point Mugu, Calif.
SUMMARY OF DESIGN MARGIN EVALUATIONS CONDUCTED AT THE U.S. NAVAL MISSILE CENTER
C. V. Ryden *In* Defense Dept. Shock Vibration and Assoc. Environments, Pt. 4 Mar. 1964 p 209–217 refs (See N64-23151 16-01)
(N64-23164)

Incremental levels of enviromental stresses are applied to missile systems to induce failures deliberately. It is assumed that those components that fail are the weakest link in the structure. Improvements to missile reliability on the basis of such test programs will be discussed. Author

Review: The kinds of tests performed and the statistical design appear to be good and useful. The explanations and some of the analyses are confusing at best; the discussion at the end of the paper illustrates this. Some of the other poor points in the explanations are: (1) Random or chance are used synonymously with constant failure rate. By implication, if the failure rate is not constant, the failures are not random. The implication is wrong and it is poor practice to use the terms synonymously. (2) The overlapping area of the stress-strength curves is asserted to be proportional to the failure probability. This is quite incorrect, even if it does appear too often in the literature. (3) The stress-strength concept is not used in the analysis at all. Instead, apparently, equivalent missions are used to calculate a failure rate. This procedure is not discussed at all. (4) While the name is Design Margin, that concept is not used in the test evaluation.

83 DESIGN

R67-12984 ASQC 831; 612
COMPUTER SIMULATION AND ANALYSIS TECHNIQUES FOR RELIABLE CIRCUIT DESIGN.
W. Hochwald, K. F. Mc Quade, and H. S. Scheffler (North American Aviation, Inc., Autonetics Div., Downey, Calif.).
(Nachrichten-Technische Gesellschaft, Meeting, Nuremberg, West Germany, Apr. 22, 1965, Lecture; Technische Zuverlassigkeit in Einzeldarstellungen, vol. 6, 1965.) *Microelectronics and Reliability,* vol. 5, May 1966, p. 97–128. 6 refs. Translation.
(A66-32302)

Discussion of a program implementing the worst-case computer simulation and performance prediction method, and of a program implementing the Monte Carlo method. A third approach is also described which combines both methods. These programs require mathematical models for simulation *of the electronic components.* The models, primarily the diode and transistor mathematical models, are presented in detail. Special emphasis is given to the nonlinear model characteristics required to closely duplicate physical behavior. IAA

Review: This is a good paper. It is directed largely toward circuit design and reliability engineers and explains the program and concepts at a level suitable for them. The transistor and diode models are presented in some detail (the equations were not checked) and are useful per se and for their illustrative value. Techniques such as this depend heavily on the adequacy of the models of the circuit elements. Integrated circuits are mentioned but the question of equivalent circuits (models) for them is not broached; they will be much more difficult to find than models for transistors. Also not explicitly mentioned is how the variations in performance from one transistor individual to another (from the same population) are translated into parameter variations in the mode. For designers without the large purchasing power of a big corporation with a big program, trying to relate model parameters to performance parameters which are guaranteed by the manufacturer may be virtually impossible. In a private communication the first author has added the following comments. "(1) With regard to modelling integrated circuits, it is possible to use techniques which, by means of the computer, reduce a multinode circuit (such as an integrated circuit) to an equivalent four-terminal model for a constant, specified set of conditions. This simplifying process can be used for analysis involving a large circuit using many I/C's. A further refinement of this technique allows the switching back to the complete I/C model for purposes of tolerance analysis. . . (2) The relating of mathematical model parameters to performance parameters guaranteed by the manufacturer can be aided by a computer program, such as the PARTS Program recently developed by Autonetics for the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico 87117; on Contract AF29(601)-7230. PARTS converts parameters. . . supplied by the manufacturer, or parameters obtained by relatively simple laboratory measurements, to the parameter values used in the mathematical models of most current circuit analysis codes."

R67-12985 ASQC 831; 844
PREDICTION AND ENGINEERING ASSESSMENT IN EARLY DESIGN.
W. P. Cole (General Electric Co., Ltd., Applied Electronics Laboratories, Stanmore, Middx, England).
(Institution of Electronic and Radio Engineers, and Institution of Electrical Engineers, Symposium on Engineering for Reliability in the Design of Semiconductor Equipment, Hatfield College of Technology, Hatfield, Herts., England, May 13, 14, 1965, Paper.) Microelectronics and Reliability, vol. 5, May 1966, p. 129–144. 11 refs
(A66-21858)

The paper discusses the steps which could be taken in the early design stages to predict, assess and then verify the reliability of the component parts of the system. Prediction of "mean time between failures" of electronic equipment is dealt with in particular. The Advisory Group on Reliability of Electronic Equipment (AGREE) type of testing carried out by the manufacturer to determine the reliability of his final product is described in some detail in an appendix. Author (IAA)

Review: This paper deals largely with the adding of generic failure rates to get a system failure rate. It gives a reasonable discussion of this process. Reliability testing and verification of element failure rates is also covered. This paper is typical of those appearing on this subject. A few minor difficulties are the following. (1) The term "random" is used to imply constant hazard rate. This practice is poor. (2) There is no discussion of variations in life of parts made by various manufacturers. This can be very important. (3) One of the reasons integrated circuits were predicted to improve reliability so little is that the failure rate per integrated circuit was defined to be that of six silicon transistors. In some cases, the effect on overall failure rate of perfect transistors or integrated circuits would be small. (4) The emphasis in the discussion of AGREE testing seems to be on the sequencing of the environmental tests. In practice many of the problems arose because the tests had to be carried out under extreme rather than benign environments. The comment that a 2:1 ratio (either way) represents reasonable agreement between predicted and measured failure rates is interesting. Some claim a much higher, others a much lower ratio.

R67-12986 ASQC 833; 871

ELECTROMECHANICAL SWITCHING DEVICES–RELIABILITY, LIFE AND THE RELEVANCE OF CIRCUIT DESIGN.

A. G. Leighton (General Post Office, Engineering Dept., London, England).

(Symposium on Engineering for Reliability in the Design of Semiconductor Equipment, Hatfield College of Technology, Hatfield, Herts, England, May 13, 14, 1965, Paper.) Microelectronics and Reliability, vol. 5, May 1966, p. 161–173. 20 refs.

(A66-23791)

Discussion, with reference to electromechanical switching devices, of those aspects affecting reliability which are within the orbit of influence of the user rather than those within that of the designer or manufacturer. General considerations include mechanical wear and tear. Many EM devices are affected by a comparatively short early failure period, followed by a longer period during which a lower but constant failure rate can be expected. Extensive consideration is given to the maintenance organization setup, which plays a large part in establishing the overall reliability. Two-motion selectors, uniselectors, relays, and electrical contacts are described. Attention is given to the quenching of electrical contacts and to circuit design. IAA

Review: This paper was covered by R66-12738. Reference to the earlier publication is cited in the paper.

R67-12990 ASQC 838

AN ASSESSMENT OF THE VALUE OF TRIPLICATED REDUNDANCY IN DIGITAL SYSTEMS.

M. Longden, L. J. Page, and R. A. Scantlebury (Ministry of Technology, National Physical Laboratory, Teddington, Middx., England).

Microelectronics and Reliability, vol. 5, Feb. 1966, p. 39–55. 4 refs.

(A66-24914)

The use of redundant components has been suggested as a method of improving both the manufacturing yields of "integrated" electronic devices and the reliability of operation of electronic digital systems. One method is to employ three copies of the equipment and take a "vote" on the output. Provided only one system is in error, the correct output will be maintained, but two systems in error will produce an erroneous result. The basic idea can be improved by undertaking voting at more than one place in the system so that a multiplicity of faults may (with calculable probability) be tolerated. The number of stages of voting can be optimized with respect to parameters which include the reliability of individual components and the size of the system. A further improvement can be achieved by triplicating the voting circuits themselves. This latter system is more reliable than the former but requires the use of six times as many components as the equivalent nonredundant system. Significant improvements in yield and reliability over that obtained with the nonredundant system, while maintaining reasonable levels of yield and reliability, are only obtained with very large systems employing very good components. Author (IAA)

Review: This paper covers quite a few, but certainly not all, of the models for triplicated redundancy in digital systems. The mathematics appears to be of high quality although not all of it was checked. Some of the cases which are not covered are the following. (1) Those in which success/failure is not an adquate description of the system. For example, it may be important whether a logic circuit fails to a 0 or to a 1. (2) Those where there is more than a proportionate increase in interconnections due to the redundancy; these increased in-interconnections may increase the probability of failure. It may even be that the proportionate increase in interconnections will cause more failures due to the more complicated topology. (3) Those in which the proportion of defectives is higher than usual due to the added complexity. The reason for the last two situations is that the same probability of failure per element is assumed in the text for the redundant and nonredundant cases. In applying the results of analyses such as are given in this paper, be sure that the model being analyzed suits your case quite well. If this is not so, the results can be most misleading. This fact is illustrated by some of the authors' examples.

R67-12997 ASQC 837; 824

THE SENSITIVITY FUNCTION IN VARIABILITY ANALYSIS.

Charles Belove (Brooklyn, Polytechnic Institute, Dept. of Electrical Engineering, Brooklyn, N. Y.).

IEEE Transactions on Reliability, vol. R-15, Aug. 1966, p. 70–76. 9 refs.

(Contracts AF 49(638)-1373; DA-31-124-ARO(D)-316)

(A66-39342)

Collection of various results concerning the sensitivity function which are of direct use in variability analysis. A relation concerning sensitivity sums is given which furnishes a check on sensitivity calculation for homogeneous functions; it is held that use of this check should become a routine part of variability analysis wherever it is applicable. Applications to pole-zero sensitivity of electrical networks are also included. IAA

Review: This is a good paper on a subject not often written about in the open literature. The sensitivity function does have its uses and these relationships are handy to have. The development is generally clear and easy to follow. Engineers who are doing design and analysis may well find this paper helpful.

R67-12998 ASQC 831; 872

RELIABILITY OF A SYSTEM HAVING STANDBY SPARE PLUS MULTIPLE-REPAIR CAPABILITY.

Eginhard J. Muth (General Electric Co., Missile and Space Div., Apollo Support Dept., Daytona Beach; Florida, University, Gainesville, Fla.).

IEEE Transactions on Reliability, vol. R-15, Aug. 1966, p. 76–81. 6 refs.

(A66-39343)

The reliability of a system having two identical and repairable units, one of which is operating while the other is in inactive standby, is treated. It is assumed that each unit has independent exponentially distributed failure times and independent gamma distributed repair times. The failure rate is μ, and the mean time to repair is τ. Formulas are derived which express system reliability and expected time to system failure, specifically, as a function of the capability for one repair, two repairs, and so on. Results are presented in graphical form. Important conclusions are: (1) the benefit of repair capability is negligible when $\mu\tau > 0.5$; (2) the choice of the repair time distribution does not influence the results when $\mu\tau < 0.2$; and (3) the effect of repair capability is comparable to that of additional standby units when $\mu\tau < 0.01$. Author (IAA)

Review: This paper is essentially the same as the one covered by R65-12118 although the previous publication is not mentioned.

R67-12999 ASQC 838; 844

RELIABILITY STILL MEANS BACKUP.

G. C. Hendrie (Honeywell, Inc., Computer Control Div., Minneapolis, Minn.) and R. W. Sonnenfeldt (Digitronics Corp., Albertson, N. Y.).

Control Engineering, vol. 13, Sep. 1966, p. 131–135.

Computer control through backup is discussed; and computer reliability is considered in terms of backup needs, mean time to failure, and equipment maintainability. Typical causes of computer failure are mentioned; as are stored program systems, redundancy, and reliability testing. Backup and supervisory control systems, analog backup systems, direct digital control (DDC) backup, and fully redundant DDC systems are discussed. Conventional analog and digital systems are compared, and it is noted that overall availability is easier to achieve in the former because failure in individual loops do not usually impair system functioning. An analog backup system that allows instantaneous transfer from digital control to analog standby can avoid systems shutdown during computer failure. A master-slave computer setup is shown that permits smooth transfer of control between prime and backup computers; and, for this setup, the memory content of the backup computers is continuously updated with information developed in the prime control computer. M.W.R.

Review: This paper is written for the control engineer who does not have a sophisticated background in reliability. It serves the purpose rather well. Some of the details of measuring and calculating reliability are not quite accurate or consistent, but the intended reader will likely gloss over these anyway; thus there is little call to dwell on them. The need for hardware redundancy is handled well and control engineers can be expected to get a feel for the need of it from this paper. Some very practical problems are mentioned as well as those traditionally discussed in reliability models.

R67-13005 ASQC 833; 815; 844

CAPACITORS–RELIABILITY, LIFE AND THE RELEVANCE OF CIRCUIT DESIGN.

D. S. Girling (Standard Telephones and Cables, Ltd., Capacitor Div., Paignton, England).

(Institution of Electronic and Radio Engineers, and Institution of Electrical Engineers, Symposium on Engineering for Reliability in the Design of Semiconductor Equipment, Hatfield College of Technology, Hatfield, Herts., England, May 1965, Paper). The Radio and Electronic Engineer, vol. 31, Jun. 1966, p. 373–384. 6 refs.

Electrical characteristics of various types of capacitors, their selection for particular applications, failure mechanisms, and derating to improve capacitor reliability are discussed. Foil; metallized, and aluminum, tantalum wet, and solid tantalum capacitors are characterized. Variation of impedance with frequency is graphed for a tantalum foil electrolytic capacitor. Limits of parametric change allowed in nonelectrolytic and electrolytic capacitor specifications are tabulated. A graph for calculating the effect of derating for voltage or temperature is shown, as is the effect of derating on failure rate. Failures are categorized as catastrophic due to open or short circuit, sudden parametric change, or gradual parametric changes beyond given limits; and causes considered are open and short circuits, ingress of moisture, and mechanical failures. Both wear-out and random failure characteristics are considered; and for the latter a table presents the percentage failures at various times from 100 hours to 20 years for failure rates between 0.001 and 10%. M.W.R.

Review: This is a quite detailed paper which will be of value to designers and component engineers concerned with the selection and application of capacitors. A useful summary of electrical characteristics of various types of capacitors is included. Also helpful is a tabulation of the main mechanisms of failure in capacitors. Since the choice of the most suitable capacitor for a particular application can be a key to satisfactory performance, this paper serves an important practical purpose. The author emphasizes a need for regular and systematic testing, coupled with feedback of data on failures to improve control of manufacturing processes.

R67-13006 ASQC 833; 815; 816; 844

ACHIEVING COMPONENT RELIABILITY.

Paul T. Leibovitz, and Guy N. Kenney (General Electric Co., Apollo Support Dept., Daytona Beach, Fla.).

Industrial Research, vol. 8, Jul. 1966, p. 41–48.

Design and delivery of reliable electronic components is discussed in terms of delivery schedules, vendor and user data, and assembling and testing components in the equipment or systems. Recommendations include the use of proven components or subsystems, parts screening, design review of components, and team effort. Component selection must consider both reliability and procurability within equipment delivery constraints; and the first step in selection is to reduce the equipment to its major functional components. A procedure recommended for selected or limited testing is to outline a complete test program; with order of testing based on item cost and application, test cost, data produced, time available, and effect of the test on future testing. Component location and mounting provisions; relative cost, availability, and reliability; and application are essential to selection. Derating, worst-case considerations, and component failures mechanisms come under the latter heading; and the importance of good failure reporting and failure analysis is stressed. M.W.R.

Review: A practical method is suggested for achieving reliability when schedules and funds are deterrents Emphasis is placed on a total team effort applied in a step-by-step approach to part, component, and subsystem selection and application. The ideas are clearly and concisely presented and the paper should be of value to those concerned with the selection, application, and documentation of components.

R67-13019 ASQC 831; 612; 844

Sandia Corp., Albuquerque, N. Mex.

A COMPUTER PROGRAM FOR PERFORMING RELIABILITY ANALYSES

A. M. Breipohl and R. A. Hernquist Dec. 1965 39 p
(Contract AT(29-1-789)
(SC-TM-65-523; N66-30224) CFSTI: HC $2.00/MF $0.50.

A computer program which will perform system reliability analyses is discussed. The program, after receiving component and wiring diagram information, constructs the dud and premature equations which relate the probabilities of the various subsystem (component) behaviors. The ability to evaluate the consequences of electircal shorts in both dud and premature studies, and the ability to obtain component information from such tests as QEST and NMST, were included in the program's logic. The modeling scheme used by a reliability analyst in describing component information for the computer is discussed. Some general comments concerning the treatment of electrical shorts are also included. Author (NSA)

Review: The orientation of the approach presented in this report is the computerized development of logic models which will describe the sequence of events which could cause failure, however remote. There is no emphasis on the probability numbers. Potential applications are with atomic warheads, necessitating extremely detailed analyses in search of causes of accidental detonation. The approach which is developed has not been emphasized in the literature, and it appears to be a worthwhile one. Note that the computer program was being developed by another organization, Mathematica. This report will be of interest to those concerned with reliability and safety analysis, and would be of special value to those working in the ordinance and munitions area. An example contained in the report serves a useful purpose.

R67-13023 ASQC 837; 782
Naval Ordinance Test Station, China Lake, Calif.
RELIABILITY CONCEPTS IN THE HERO PROGRAM
Russell N. Skeeters Aug. 1965 8 p ref.
(NOTS-TP-3895; NAVWEPS-8794; AD-620984; N66-12605)

The report examines the basic philosophy, general objectives, and definition of tasks of the HERO program. It is believed that efforts to solve the HERO problem have been stultified by adherence to a doctrine of absolutism in which HERO has been regarded more as a safety program than a means for contributing to the Navy's mission. The report emphasizes the importance of reliability concepts for the stated objectives, and proposes a breakdown of the general problem into four phases, together with a realignment of responsibilities based on this division. Author (TAB)

Review: The applicability of the statistical methods of reliability analysis, and of the worst-case philosophy to the problem of energy induced into ordnance ignition circuitry from electromagnetic fields is discussed in a brief and qualitative way. The overall problem of electromagnetic hazards to ordnance is large and complex. The suggestions made in this paper should prove helpful in facilitating the use of well-developed techniques in attacking this problem.

84 METHODS OF RELIABILITY ANALYSIS

R67-12979 ASQC 840; 775
Navy Electronics Lab., San Diego, Calif.
THERMAL (INFRARED) RADIOMETERS AS INSTRUMENTS FOR NONDESTRUCTIVE RELIABILITY TESTING Research Report, Oct. 1965–Mar. 1966
R. M. Fraser 10 May 1966 29 p
(NEL-1377; AD-635607; N66-36823) CFSTI: HC $2.00/MF $0.50

Exploitation of radiometers for the reliability testing of monolithic integrated circuits requires a knowledge of the capabilities and limitations of these instruments. As a basis for the design, development, and evaluation of radiometer systems, graphs have been worked out which illustrate the interaction of the major design parameters and the system requirements. The graphs were obtained by an analysis of the thermal detection and display problems from an engineering viewpoint. Author (TAB)

Review: A worthwhile contribution to the growing body of literature on nondestructive techniques for reliability determination is made by this paper. It will be of value to those concerned with the evaluation, application, and development of techniques involving surface temperature distributions obtained by the use of infrared radiometers. The graphs illustrating the interaction of design parameters and radiometric system requirements are a central part of the paper. Their use and also the basis for them are adequately explained.

R67-12988 ASQC 884; 833
THE BEHAVIOUR OF ELECTRONIC COMPONENTS AT LOW OPERATING STRESS LEVELS.
H. Reiche (Royal Canadian Army, Army Equipment Engineering Establishment, Ottawa, Canada).
Microelectronics and Reliability, vol. 5, Feb. 1966, p. 1–6. 3 refs.
(A66-24911)

The operation of components and materials at lower than maximum ratings does not always result in an increase in reliability. The results of life tests on some components and materials operated at rated environmental and electrical stress are compared with results at low stress levels. It is found that *higher failure rates and different failure distributions* may be obtained at low stress levels. There is a requirement for more component testing at lower than maximum rating and more detailed investigation of the basic physics of failure mechanisms. Author (IAA)

Review: This is very similar to the reference given below [1]; much of the source material is the same. (The comments on its review apply to this as well.) The subject is an important one and this paper introduces the subject well. At the moment, *not much more can be done because* so little is known, although the author gives several interesting examples of bad "derating." Several authors have investigated non-operating failure rates and found a dearth of information.

Reference: [1] "Component reliability at low stress levels and the significance of failure mechanisms," by Arnold Simoni, *IEEE Transactions on Parts, Materials and Packaging,* vol. PMP-1, Jun. 65, p. 303–308.

R67-13000 ASQC 844; 770
SWITCHING DEVICES: FALLACIES OF LIFE TESTING.
Charlotte Kaizer
Electromechanical Design, vol. 10, Sept. 1966, p. 22–24.

Life testing the capabilities of switching devices and the military specifications covering various types of switches are discussed. Testing should indicate acceptability to an application and not a hypothetical rating outlined in these specifications or given by a manufacturer. Loading and temperature aspects are discussed, as are various fallacies inherent to the usual form of life testing. It is recommended that all life testing should be made at a minimum of two cycling speeds, and that all switches be life tested at the 100 millampere level in addition to the rated load. Testing should be made while the switch is thermally cycled as well as thermally shocked; and each operation should be carefully monitored to determine the exact capability of the unit being tested. M.W.R.

Review: This review column, as the title implies, discusses some of the problems involved in the life testing of switches. The criticisms are generally valid and should be understood by switch users. There is a problem in too much individuality in life tests because of the tremendous variety of switches available. The suggestions are constructive; their implementation will rest largely on the realization of the customer for their need and his willingness to pay for them. Many an otherwise good suggestion has foundered when confronted with these two problems.

R67-13012 ASQC 844

HIGH-RELIABILITY TESTING AND ASSURANCE FOR ELECTRONIC COMPONENTS.

Charles A. Meuleau (International Telephone and Telegraph Europe).

(Electrical Communication 38, 1963, p. 307–324.) *Microelectronics and Reliability,* vol. 4, 1965, p. 163–177. 11 refs.

Principal limiting factors involved in direct determination of very small failure rates in electronic components include: (1) the hypothesis that failure rate (lambda) equals a constant that can be applied to a limited period in the life of a component; (2) the defining of both random failures and wear-out failures by a single parameter; (3) the actual representativeness of the sample; (4) the validity of extrapolation in accelerated tests, and (5) the frequent disregard of factors such as humidity, shock, vibration, radiation, and human errors. The utilization of sequential testing is proposed, and cooperation and reciprocal confidence between manufacturers and users must be developed, and only random and total failures are to be considered in the preparation of statistical information. Caution is advised in the use of failure rate tables which do not specify conditions. M.W.R.

Review: This is a good review article and the examples aid in understanding the text. The general discussion of testing problems and the attitude that "we do the best we can with what we have" are well taken. One should not blindly and innocently use extrapolations, but neither should they be completely disparaged. There are more or less severe problems with some details; for example: (1) The word random is apparently used to mean "Poisson" and/or catastrophic. This is poor practice at best. (2) It is considered by many that electronic computer components rarely if ever operate in the wear-out region. (3) The term "wear-out", when used in conjunction with the bathtub curve, can mean little more than an increasing hazard function. It is taken from mechanical devices by analogy where wear causes properties to slowly change until there is failure. (4) In Fig. 2, on Gaussian probability paper, λ=constant is unlikely to be a straight line, contrary to what is shown. (5) In one graph for the exponential distribution, the three points available fall "exactly" on the straight line. This is most unusual behavior and perhaps would suggest something peculiar about the process. (6) Weibull plots are useful, but not *always* useful. (7) Not all physico-chemical processes obey the Arrhenius Law. (8) The term "confidence" is not generally applicable to sequential tests, nor is the analysis of such tests always well-known to statisticians. The problem being discussed (sequential determination of λ) is far from solved. Fig. 8 probably is not correct as far as confidence levels are concerned. (9) In Sec. 2.1 on statistical aspects of finding the failure rate, the concept of confidence is not defined in the classical way. There is confusion in an example of upper and lower bounds for failure rate since zero failures were assumed. From the table and text, it is not clear whether test time of number of failures is the random variable and the numbers are not the same for both cases. In a private communication the author has indicated that he was implicitly using a Bayesian approach; this may account for the difficulties. In [1] this paper is critically but briefly discussed. The explanation for the discrepancy with another paper should be as given in #9 above.

Reference: [1] Lambda and the question of confidence, by J. M. Groocock, *Microelectronics and Reliability,* vol. 5, no. 2, p. 191–192 May 66 (Letter to the Editor) (R67-12987)

R67-13015 ASQC 844; 770

PERFORMANCE AND RELIABILITY OF PLATED MULTILAYER PRINTED WIRING JOINTS.

Albert Kamensky (Douglas Aircraft Company, Materials Research and Production Methods Dept., Santa Monica, Calif.). *In: Electronic Components Conference, Washington, D. C., May 4–6, 1966, Proceedings.* Conference sponsored by the Institute of Electrical and Electronics Engineers, and the Electronic Industries Association. New York, Institute of Electrical and Electronics Engineers, 1966, p. 178–183. 5 refs.

Performance limits and reliability of through-hole plated multilayer epoxy glass printed wiring board joints were found to be satisfactory under simulated severe space environments. Of the 49,600 joints tested, 2,380 were individually measured for electrical resistance before and after each environmental test. Environment had very little adverse effect on joint behavior, and reliability of the joint is considered fixed by its design and the fabrication process. With a 99% confidence level, reliability of the joints fabricated by this through-hole plate process is considered to be not less than 99.6%. Failure analyses indicate that microsectioning gives a good indication of board and joint quality, but electrical continuity testing appear to be of little value in quality testing. All failures were caused when drilling, plating, and epoxy glass etching operations did not meet the specification requirements. A reliability model developed for plated joints is considered usable for other applications. M.W.R.

Review: The emphasis in the paper is on the methods of test rather than the results themselves. The tests apparently presume the simple stress-strength model for failure, viz., no cumulated damage; or else the tests are considered to be the equivalent of a reasonable lifetime for the boards. (If not, it is difficult to see how the term "reliability" is used.) The discussion seems to be frank, in that some difficulties experienced during the tests are pointed out. The interest in this paper will be largely confined to users and producers of such boards.

R67-13016 ASQC 844; 775

THE USE OF PENETRATING RADIATION IN FAILURE ANALYSIS.

Warren J. Mc Gonnagle (IIT Research Institute, Nondestructive Testing Section, Chicago, Ill.).
In: Electronic Components Conference, Washington, D. C., May 4–6, 1966, Proceedings. Conference sponsored by the Institute of Electrical and Electronics Engineers, and the Electronic Industries Association. New York, Institute of Electrical and Electronics Engineers, 1966, p. 361–368. 12 refs.

Penetrating radiation from X-rays, gamma rays, neutrons, and beta particles is investigated for use in the study of failure phenomena in electronic components. Stereoradiography, microradiography, laminography; and electron, neutron, and color radiography are reviewed in terms of their ability to detect the following conditions which contribute to failure: flaws, lack of material, poor solder joints, poor welds, contamination, and construction and dimensional variations. Geometric principles applied to shadow formation in film radiography are summarized in terms of parameters which must be controlled, including focal spot size, type and energy of radiation, and choice of radiation detectors. M.W.R.

Review: This is a short general summary dealing largely with the production of X-ray pictures (shadowgraphs). It will be suitable mostly for those who are previously unacquainted with the subject, but who do understand some of the technical language. There is not enough detail in any part to enable its use as a cookbook. The material which is presented is good.

R67-13021 ASQC 844; 782; 851
New York Univ., N. Y. Research Div.
THE SYNERGISTIC EFFECT IN ENVIRONMENTAL TESTING
Walter J. Kiernan Sep. 1965 39 p refs
(Contract NObsr-89288; Proj. Sete)
(SETS-228/7; AD-624233; N66-30516) CFSTI: HC $2.00/ MF $0.50

The evidence in this report clearly indicates that test equipment, whether in transit, in storage, on board a moving vehicle, or in a fixed location is often subjected simultaneously, to many environmental stresses whose combined action on a particular instrument is presently unpredictable. An examination of the available combined commercial test facilities demonstrates that few organizations can provide wide range combined environments. Most of the commercial companies limit themselves to standard groupings (i.e., temperature-humidity, temperature-altitude, etc.). Government facilities as a rule place greater emphasis on combined environmental testing. Yet even on extensive government installations the testing often is confined to narrow objectives. The cost factor has frequently proven to be a major stumbling block in enlarging the scope of synergistic testing and must continue to be weighed against the advantages gained by introducing more complex test environments. The instant investigation has uncovered only three studies concerning the multienvironmental effects on electronic equipment. The results of these studies, however, were not positive and the authors pointed to the need for further research into this important field. Author (TAB)

Review: This report is a qualitative discussion of the effects of combined environments and the advisability of combined environmental testing. As such it contains no specific test or analysis procedures or test data, and serves to convey a general picture of the subject. Listing of combined environmental test facilities at various DoD and NASA facilities, and of commercially-available combined environmental test equipment are included. The seven references cited in the report will be useful to those who desire more details. It is important to consider the increased severity of some combined environments.

R67-13026 ASQC 844; 770; 782
Martin Co., Denver, Colo.
VIBRATION TESTS, AN ESTIMATE OF RELIABILITY
J. L. Rogers *In* Defense Dept. Shock, Vibration and Assoc. Environ., Pt. 3 Mar. 1964 p 189–194 (See N64-20235 13-01)
(N64-20261)

This paper discusses the use of vibration tests as a tool in the evaluation of component reliability. Test data will be presented to show how raw data are tabulated, reduced, and illustrated. Examples of correlation between flight-test-measured reliability and estimates from vibration tests will be shown. Author

Review: The test philosophy expressed here is good, though the presentation is brief. The title is somewhat misleading since the paper is more broad than is implied. It is presumed that the simple stress-strength model for failure (viz., no cumulative damage) applies for the margin of safety testing. This may well not always apply. Some of the correction factors are not clear although they probably assume a Gaussian distribution. Whether, for small samples, the standard deviation estimate should be made from the unbiased variance, or be unbiased itself is not universally agreed upon. The idea of analysis of each failure is a good one.

85 DEMONSTRATION/MEASUREMENT

R67-12983 ASQC 851; 540; 782
Army Electronics Labs., Fort Monmouth, N. J.
A RELIABILITY PROGRAM FOR MISSILE BATTERIES
Nicholas T. Wilburn [1964] 8 p refs Reprinted from 18th Ann. Proc. of the Power Sources Conf., May 19–21, 1964
(AD-45283; N65-83025)

This paper deals with a new procedure for establishing the reliability of one-shot items under simulated operational environments where extremely high reliability is required. One-shot items may be defined as components or equipments which are expended in use and which, prior to use, do not lend themselves to non-destructive checkout tests from which their probability of successful operation or reliability can be inferred. The military one-shot items of perhaps the greatest interest to USAELRDL at present are the automatically activated battery power supplies which have been developed for guidance and control functions in a wide range of missiles. High reliability standards have been established for these batteries since failure in any sense will destroy the effectiveness of the missile. Author (TAB)

Review: This appears to describe a good program for the evaluation of one-shot devices. The principle of evaluating the capabilities at combined "stresses" is a valuable one. None of the mathematics or statistics is given here, so it is not possible to evaluate them. The discussion of the Normality assumption and constancy of variance leaves one uncertain as to the adequacy of the philosophy behind them. For example, tests to "prove" Normality, using about 15 points, are implied. Certainly from this one cannot extrapolate too far out on the tails (no more than 1–5%). Also it is stated that if the statistical tests do not prove non-uniform variance, it can be presumed uniform. With only two points at each condition, the power of the test is quite low and the inference is not at all justified. The physical part of the program is reasonable and the principle of response surface fitting is a good one, worthy of pursuing further. Background material on the response surface method for establishing the reliability of one-shot items with detailed examples to illustrate the calculations, will be found in [1].

Reference: [1] Wilburn, N. T., Response surface determinations in establishing the reliability of one-shot items, USAELRDL Technical Report 2428, February 1964

R67-12989 ASQC 851; 844

THE RELIABILITY OF INTEGRATED CIRCUITS.

I. M. Mackintosh (Elliott-Automation Microelectronics, Ltd., Glenrothes, Fife, Scotland).
Microelectronics and Reliability, vol. 5, Feb. 1966, p. 27–37. 3 refs.
(A66-24913)

Description of the basic principles of high-stress reliability-evaluation techniques. The use of properly controlled high-stress life-testing to evaluate the failure rates of solid-state components of extremely high reliability is discussed. It is shown that the high-stress aging program can be stepped-time, stepped-stress, or a combination of the two, depending on experimental convenience. High-stress aging is recommended for the case where only one failure mechanism is the one accelerated by the high-stress levels. It is shown that freaks (i.e., abnormally unreliable units) can be effectively eliminated by one or more carefully selected high-stress preagings. IAA

Review: This paper deals largely with the evaluation of reliability techniques rather than with the failure rate numbers or with physics of failure. Most of the discussion is concerned with constant-stress and step-stress tests. The emphasis on difficulty of failure criteria is good. The philosophy expounded is quite good, but many of the practical details leave something to be desired and/or are quite controversial (not that there is anything wrong with controversy). For example: (1) Many people assert a decreasing failure rate (hazard) for semiconductor devices even long after the useful life. This paper asserts that the useful life is in a period of increasing hazard function. (2) In the step-stress discussion, some of the hypotheses are logically equivalent to no cumulated damage. In that case, of course, the time length of each step could be negligibly long. Later there are some contradictions because cumulative damage is asserted to be a problem. (3) It is asserted that tests are available which will fail a device in a given time. Such a test has not yet been published for anything since the strength is presumed unknown beforehand. (4) The method of putting lines through points is difficult at best. The points rarely imply the conclusion desired (i.e., imply the model). At best one can only say they are consistent with a model. The author states in several places that the points obviously imply particular models, whereas they obviously do not. (5) The author is quite willing to extrapolate his extrapolated Gaussian distribution out to 0.01% in the tail, whereas his experimental ones illustrated were Gaussian only to a few percent in the tails. (6) The statistical uncertainties in extrapolation from accelerated tests have been ignored. Even granting that the model is accurate, there is usually a very great uncertainty in the extrapolated average because of the "lever arm" effect. (7) The problem of early failures is said to be no longer serious. Articles by consumers and producers tend to be different on this score. Even very recent articles show that incoming inspection uncovers circuits that do not even meet specifications and that foolish failures are a continuing severe problem.

R67-13014 ASQC 851; 835; 844

STATUS REPORT ON INTEGRATED CIRCUITS RELIABILITY.

Microelectronics and Reliability, vol. 4, 1965, p. 315–330.

The critical need for reliability data on integrated circuits in the semiconductor industry is stressed, and results are presented that reflect the life testing of more than 4000 integrated circuits or components and reliability testing of more than 5000 devices. These testing results have shown that the integrated circuit in any package is extremely stable and is basically a high reliability product with which high resistance to mechanical and thermal shocks. Storage life, operating life, and life testing techniques are discussed; as are bulk, mechanical, and surface failure mechanisms. Temperature and mechanical step stress testing is developed; and this sequence includes testing for shock, constant acceleration, vibration fatigue, vibration through constantly varying frequency range, solderability, temperature cycling, thermal shock, and moisture resistance. Radiation tolerance of integrated circuits is discussed, and preliminary investigation results are similar to those for conventional high frequency n–p–n silicon planar transistors exposed to gamma irradiation as discrete devices. M.W.R.

Review: This is a rather comprehensive survey of methods for checking the life of good-quality integrated circuits. Many of the tests are described in enough detail to get a real appreciation for them. The severe problem of criteria for drift failures was not emphasized. The complexity of functions performed by an integrated circuit makes this a much more difficult task than for discrete components. There is a little question now that integrated circuits can be reliable; efforts such as described here have helped tremendously to make them that way. There is also little question that integrated circuits can be very poor—many will not even meet specifications at incoming inspection. Some have gross manufacturing faults. Papers written by producers and by consumers tend to have quite different tones when discussing reliability. Both are probably needed for the overall picture, but obviously not everyone is putting out the whole story.

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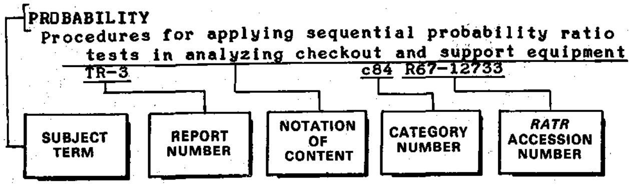

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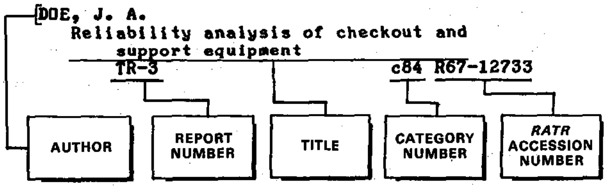

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 2

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Reliability Abstracts and Technical Reviews

MARCH 1967

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The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

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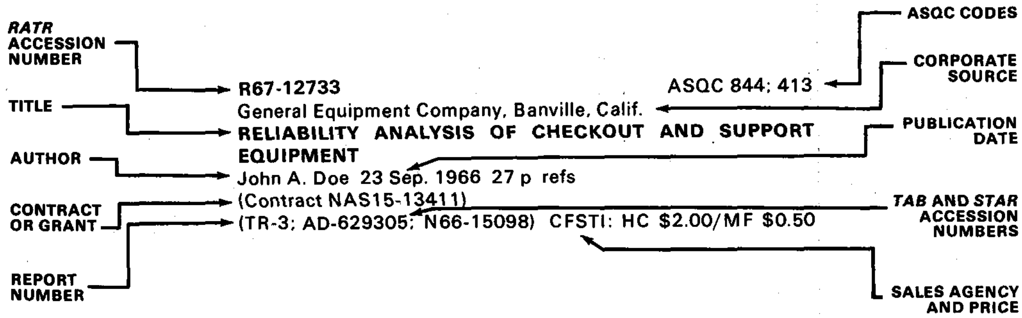
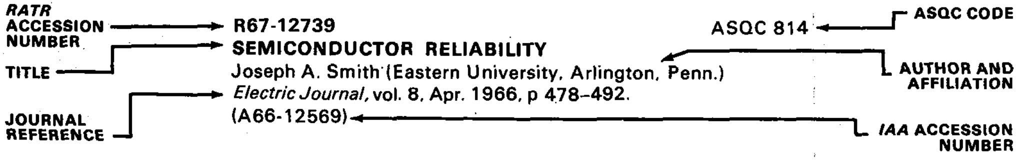
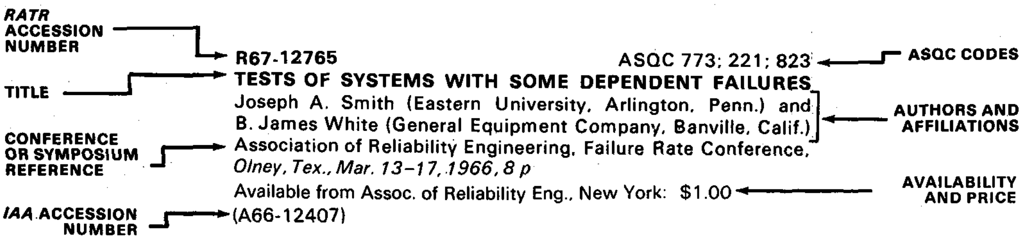


R67-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N66-15098) CFSTI: HC $2.00/MF $0.50



R67-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A66-12569)



R67-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, *Olney, Tex., Mar. 13–17, 1966, 8 p*
Available from Assoc. of Reliability Eng., New York: $1.00
(A66-12407)

Volume 7 Number 3

Reliability Abstracts and Technical Reviews

A Monthly Publication

of the National Aeronautics and Space Administration

March 1967

80 RELIABILITY

R67-13038 ASQC 800

AIRCRAFT RELIABILITY IN SERVICE.

Reprinted from the *Journal of the Royal Aeronautical Society,* vol. 70, p. 393–429.

Status of aircraft reliability in the navy, the army, and civilian airlines in Great Britain is reviewed; and present-day practices are discussed from both the civilian and military points or view. Engineering, from the requirement to the engineering concept, is considered in light of manufacturing and subcontracting problems. Proving the design of accessories, safety of complex systems, and failure in electronic equipment are discussed. Manufacture and control of product quality is reviewed for both aircraft and accessories; responsibilities of user personnel are mentioned; and collection, collation, and feedback of user experience are discussed. Papers dealing with reliability improvement compare civilian and military systems from the users' viewpoint and lessons from engine experience. A section on "buying and selling" reliability includes a resume of methods of contracting, the influence of competition in civilian fields, and special problems of military contracting. M.W.R.

Review: The short presentations by 22 different people give a timely overview of the status of aircraft reliability in Great Britain. Some quantitative measures of reliability are given in a number of the papers, but there is essentially no mathematical analysis. A few of the interesting figures which were reported are that the overall availiability of Royal Navy aircraft is 33% and that 7% of the revenue of the British European Airways Corporation is used to pay for unreliability, covering such areas as standby aircraft, delays, and modifications. A British Aircraft Corporation spokesman stressed the current competition in better warranties and guarantees, and concluded that it pays to take the initiative in this sort of activity rather than be driven to agree to the demands of an airline. The same speaker regarded an American airline as being a tougher customer for reliability than the British Ministry of Aviation. The authors appear to be senior people who are well versed in a traditional area, e.g., chief engineer or director of contracts, and who have also given serious thought to reliability. Overall, the remarks are analogous to the better ones which are heard in the United States, but with much of the characteristic trivia omitted. Note that October 1966 started the National Quality and Reliability Year in Great Britain.

R67-13051 ASQC 802

Stanford Univ., Calif. Dept. of Industrial Engineering.

RELIABILITY HANDBOOK

W. Grant Ireson, ed. New York, McGraw-Hill, 1966 720 p refs

Basic guidelines for the determination and use of characteristic life patterns, selection of test plans, applications of mathematics and statistics, and estimation of reliability are treated in 17 chapters written by men who are specialists in the various facets of reliability. Subjects covered include system effectiveness, maintainability, human factors, cost aspects, and program organization and management. This handbook provides a comprehensive collection of reliability experience at various industrial and research establishments. Concepts and principles used to establish a reliability program are developed, and specific guidelines for the design of the different elements of the program are provided. Appendixes include tables and/or charts dealing with confidence limits, tolerance factors for various probability distributions, and other statistical data used by the reliability specialist. M.W.R.

Review: This handbook brings together in book-format much material which is scattered about in the reliability and related literature of the past decade. Much of it is treated qualitatively rather than mathematically; thus the book is suitable for complementing any of the good mathematically-oriented texts which have been published. If someone with an applications bent who had not been exposed to the product assurance literature of the past decade wished to select a single reference introducing it, this handbook would be a good choice. Since it is a collection of material which was prepared by many different authors, there is considerable variation between sections in style, format, and quality. Some sections are good, while others are marginal. Lengths of the sections are, in some cases, not proportional to their value, and there is too much material on quality control for a reliability handbook, or else the title should have been something like "Product Assurance Handbook." More emphasis on design tools for reliability and less on traditional quality control would have been expected in a reliability handbook. Sketchily treated design-reliability topics are failure mode and effect analysis, physics of failure (failure mechanisms), use of computers for reliability design analysis, natural/induced environments, design reviews, and reliability models. (The last topic—reliability models—is treated in depth in other reliability texts.) In the section on system effectiveness, the mathematical formulations which are presented are not the best for introductory purposes (e.g., those on page 1–11 and 1–12 on propagation of density functions), considering the small proportion of space devoted to quantitative material. No references are given in this section. Reasonable coverage of the basic concepts pertaining to the life lengths of single items is given in Section 2. However, the coverage of combinations of items is sketchy. Stand-by redundancy is covered under the heading "Parallel-strand Theory," but active redundancy is omitted. The phrasing is that of the mechanical field. The title of Section 3, "Selecting Reliability Test Plans," is not a very apt description of its content. The section does not reflect the wealth of experience accumulated by those who have been implementing reliability test plans as the title might imply, and no references are cited. The orientation is that of economic-statistical aspects of reliability test plans, and some new material is included. Section 4 is a good treatment of the fundamentals of probability and statistics, with elementary examples on reliability, presented in traditional handbook form. Markoff processes are not included. Section 5, entitled "Reliability Estimation," is concerned with performance variation analyses. The contents are poorly organized, and there is some repetition (e.g., pages 5–6 and 5–20). Some parts of the paper are taken almost verbatim from the published work of other authors without acknowledgment of this fact. In most cases the source publications are not even cited in the bibliography at the end of the paper. Some of the ideas and techniques on drift failure mode prevention are good, but they could have been presented more clearly. Sections 6 through 9, dealing with reliability data systems, test programs, and malfunction and failure analysis, are good, although in places more illustrations and references would have been helpful. Section 10 on engineering design and development includes philosophy, general design description, specifications, test plans, design review, and organization. This is admittedly a tough subject, but it is hard to imagine the type of technical person to whom this presentation will be useful. Section 11 is a good introduction to maintainability and its relationship to reliability, although the organization could have been improved either by omitting statistical inference, or by introducing it after all of the basic concepts had been developed. A good overview of human factors in reliability is given in Section 12. Section 13, dealing with production, is traditional quality control. The notion of inherent reliability is brought in; this is unfortunate since the concept is controversial, and is nowhere clearly defined. Production need not degrade reliability; it can have the reverse effect. Some production-related procedures which are finding increased usage for reliability purposes, but which are not covered adequately in this section, are non-routine testing (burn-in, non-destructive screening, environmental sampling, configuration control), and considerations related to the physical production environment (e.g., clean rooms). A reasonable overview of specification and procurement is given in Section 14. The title of Section 15, "Acceptance Testing," is somewhat misleading as it is concerned mainly with the statistical considerations involved in measuring some reliability index. Section 16 on organization is very lengthy, conveying considerable detail relating to basic organization functions and interfaces. It is hard to convey proper appreciation of this topic through words alone. Although the student or practitioner must actually get inside an organization to see what the words mean, the text provides insight into the necessary functional scope, depth, capability, and authority required. There is a heavy emphasis on quality control, probably due to the many organization elements and functions which must be efficiently managed to achieve optimum product reliability. Section 17 is concerned essentially with cost categories of traditional quality control, and no cost information is presented on reliability. The list of selected references under subject-matter headings found in Appendix C is deficient in a number of ways. Most of the references pre-date publication of the book by at least five years. The set of headings is far from optimum from the point of view of workers in reliability, and there is no indication of the criteria which controlled the selection of the items cited under the headings. The topical index is a useful feature. It is interesting, however, that few of the entries refer to more than one section, despite the fact that many detail topics are discussed in two or more sections of the book.

R67-13053 ASQC 800; 812

SELECTED RELIABILITY FILMS–1966 UPDATED LISTING, PARTS I, II AND III.

Evaluation Engineering, vol. 5, Jul.–Aug. 1966, p. 30; Sep.–Oct. 1966, p. 50, 52; Nov.–Dec. 1966, p. 32, 40.

Currently available films dealing with various aspects of quality assurance and reliability problems are listed. Time and source is given for each of the films, and a contents note is included for some of them. The listing includes a series of nine films which describe the Navy's reliability program as well as industrial policies and maintainability concepts. M.W.R.

Review: Forty-seven films are listed in this sequence. Most of the running times are in the range between 10 and 30 minutes. The time for each film is shown and for some of them the interest groups are indicated. The latter would be important in determining which films to order. There is no mention of the quality of the film; presumably in each case the supplier at least is proud of it. There is no mention of the size of the film; presumably they would be 16 mm. sound. There is no mention of any rental charge. Presumably they are all free, at least except for the return postage. Six related films are also mentioned, but they do not deal with the reliability discipline per se. The relationship to reliability for these "related films" is rather tenuous at best except that virtually any film on an engineering subject is related to reliability. These listings do serve a useful purpose and many engineering groups would undoubtedly profit by showing a few of these films from time to time.

R67-13054 ASQC 800

FIVE MISTAKEN IMPRESSIONS–THE RELIABILITY IMAGE.

Martin T. Pett (Hughes Aircraft Co., Missile Systems Div., El Segundo, Calif.).

Evaluation Engineering, vol. 5, Sep.–Oct. 1966, p. 6.

Mistaken impressions about reliability engineers and the image created by both the engineer and the reliability program are treated, and some corrective measures are noted. These impressions are that the reliability engineer is extremely conservative, that he makes the worst of a situation, that he juggles statistics and makes impractical recommendations, and that he has a superiority complex. These are refuted, and it is suggested that the reliability specialist operate as a public relations man as well as an engineer in order to get his job across. Another criticism often mentioned is that reliability is a parasitic endeavor that exists on the work of others without significant contribution of its own. M.W.R.

Review: The topic addressed in this short article is one about which reliability workers should be concerned, but which they should also keep in perspective. Some of the criticism leveled at reliability is not malicious, but arises from the tendency of human nature to be critical rather than complimentary. People in "essential line" functions often tend to be critical of those in "non-essential supporting" functions. Here the person being critical may think he is humorous, while the one being addressed often does not. This sort of thing just has to be accepted and discounted. The article spells out five image spoilers, and the advice given is largely to do a better job at human relations. This is sound advice, which could easily be extended to include continued improvements in technical competence and integrity. The reliability discipline will be a long time in living down the effects of the trivia of some ten years ago, much of which came about because of the over-play of words instead of an honest declaration of ignorance. There now exists experience and much good documentation of this experience, rather than the void of a decade ago. Reliability professionals need to continue to learn of this experience in order to upgrade technical competence. In RATR reviews it is sometimes remarked that the content of a document is elementary, in reply to which the author may comment that he does not regard the content as inappropriate because in his experience he has found reliability engineers and reliability managers who were woefully uninformed about the dated, elementary material. Ten years ago reliability contributed greatly to its poor image in ways other than human relations, and apparently is still doing so. This subject of image must be kept in perspective; the only reason the reliability discipline exists today is because of the extremely poor record of equipment reliability which was achieved by some of those who today are critical of reliability activity. There has been an increasing number of solid reliability programs, and the reliability discipline has many friends in government and contractor program management. All in all, the reliability discipline must face up to the image criticisms, work toward improvement, and if someone cannot live with these criticisms he should leave reliability work, as a disconcerting number of technically competent persons have done.

R67-13056 ASQC 802

RELIABILITY BOOKS AND THEIR EVALUATION.

Dimitri Kececioglu (Arizona University, Aerospace and Mechanical Engineering Dept., Tuscon, Ariz.).

Evaluation Engineering, vol. 5, Nov.–Dec. 1966, p. 54–56. 34 refs.

Publications relating to reliability are evaluated according to (1) level of mathematical coverage; (2) coverage of the subject matter, and (3) overall evaluation in terms of suitability as a classroom or reference text. Of the 34 publications, 16 are classified as textbooks that adequately cover the field of reliability engineering, 3 deal with maintainability, and the remaining 15 are reference books in specialized areas. M.W.R.

Review: The listing of 34 books which are on reliability or have substantial portions devoted to reliability is quite complete. A classification scheme which gives the mathematical level in the fields which are covered is of necessity perhaps quite brief. For example, one of the topics is reliability but there is no indication of the depth or breadth of the treatment of the subject. The overall evaluation for suitability as a textbook in a reliability course lists only very good, good, average, and reference text. Each book is put into only one of the four categories; presumably none of the books are below average (a most unusual circumstance), or if they are, they are relegated to the class of reference texts. Despite the obvious limitations of so brief a listing, the article can be of use to engineers if for no other reason than the listing of the books themselves. The list of titles actually provides a great deal of information in itself.

R67-13071 ASQC 802

Avco Corp., Cincinnati, Ohio. Electronics Div.

RELIABILITY GUIDE FOR DESIGN, MANAGEMENT, AND PROCUREMENT PERSONNEL

[1965] 37 p

The achievement and demonstration of reliability and the basic factors relating to reliability estimation are among the topics considered in a handbook prepared for management, design, procurement, test, and reliability personnel. Basic terms used in reliability are defined, the constancy and calculation of failure rates are considered, and the use of redundancy is treated. Potential design and operational reliability aspects are discussed, along with specifications deviations, confidence levels, and premature operation versus reliability. It is noted that reliability prediction is not an exact science, but rather requires extensive knowledge and judgment relating to quality, design, environment, performance, and state-of-the-art. Predictions are restricted because of limited information on failure rate and parameter degradation under the many combinations of possible operating conditions. Determination of reliability test criteria is discussed, as is the amount of time required to demonstrate reliability. M.W.R.

Review: This reliability guide is asserted to be for design, management, and procurement personnel. It is definitely an introductory guide and would be satisfactory for management and procurement personnel, but would need to be supplemented by more guidance for design engineers (as indicated in the text itself). It is a generally adequate guide but is pitched at a level at which failure rates can be presumed constant, and there is some confusion between statistical confidence and engineering confidence. Tips for the designer, for example, do not include having his design reviewed nor becoming more familiar with manufacturing facilities. Some good points of the manual not ordinarily found in these elementary treatises are: (1) a term "potential design reliability, a qualitative concept" is used instead of the term "inherent reliability"; (2) in the discussion on redundancy, albeit somewhat late, the necessity of independence of failure events is emphasized (this is statistical independence as opposed to physical independence). Another poor choice of words is in the sentence, "Theoretically, the greatest improvement can be achieved by providing the redundancy at the part level, ..." While it is very common practice, the use of the word "theoretically" in this manner is actually a substitute for the phrase "using a very simple-minded outlook"; i.e., the lay meaning rather than the technical meaning is intended. All in all this is one of the better such short "handy-dandy" guides that are put out by companies from time to time, both for the enlightenment of engineers and promotion of the company.

81 MANAGEMENT OF RELIABILITY FUNCTION

R67-13030 ASQC 815; 870; 880

Air Force Inst. of Tech., Wright-Patterson AFB, Ohio.

MAINTAINABILITY, RELIABILITY AND AVAILABILITY

Howard Leroy Barden (M.S. Thesis) Dec. 1965 88 p refs (AD-627650; N67-14241) CFSTI: HC$3.00/MF$0.75

Following a complete discussion of the problems associated with the definition and quantification of maintainability, it is argued that maintainability is not the equipment parameter to be specified and achieved without regard to other performance parameters. It is proposed in this thesis that inherent availability is the critical parameter to be specified and met by an aircraft weapon system contractor. It is further proposed that a series of availability tests be conducted to reflect a progressively decreasing consumer's risk and allow for increased system performance resulting from increased human experience and engineering improvements. A sequential sampling plan is designed for an exponential or a Weibull distribution of times-between-maintenance and times-to-repair. A hypergeometric sampling plan is presented for use in testing the operational readiness of the test fleet for any given proposed squadron size. Author (TAB)

Review: The key concept of this thesis is that availability is the important maximization parameter of a weapon system, and that it should be verified by tests conducted with Air Force personnel, with the contractor acting as a monitor. There is merit to this approach. The student–author, an Air Force officer, is in a better position to promote his views on availability than are many other persons, and hopefully he will do so. In the process of developing the concept, many criticisms are leveled at the maintainability specification, MIL-M-26512C. Some of the criticisms are overly severe, such as that maintainability is not related to such other system requirements as reliability or operational readiness. Now a specification such as MIL-M-26512C is an existing document intended to guide and to assist in the procurement process; it is not a treatise on the state-of-the-art. It can be assumed that a government project office implementing this specification will perform system analysis, from which will be obtained availability, reliability, or maintainability requirements which are then contractually specified. A specification can and usually is amended when it is actually applied. These remarks are not to say the MIL-M-26512C or the state-of-the-art of maintainability do not need improvement. The history in the thesis of the problem of maintainability contains some "motherhood" type discussion which could well have been omitted. Availability is considered to be the ratio of MTBM to MTBM plus MTTR, and quite a bit of space is devoted to presenting some statistical features of sequential tests for this availability (which are from the paper covered by R63-11033). Availability equations other than the one used here will be pertinent in some cases, such as those in which redundancy exists and in which maintenance can be performed while the system is operational. Sequential tests other than the one cited here would be needed for other availability equations. The pertinence of other availability equations is not acknowledged by the author. An extensive bibliography is presented.

R67-13059 ASQC 813; 720

Texas Instruments, Inc., Dallas. Semiconductor-Components Div.

PROCESS SURVEILLANCE—A TOOL FOR IMPROVING IN-PROCESS QUALITY CONFORMANCE

Roger W. Anderson [1964] 9 p Presented at Conf. on Reliability of Semicond. Devices and Integrated Circuits, 19 Jun. 1964

(SC-5463B)

A seven-step procedure that retains the advantages of lot-by-lot process control currently in use at assembly areas in many electronic firms is discussed. The specification survey and product audit form the basis of this process surveillance system that improves in-process quality conformance and reduces costs. In addition to improved quality, the system achieves closer adherence to specifications as well as positive in-process corrective action. Lower costs result because production workers spend less time on defective work, and sampling can be substituted for 100% screening in some of the production areas. Other advantages are improved documentation of product control at each station in the manufacturing process, as well as renewed emphasis on the need to build quality into the product. M.W.R.

Review: This paper is interesting largely because of a practical manner in which the problems of quality control are approached. Procedures which have severe disadvantages appear not only in semiconductor manufacture, but in all kinds of manufacturing. The problems in those procedures tend to need solving at intervals even though reforms have been instituted. The reasoning that suggests that manufacturing should be responsible for its quality is also used to suggest that the design engineers should be responsible for the reliability of the equipment designed. The reliability engineers are there as consultants and auditors in the same way that this paper suggests that quality control operates with respect to manufacturing. Even though the new set of procedures which put responsibility and authority together has eliminated many or most of the old problems, new problems will become apparent, both as the system demands become greater and as each employee tries to maximize his own benefits under the system. Since reliability is so heavily dependent upon the skill and care employed at every level, the process control procedures should be constantly reviewed to see if they are still adequate. This paper presents material of interest not only to process engineers but to parts specialists and to reliability engineers.

R67-13060 ASQC 824; 831

Stanford Univ., Calif.

RELIABILITY GROWTH MODELS

Jack E. Bresenham 24 Aug. 1964 49 p refs

(Contract Nonr-225(53))

(TR-74; AD-605993; N65-14265)

Four different characterizations of a reliability growth process are considered. The first two models involve different attribute reliability sampling situations. The third model concerns variable sampling of a Poisson process having a changing mean time to failure parameter. The fourth model is an extension of the investigation of the first by experimental Monte-Carlo sampling to observe the effect of parameter perturbation and hypothesis relaxation. In the first model, probability of failure is partitioned into an inherent or intrinsic component together with a transient or embryonic part. A Markov chain formulation in which states are indexed by the presence or absence of modal transient failure probability is employed for model 2. Model 3 is concerned with the problem of growth characterization when variable data is available. P.V.E.

Review: This paper summarizes and extends the prior work which has been done on several reliability growth models. It is the longer work referred to in R66-12772 and gives a thorough mathematical and statistical treatment of the estimation problems associated with each of the models. The paper is very worthwhile reading for one having the background and the interest in the subject matter. (For another paper on reliability growth models see R66-12476.) It is hoped that these modeling techniques may be tested with real applications. As expressed by the author, "A model can seek only to describe the characteristics of a complex process; actual reliability improvement stems from direct engineering action. Thus the ultimate best usage of reliability growth projections will be in helping to ascertain the causes for growth in order that future endeavors may more effectively allocate the critical resources of time, money, manpower, and materiel."

R67-13066 ASQC 814; 817; 840; 871
Institute of Naval Studies, Cambridge, Mass. Center for Naval Analysis.

ECONOMIC CONSIDERATIONS IN ESTABLISHING AN OVERHAUL CYCLE FOR SHIPS: AN EMPIRICAL ANALYSIS

D. E. Farrar and R. E. Apple 22 Jun. 1964 34 p refs *Its* Res. Contrib. No. 7
(Contract Nonr-3732(00))
(AD-624784; N67-80760)

Cross sectional data from the U. S. Navy's Atlantic Fleet Destroyer Force are analyzed in a three-part study of relationships between a ship's total maintenance cost, time lost from operations, reliability, and the length of its overhaul cycle. Factors such as ship age, size, complexity, and usage are held constant as required. The overhaul cycle is viewed as the primary control variable by which maintenance managers allocate effort between scheduled and unscheduled repairs. A minimum cost overhaul cycle is obtained. In the absence of defensible cost penalties for time lost and reliability (where the latter is measured by the frequency of unscheduled repair), minimum cost and optimal cycles are not one and the same. Tradeoffs between cost and reliability are obtained, however, and the range within which an optimal cycle may be expected to lie is narrowed considerably. Author

Review: Useful guidelines on overhaul cycles for ships are extracted from historical shipyard data on destroyers. The analysis is pitched at a gross operational and economic level; little is given related to the technical nature of the shipyard work. Emphasis in the report is on the interpretation of the results; these would be of high interest to Naval operational planners and of background interest to those who are concerned with ship reliability. Both minimum cost and maximum availability have relatively flat curves for an overhaul cycle of three to five years, with sharply increasing curve for a period of less than three years. The report assumes that the reader is acquainted with statistical regression.

R67-13069 ASQC 813; 340

RELIABILITY PLANNING AND PRACTICE, PARTS 1 AND 2.

A. A. Seldner (ITT Gilfillan, Inc., Los Angeles, Calif.).
Electronic Procurement, vol. 6, Sep. 1966, p. 42, 43, 44; Oct. 1966, p. 44, 45, 46.

Circuit analysis; parts stress analysis, selection control, and procurement specifications; design reviews; assembly controls; and failure analysis and corrective action are discussed in relation to the development of a reliability program. Other tasks considered essential to the program plan includes engineering training and indoctrination, reliability demonstration testing, and monitoring and reporting data. The reduction of rework on the assembly line is treated, with details given for improving a zero defects program for etched circuit boards. A reevaluation of inspection standards and manufacturing techniques resulted in the elimination of seven of the eight persons assigned to the rework process, and increase in production, and substantial reduction in overall production costs. The basic principle noted in the case study is that inspection is not intended to sort out the bad products from the good, but rather to measure quality and produce instantaneous results of the distribution of defects. Such a program encourages close cooperation between the production foreman and the quality control engineer. M.W.R.

Review: A representative reliability program is described in Part 1 of this paper. Much technical skill is needed to implement effectively the program tasks which are briefly described. Part 2 is about production rework, and thereby is more "quality" than "reliability." It illustrates in a simple manner the area of production quality measurement and improvement. Both parts are non-technical discussions of the two subjects.

R67-13075 ASQC 814; 552
Pratt and Whitney Aircraft, West Palm Beach, Fla.

ENGINE COST AND RELIABILITY CONSIDERATIONS FOR REUSABLE LAUNCH VEHICLES

Robert R. Atherton and Martin Pike 10 Nov. 1964 23 p
(PWA-FR-1191; N65-14171)

For a vehicle requiring a million and a half pounds of thrust and a flight program of 2000 launches over a 10-year period, it was found that the total program costs chargeable to propulsion decreased significantly if the engine development program is continued well beyond PFRT, because of the improved level of engine reliability so obtained. The number of engines used to provide the total thrust required was found to have little effect on program cost in the range of four to ten engines (150,000 lb to 375,000 lb thrust per engine). Major variations for flight operations cost, vehicle cost, and vehicle overhaul cost had little effect on the conclusion as to the extent of engine development for minimum propulsion cost. As the number of flights in the launch program was increased, significantly more engine development was found necessary to obtain the lowest overall propulsion costs. Author

Review: Fifteen single curves and families-of-curves for reliability or cost considerations of rocket engines comprise the core of this report. There is only a small amount of accompanying discussion. Some of the curves reflect the experience of the authors' company, and these will be of particular interest to others studying the area of reusable launch vehicles. Other curves are obtained from various sources, but no specific references are given. There is a heavy reliance on judgment in formulating and using these relationships, but this is unavoidable in studies such as this one where little specific experience exists.

R67-13080 ASQC 812

RELIABILITY EDUCATION FOR NON-RELIABILITY ENGINEERS.

Donald M. Layton (Naval Postgraduate School, Monterey, Calif.).
Annals of Reliability and Maintainability. Volume 5–Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1966, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 935–936. 2 refs.

The need for reliability programs in engineering curricula is stressed, and a concerted effort by the concerned professional associations is suggested. It is recommended that courses on reliability be included at the baccalaureate level, perhaps as part of courses in design and systems engineering. Both theory and practice should be included in any program; which might also deal with specifications, standards, tolerances, and tradeoffs. It is suggested that engineering schools might be offered a complete set of course outlines, lecture notes, source material, and a bibliography; which could be prepared by the reliability committees within the concerned professional societies. M.W.R.

Review: (This paper is included in the set covered by R67-12973 through R67-12977). It calls for action on the part of professional societies to get some amount of training in Reliability introduced into the curricula of engineering schools. The ideas presented are worthwhile and succinctly expressed.

R67-13081 ASQC 812

RELIABILITY EDUCATION–THE CHALLENGES.

Paul H. Zorger (Vitro Labs.; American University, Washington, D. C.).

Annals of Reliability and Maintainability. Volume 5–Achieving System Effectiveness; Annual Reliability and Maintainability Conference, 5th, New York, N. Y., July 18–20, 1966, Papers. Conference sponsored by the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. New York, American Institute of Aeronautics and Astronautics, 1966, p. 942–943.

Training reliability personnel is considered an essential facet of a good reliability program, and four challenges are proposed to those concerned with the development of the appropriate educational programs. First, qualifying standards must be established for reliability personnel; and all of the professional organizations concerned should be involved in this effort. Next, educational opportunities must be established that will permit persons to meet these standards; summer workshop-type programs are suggested to acquaint educators with the concepts of reliability and maintainability. The third challenge, directed to the universities, asks for the establishment of appropriate courses in college curricula to train personnel for the military, and industrial programs. Last, it is stressed that industrial organizations identify the specific reliability personnel need before requisitioning a new job billet. M.W.R.

Review: (This paper is included in the set covered by R67-12973 through R67-12977). A reader might easily infer from this paper that the author is advocating that reliability be raised to the status of a full-fledged professional discipline. This impression comes in part from the reference to "qualifying standards," and the section on "professionalism" at the end of the paper. However, the author in a private communication has advised that he was not suggesting that reliability could be a separate discipline. Points of view in the field seem to vary considerably on this matter, but most will agree that the fundamental need is for sound engineering knowledge.

82 MATHEMATICAL THEORY OF RELIABILITY

R67-13027 ASQC 822; 412

Iowa State Univ. of Science and Technology, Ames.

CHI-SQUARE DISTRIBUTION THEORY WITH APPLICATIONS TO RELIABILITY PROBLEMS

Ahmed Hassan El Mawaziny (Ph.D. Thesis) Ann Arbor, Mich., Univ. Microfilms, 1965 69 p refs

(Grant NSF GP-274)

(Rept.-65-12470)

Confidence limits for the reliability of series systems of k-dissimilar components having exponential failure laws are considered. An exact finite expression was obtained for the density function of a sum of positively weighted chi-square variates with an even number degrees of freedom; and this expression is used to obtain the fiducial limits for the mean life of the series system. Conditional distribution theory was used to obtained inference about the parametric function chi. Since these two results have rather complicated cumulative distribution functions for large samples, three different asymptotic approximations were also obtained. Applications to a reliability problem discussed include fiducial limits for the parameters of series systems, inference based on conditional distributions, large sample approximations, and comparison between continuous and discrete cases. An appendix deals with the distribution of weighted sums of chi-square variates. M.W.R.

Review: For the most part this dissertation is quite theoretical and will require a rather good knowledge of Statistics for full comprehension. The applications to reliability problems are, however, collected in one chapter and thus can readily be found. The main problem considered is that of setting confidence limits on the reliability of a series system when the components have exponential failure laws (with possibly different parameters). A good review of previous approximate solutions to this problem is given.

R67-13028 ASQC 823

California Univ., Berkeley. Operations Research Center.

INEQUALITIES FOR LINEAR COMBINATIONS OF ORDER STATISTICS FROM RESTRICTED FAMILIES

R. E. Barlow and Frank Proschan Apr. 1966 46 p refs

(Contract Nonr-3656(18))

(ORC-66-44)

Order statistics and their spacings from certain restricted positive random variables are discussed in relation to life testing applications. Comparisons for linear combinations of expected values of order statistics from F and G are obtained when G^{-1} F is convex as well as starshaped; and stochastic comparisoms are made when $G^{-1}F$ is convex as well as starshaped. when one distribution is the exponential. Attention is given to bounds on expected values of order statistics from monotone failure rate distributions; and properties preserved in taking order statistics from both increasing (IFR) and decreasing (DFR) failure rates. M.W.R.

Review: While the authors state that the results in this report have applications in life testing where the underlying distribution has monotone failure rate or monotone failure rate on the average, the report itself is completely mathematical in content and deals exclusively with certain theorems and their proofs. As such it will be of interest to theoreticians, but it will not be of direct use to reliability analysts. However, the first author, in a private communication, has indicated that subsequent papers which depend heavily upon this paper are [1,2]. (Not all of the detailed mathematics in the present report was checked, but it appears to be of high caliber.)

References: [1] Barlow, R. E., and Proschan, F. (1966). Tolerance and Confidence Limits for Classes of Distributions Based on Failure Rate. Boeing document D1-82-0503 (see R66-12583). [2] Barlow, R. E., and Proschan, F. (1966). Exponential Life Test Procedures when the Distribution has Monotone Failure Rate. Boeing document D1-82-0415 Revised (AD-636125).

R67-13031 ASQC 824; 412

Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.

ON CONFIDENCE LIMITS FOR THE RELIABILITY OF SYSTEMS

Janet Myhre (Claremont Men's Coll.) and Sam C. Saunders Nov. 1965 40 p refs *Its* Mathematical Note 435
(D1-82-0489; AD-627305; N67-14242) CFSTI: HC $2.00/ MF $0.50

An application of the asymptotic Chi-square distribution of the log-likelihood ratio is made to obtain approximate confidence intervals (or interval estimates) for the reliability of any structure of the class of structures which can be represented by a monotone Boolean function of Bernoulli variates. This is for the case when the data available consist of a number of Bernoulli trials for the performance or non-performance of the components. Some special methods are obtained for a subclass of structures which contain those which fail if, and only if, a certain prescribed number of their components fail. This generalizes the results of A. Madansky for series, parallel and series-parallel systems. Computational procedures are given and some numerical studies are reported which assess how accurate the confidence intervals are as a function of the sample size. Some comparisons are made with exact results in the cases where they are known. Author (TAB)

Review: An extension of the results in the report covered by R65-12235 is presented in this report. It is a compact mathematical paper which makes a contribution to the theory of reliability estimation. References linking the work to related published results are cited.

R67-13032 ASQC 824; 412; 831
Naval Postgraduate School, Monterey, Calif.

A METHOD FOR COMPUTING SERIES SYSTEM RELIABILITY WITH UNEQUAL COMPONENT SAMPLE SIZES

Technical Progress Report, Jun.–Dec. 1965.
J. R. Borsting and W. M. Woods Jan. 1966 12 p
(TR-62; AD-628043; N66-22633) CFSTI: HC $1.00/MF $0.50

A method is presented for constructing system reliability using component failure data when the sample sizes for testing on the component parts differ greatly. The procedure can be applied to weapons systems as easily as subsystems. No assumptions about failure distributions are made. The accuracy of the procedure was examined by computer simulation and in this manner the procedure has demonstrated high accuracy for cases of practical interest. Author (TAB)

Review: No analytical justification is given for the procedure presented in this report, although it is indicated that it will be supplied in a later report. Without seeing the justification, one cannot evaluate the validity of the method, or even properly identify the type of situation to which it is applicable. Equation (2.1) implies that component failures are assumed to be independent events, but this assumption is not mentioned in the text. This is an example of the fact that this presentation is too sketchy to permit proper evaluation. The second author in a private communication has indicated that this document was written to acquaint middle management personnel with the procedure, which has very wide application within the Navy. It enables one to make a confidence interval estimate of the reliability of a series system when discrete failure data of unequal sample sizes are available on the component parts. All of the analysis, assumptions, approximations, etc. will be supplied in the later report mentioned above, which is to be published in March 1967. The later report will also provide a procedure that is more accurate than the one given in this report.

R67-13036 ASQC 821; 431
Columbia Univ., New York. Inst. for the Study of Fatigue and Reliability.

DEVELOPMENT OF RANDOMIZED LOAD SEQUENCES WITH TRANSITION PROBABILITIES BASED ON MARKOV PROCESS

R. A. Heller and M. Shinozuka Jun. 1964 21 p refs
(Contract Nonr-266(91))
(TR-4; AD-607221; N64-33321)

Because of the controversial nature of the reliability of cumulative damage rules, fatigue life estimates of aircraft structures and components, subjected to variable amplitude service loads, are presently based on programmed fatigue tests. The most frequently utilized load sequences–up, down, up-and-down, and randomized steps–are either unrealistic or difficult to apply in testing machines. A time series combining the advantages of both randomized and programmed sequences while avoiding the disadvantages of both is presented based on the mathematical model of a Markov chain. Author

Review: This paper shows the results of several assumptions concerning the transition probabilities in a random sequence of loads which might be applied during a fatigue life test of mechanical equipment. If the ordering sequence of loads was found to be important for electronic equipment, this theory would be applicable there too. The important assumptions are the following. (1) The loads fall in any one of a given number of states. (2) The transition probability to the next state depends only on the present state and the state to which it is to go. (3) There is no past history effect (this makes it a simple Markov process). (4) All transition probabilities between non-adjacent or non-identical states are zero. This is said to correspond to the way in which mechanical loads are imposed on aircraft in flight. (5) The Markov process is stationary. The probability matrix can now be written down in terms of just a few unknowns. If a probability density function for the loads is hypothesized, the transition probabilities for each state can be calculated. This is done for two examples: (1) an exponential distribution and (2) the Rayleigh distribution. A set of figures shows how the time sequence of loads is affected by these assumptions. Thus designers may well find these results to be helpful. But they should be reminded that the theory given here follows from the assumptions which are justified by usefulness rather than by theoretical considerations.

R67-13035 ASQC 822; 530
Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

CALCULATING THE INTERDEPENDENCE OF MACHINE SUBASSEMBLIES IN DETERMINING RELIABILITY

E. G. Vol'pert 3 Dec. 1965 8 p refs Transl. into ENGLISH from Standartizatsiya (Moscow), no. 7, 1964 p 14–16
(FTD-TT-65-1054/1+4; AD-625301; N66-19263) CFSTI: HC $1.00/MF $0.50

Methods of calculating the reliability of parts from component elements are reviewed, based on the assumption of mutual independence of failures of elements in operation. It is indicated that this premise is frequently not justified in machine construction. In fact, a disbalance of the shaft of one interlinked subassembly can substantially decrease the service life of the bearing in another subassembly, and the creation of additional support when a console shaft of one subassembly is attached to another can increase the service life of the parts of the first subassembly. It is shown that to obtain the necessary data for calculating reliability, it is necessary to test the subassemblies both separately and in the assembly. The correlation coefficients must be found from the data, and the distribution functions for the separate subassemblies must be selected. In addition, the reliability indices of the whole group of subassemblies must be simultaneously determined. It is pointed out that the multidimensional distribution function can be found from the distribution functions of the separate subassemblies, and the obtained data can then be statistically evaluated. R.R.D.

Review: In analyzing the reliability of systems, it is often desirable to allow for interdependence of subsystems and components, instead of simply assuming that failure events are mutually independent. Mathematical models for this purpose involve correlation coefficients, which, like the other parameters of the distributions, must be estimated from test data. This brief paper presents the essentials of this idea, referring to other Russian work for details. It would seem that there are situations in which such an approach would be worth pursuing. The details of the analysis could be developed. Fruitful application would depend on the availability of appropriate test data.

R67-13044 ASQC 824; 553
California Univ., Livermore. Lawrence Radiation Lab.

TABLES OF CALABRO KAPPA SQUARE STATISTIC

James L. Willows 1 Sep. 1964 64 p refs
(Contract W-7405-ENG-48)
(UCRL-7920, Rev. I; N65-11922) CFSTI: $3.00

The tables in this report present values of the K^2 (kappa square) statistic developed by S. R. Calabro in which

$$K^2 = \left[\frac{Z_\alpha - Z_\beta\sqrt{k}}{k-1}\right]^2$$

where Z_α *is the normal deviate corresponding to the pro*ducer's risk, R_α; Z_β is the normal deviate corresponding to the consumer's risk, R_β; and

$$K = \frac{\text{lot tolerance fractional reliability deviation}}{\text{acceptable reliability level}}$$

This statistic is useful in calculating test time for a given reliability and confidence level. Author

Review: The statistic that is tabulated, although useful in calculating test time for a given reliability and confidence level, can be calculated very easily on a desk calculator or even a slide rule, and using Normal probability tables. Unless it is used very frequently, one may find it hard to justify the use of filing space and the time for searching through this three-parameter family of tables.

R67-13045 ASQC 824; 553
Aerospace Research Labs., Wright-Patterson AFB, Ohio. Applied Mathematics Research Lab.

EXPECTED VALUES OF EXPONENTIAL WEIBULL, AND GAMMA ORDER STATISTICS.

H. Leon Harter Feb. 1964 113 p refs
(ARL-64-31; AD-436723; N64-23107)

Five-decimal-place tables, accurate to within a unit in the last place, are given of the expected values of the M^{th} order statistics [M = 1 (1) N] of samples of size N from the exponential population [N = 1 (1) 120] and from the Weibull and gamma populations [N = 1 (1) 40]. In each case, the values of the location and scale parameters are assumed to be 0 and 1, respectively. Results are tabulated for the Weibull population with shape parameter K = 0.5 (0.5) 4 (1) 8 and for the gamma population with shape parameter α = 0.5 (0.5) 4, as well as for the exponential population, which is a special case (shape parameter 1) of each of the other two populations. Also given is an eight-decimal-place table, accurate to within a unit in the last place, of the moments (mean, variance, skewness, and kurtosis) of the exponential population and of the Weibull and gamma populations with the above-mentioned values of the shape parameters. The mathematical formulations are given, along with a description of the methods of computation and a discussion of uses of the tables. Author

Review: These tables will be found useful by those using order statistics in experiments concerning exponential, Weibull, and Gamma distributions, which are of frequent occurrence in reliability and life testing applications. The values concerning Weibull and Gamma distributions are tabulated for a few values of the parameters. These tables could have been made more useful if they were to contain (i) a suitable method of interpolation to evaluate the functions with desired accuracy for the intermediate values of Weibull and Gamma parameters, and (ii) some indication for obtaining at least approximate numerical values for the parameters outside the range of the tables. The author in a private communication has commented on the above as follows. "It is true, as the reviewer states, that the tables would be more useful if suitable methods of interpolation and extrapolation were given. This was not done because it would be more accurate, and probably also simpler, to compute the expected values directly for other values of the Weibull and Gamma shape parameters. The latter would require only very minor modifications of the computer programs, which are available from the author on request."

R67-13052 ASQC 824; 830; 870
Joint Publications Research Service, Washington, D. C.

ON EVALUATION OF THE RELIABILITY OF SEQUENTIAL SYSTEMS WITH REPAIR

O. V. Shcherbakov *In its* News of the Acad. of Sci. USSR Dept. of Tech. Sci. Tech. Cyberenetics no. 1, 1966 Jun. 1966 p 64-71 refs (See N66-28428 16-10) CFSTI: $6.00 (N66-28434)

The problem of determination of the reliability characteristics for sequential systems, the elements of which have the possibility of being repaired, is investigated. Formulae are presented for carrying out the necessary calculations. Author

Review: The problem of the reliability of a serial system with repair is treated. Almost all the results contained in this paper may be found in [1]. Because of the slight differences in terminology and the translation difficulties, this reference would be a more suitable source of information. One must be cautioned that the results in this paper apply to systems consisting of n identical elements in series or, to put it another way, n elements in series having identical failure rates and repair rates.

Reference: [1] Sandler, Gerald H., *System Reliability Engineering*, Grumman Aircraft Engineering Corp., Prentice-Hall, Inc., Englewood Cliffs, N. J., 1963.

R67-13064 ASQC 824; 831
Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.

SOME INEQUALITIES FOR RELIABILITY FUNCTIONS

Z. W. Birnbaum (Washington Univ.) and J. D. Esary Oct. 1965 20 p refs *Its* Mathematical Note No. 431
(D1-82-0479; N66-26082)

For the class of coherent binary systems the inequality

$$h'(p) \geq h(p)\,[1 - h(p)]/[p(1-p)]$$

has been previously proven, where p = component reliability, $h(p)$ = system reliability; hence $h'(p)$ = rate of change of system reliability as a function of component reliability. In the present study essential improvements of this inequality are obtained under the assumption that n = number of components, and one or both of the following parameters are known: the "length" of the system, i.e., the smallest number of components such that their functioning assures the functioning of the system, and the "width" of the system, i.e., the smallest number of components such that if they fail the system must fail. The usefulness of these results is due to the fact that in practice n, length, and width are often known although the system is so complex that a study of some of its details for reliability purposes may be prohibitive. An immediate application of such inequalities is that when it is known that for component reliability p_o the system has attained reliability $H(P_0) = p_0$, then a lower bound can be given for the system reliability $h(p)$ for all $p \geq p_0$. Author

Review: This is a good theoretical paper on the subject of inequalities for reliability functions, using the method of coherent structure functions. Several papers have been written on this subject (see, for example, R61-10032, R63-10850, and R65-12236). The results of this paper are applicable to systems with n identical components, each of which can be in one of two states: failed or non-failed. Furthermore, the assumption of independence is made throughout. Although these results have limited application because of the assumptions made, the paper should provide good background material for one interested in estimating system reliability based on known component reliabilities.

R67-13065 ASQC 824; 612

Joint Publications Research Service, Washington, D. C.

THE ACCELERATION OF THE SIMULATION PROCESS WHEN EVALUATING THE EFFICIENCY AND RELIABILITY OF COMPLEX SYSTEMS BY THE METHOD OF STATISTICAL TESTS

V. M. Rakhval'skiy *In its* News of the Acad. of Sci. USSR Dept. of Tech. Sci. Tech. Cybernetics no. 1, 1966 6 Jun. 1966 p 57–63 refs (See N66-28428 16-10) CFSTI: $6.00 (N66-28433)

The methods of acceleration of the simulation process are investigated when evaluating the efficiency and reliability of complex systems. The proposed methods provide for high accuracy of calculations for allowable expenditures of machine time (on the order of several hours for high speed digital computers) when evaluating highly reliable systems. Author

Review: The problem of accelerating the computer simulation process when evaluating the efficiency and reliability of complex systems is treated in this theoretical paper. By a complex system, the author means one for which the failure of an individual subsystem (or circuit) does not necessarily result in complete failure of the system. Consequently, such failures result in a reduction of the efficiency of the system. In the formula given for efficiency there appears to be an incorrect definition of W_0, possibly as a result of the translation, because of the first term in the formula should be the product of the probability that all circuits are in good repair (Q_0) multiplied by the efficiency of the system, given that all its circuits are in good repair. Yet the quantity by which Q_0 multiplied (W_0) is defined as the efficiency of the system corresponding to the case of complete breakdown of all its circuits. The paper is written in a general style, and its main message is that one should make a judicious choice of analytical and simulation techniques to solve problems of this type.

R67-13072 ASQC 824; 612; 837; 844; 850

National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.

MONTE CARLO APPLICATION FOR DEVELOPING A DESIGN RELIABILITY GOAL COMPATIBLE WITH SMALL SAMPLE REQUIREMENTS

Ray Heathcock and Dale L. Burrows 22 Jan. 1964 32 p refs (NASA-TM-X-51481; MTP-P&VE-T-64-1; N64-17670) CFSTI: HC $3.60/MF $1.60

The reliability of many items in space vehicles (from piece parts to large structural elements) can be appropriately considered to be the result of probability interaction between the distributions of strength (failure) and stress (load). This investigation applies Monte Carlo simulation to the construction of empirical sampling distributions of reliability for various sample sizes taken from the strength and stress distributions, which are assumed Gaussian. Emphasis has been placed on very small sample sizes and very high values of reliability since these are situations commonly imposed on space vehicle development programs because of the costs involved. The empirical sampling distribution of reliability estimates appear to be very sensitive to the ratio of the standard deviations of the stress and strength distributions; therefore, specific sampling distributions are constructed for selected values of this ratio. It is concluded from this investigation that the constructed empirical sampling distributions can be utilized to aid the designer in establishing a design reliability goal, place a confidence coefficient on reliability estimates, and to determine if sample data, taken from the stress and strength distributions, demonstrates a specified reliability at a specified confidence level. Author

Review: This is a theoretical paper which treats two different problems although at first glance it would not appear to be so. The explanations of the theory are not clear; some of the difficulties are: (1) It is not obvious how the authors are defining the sample standard deviation—whether it is the conventional unbiased estimate of the standard deviation or whether it is the root-mean-square (RMS) deviation. (2) The parameter of case IIC is stated to be a Normal deviate but obviously does not have a Normal distribution. (3) The parameter Z is defined differently in Sections IIA and IIC. (4) The equation for R_{est} in Section IIA is not satisfactory. The following derivation for reliability in Section IIA is more satisfactory (the notation is similar to that in the text): Subscript one is strength, subscript two is stress, X is a random variable, M is the true mean, and σ^2 is the true variance. It is presumed in this discussion that the ratio of standard deviations of the stress and strength distributions is known (the authors implicitly assume this). The reliability is given by equations 1–3 below.

$$R \equiv \Pr\{X_1 - X_2 \geq 0\}. \tag{1}$$

Let $$t \equiv [(X_1 - X_2) - (\overline{X}_1 - \overline{X}_2)]/s; \tag{2}$$

then t is a Student's t variable with n_1+n_2-2 degrees of freedom, and

$$s^2 = (rSS_1 + SS_2/r)[(1 + 1/n_1)/r + r(1 + 1/n_2)]/(n_1 + n_2 - 2),$$

where $n_i (i = 1,2)$ are the sample sizes, $r = \sigma_2/\sigma_1$, and $SS_i = \Sigma_j = (X_{ij} - \overline{X}_i)^2$ is the sum of squares of the deviations of the observations X_{ij} on the ith variable from their mean value $\overline{X}_i$. We then have

$$1 - R = \Pr\{t \geq (X_1 - X_2)/s\}, \qquad (3)$$

the degrees of freedom being $n_1 + n_2 - 2$.

This is an average reliability as can be inferred from equation 1. Equation 3 is in contrast to the equation for R_{est} in the text. Since tables of the Student's distribution are ubiquitous there is no need for a Monte Carlo analysis of this phase of the problem. In the latter part of the paper the authors try to estimate safety margins. The validity of the reliability numbers depends heavily on the distribution's being exactly Normal. This could have been avoided by labeling the curves with the true safety margin rather than with reliability. The results might then be rather robust with respect to the Normality assumption. When the variance ratio is known as assumed in the text this is also a solved problem. The distribution of the estimated safety margin is expressed in terms of the noncentral t distribution as shown in equations 4 and 5 below.

$$\Pr\{(\overline{X}_1 - \overline{X}_2)/s' \leq K \mid Z\} \equiv P, \quad (4)$$

where

$$s'^2 = (rSS_1 + SS_2/r)(1/rn_1 + r/n_2)/(n_1 + n_2 - 2),$$

$$K = \text{a given number (such as an abscissa on a graph)},$$

and $Z = (M_1 - M_2)/\sigma'$ is the true safety margin.

If we represent the estimated safety margin by

$$\hat{Z} = (\overline{X}_1 - \overline{X}_2)/s';$$

we may write (4) as

$$P = \Pr\{\hat{Z} \leq K \mid Z\}.$$

Since $\hat{Z}$ may be written as

$$\hat{Z} = \frac{[(\overline{X}_1 - \overline{X}_2) - (M_1 - M_2)]/\sigma' + (M_1 - M_2)/\sigma'}{s'/\sigma'} = t^*,$$

where t^* has a noncentral t distribution with noncentrality parameter

$$\delta = (M_1 - M_2)/\sigma' = Z,$$

we see that the problem reduces to a solved one for which tables are available because (4) may be written as

$$P = \Pr\{t^* \leq K \mid \delta\}. \quad (5)$$

A good reference for the noncentral t distribution is [1]. This is an important problem that has been attacked by the authors. There was no need for the Monte Carlo solutions since the functions involved are reasonably well known and have been fairly well tabulated for some time. Analytical support for the Monte Carlo approach used in this paper is provided in the paper covered by R67-13079. A more recent treatment of this is given in the paper covered by R66-12678. It would have been helpful to discuss the estimation of the variance ratio from the samples rather than to assume it is known since the ratio strongly influences the results as the authors show. Some work has been done on this problem by statisticians where a modified number of degrees of freedom is used (see [2, 3]). In terms of practical application to materials there is rarely available enough data to make any statistically valid estimate of any strength parameter. There are in a production process heat to heat variations in both mean and variances of strength and probably in the distribution form itself. There are supplier to supplier variations. Last but not least you may not get the material you specified anyway. One is lucky if a single number, usually of questionable ancestry, is known, regardless of its exact meaning (such as median or lower limit). Good discussions of the problems associated with materials properties are given in the papers covered by R67-12930 and R67-12931.

References:

[1] Locks, M. O., Alexander, M. J., and Byars, B. J., New tables for the noncentral t distribution, ARL 63-19, Aeronautical Research Laboratories, Office of Aerospace Research, USAF, Wright-Patterson Air Force Base, Ohio, January 1963.

[2] Welch, B. L., The generalization of "Student's" problem when the population variances are unequal, *Biometrika*, 34, p. 28–35 (1947).

[3] Patil, V. H., Approximation to the Behrens–Fisher distributions. *Biometrika*, 52, p. 267–271 (1965).

R67-13073 ASQC 824; 541

Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

ON REGRESSION TECHNIQUES FOR ESTIMATING THE PARAMETERS OF WEIBULL CUMULATIVE DISTRIBUTIONS

David Ian Gross (M.S. Thesis) Dec. 1965 51 p refs
(GRE/MATH/65-4; AD-628336; N66-22399) CFSTI: HC $5.60/MF $0.50

A regression technique for estimating Weibull scale and shape parameters is introduced and experimentally investigated. The derivation involves maximizing the likelihood function of a set of normal density functions which give the probabilities of f_i items failing until time t_i. The estimation technique was evaluated using simulated failure data and the estimators were found to be optimal according to Kolmogorov–Smirnov tests. When compared with the Harter–Moore MLE iteration technique the regression method was 145 times faster and yielded Kolmogorov–Smirnov values 26% lower. Of 1100 estimations only one could not be accepted at the .20 confidence level as having come from the failure data. The method is well suited for small computers such as the IBM 1620 and may be employed to analyze incomplete r censored samples of failure data. Author (TAB)

Review: This report has several erroneous statements and the reader is warned against taking for granted any conclusions. Firstly, in the derivation of the regression in equation (2.47) the author takes the likelihood function as the product of the probabilities of the cumulative frequencies. The cumulative frequencies are not independent and hence the likelihood function is not the product. Despite the mistake, he arrives at a solution which is similar to that of least squares methods. The author's solution is also least squares with weights h_i in place of unity. In section 3, the author sets up an excellent and elaborate Monte Carlo experiment for comparing the various techniques and deserves compliments for the same. However, he seems to be motivated only by his desire to prove that his estimates are the best. The author uses as his criterion the Kolmogorov–Smirnov test, where D is the maximum of $|\hat{F}(\hat{\theta}, \hat{\delta}) - S(t_i)|$, $\hat{F}$ is the fitted distribution, and $S(t_i)$ is the cumulative distribution of the data. The purpose of the comparison is to study the closeness of $\hat{F}(\hat{\theta}, \hat{\delta})$ to the true population $F(\theta, \delta)$ and hence the criterion should have been

$$\operatorname{Max} | F(\theta, \delta) - F(\hat{\theta}, \hat{\delta})|.$$

It is almost certain that the use of this criterion will result in completely different conclusions. The author erroneously argues on page 23 than since $\hat{\theta}_R$ is not normally distributed we cannot draw any conclusions regarding $E(\hat{\theta}_R)$ and bias in $\hat{\theta}_R$. This argument is in contradiction to the basis of the Monte-Carlo technique. Thus he tries to avoid the truth. It is evident from Tables II and III that variances of all estimators are nearly the same and that the bias in the estimates based on the iteration procedure is smaller than that in other methods in most cases. In the least squares and regression techniques the biases are comparable. The author seems to have purposely omitted the calculation of the commonly-used criterion, the mean square error, as it is obvious that it would prove the iterative maximum likelihood method to be the best on the average. In conclusion, this report should serve as warning against the misuse of techniques of mathematical approximations and the ever-useful Monte-Carlo method, and the use of improper criteria.

R67-13074 ASQC 821/711; 712; 844
Aeronautical Research Inst. of Sweden, Stockholm.

ANALYSIS OF THE PROBABILITY OF COLLAPSE OF A FAIL-SAFE AIRCRAFT STRUCTURE CONSISTING OF PARALLEL ELEMENTS

Sigge Eggwertz and Goran Lindsjö 1965 42 p refs Supersedes HU-961; RTD-TDR-63-4210;
(Grant AF-EOAR-61(052)-573)
(FFA-102; HU-961; RTD-TDR-63-4210; N66-15671) CFSTI: HC $2.00/MF $0.50

A study is made of the probability of collapse of a fail-safe structure, consisting of a number of parallel members, and subjected to a random load spectrum. In the individual member a fatigue crack is first initiated and failure of the member occurs due to a heavy load on the weakened member. The probability of element failure is obtained by a combination of the probabilities of crack initiation and of meeting a load exceeding the residual strength of the member. The probability of consecutive element failures is deduced from the probability of failure of the individual members. Collapse occurs when all members are broken, or, in practice after a critical number of element failures within one inspection interval. The probability of collapse of the assembly during the whole service life results from a combination of the probabilities of all the inspection intervals. A numerical procedure for calculating the probability of collapse has been developed and evaluations have been made for an assembly of six identical, parallel members. Diagrams of the probability of collapse P versus the service life time T_L have been plotted in Figs. 5–12 for various lengths of regular inspection intervals, assuming different values of the crack initiation and strength reduction parameters introduced. Some preliminary fatigue testing of single specimens and assemblies with six members has been carried out in order to get information regarding the basic assumptions made in the theoretical investigation. They have been analyzed by a simplified method and show a good agreement with theory within a limited region around 50 per cent probability of failure. Author

Review: This report is a revision of an earlier one by the same authors and bearing the same title (see N64-17150). It corrects some numerical errors and discusses the results more thoroughly than the earlier report. (In this report the figure numbers and titles for figures 7 and 11 should be interchanged.) It is a worthwhile extension of the previous work and again will be of interest to those engineers who are pushing the practical applications of theory further in a useful direction. Like the earlier report, it is of little direct use for designing a specific structure.

R67-13076 ASQC 824; 831
Joint Publications Research Service, Washington, D. C.

AN APPROXIMATE ALGORITHM FOR CONSTRUCTION OF OPTIMALLY RELIABLE SYSTEMS WITH AN ARBITRARY STRUCTURE

I. A. Ushakov *In its* News of the Acad. of Sci. USSR 9 Jul. 1965 p 25–32 refs (See N65-27975 17-34)
(N65-27978) CFSTI: $6.00

Some index of quality of operation (effectiveness) is determined in a general form for systems with arbitrary structure. The approximate algorithm is assumed for optimal distribution of "total weight" (or any other limiting factor) of the system among its elements for increasing their reliability with the purpose of achieving a maximum index of effectiveness. The algorithm is based on the method of most rapid slope as applied to problems of convex programming for linear limitations. Author

Review: The paper seeks by dynamic programming the combination of components which maximizes the reliability of an assembled system subject to an upper bound on total "weight" of system components. The algorithm begins by selecting that one of several possible combinations of components with minimal reliability; it then proceeds to improve this system using steepest-descent techniques. The reason for beginning with the least reliable variant is that it "has naturally also a minimal value of total weight"; but this is not true, for a system with gigantic weight on a totally unreliable part is totally unreliable. Hence the proposed algorithm might well conclude that maximum reliability is less than that obtained in practice without applying the algorithm. However, for a single given variant of components, the algorithm seems sound. While the problem is formulated for a very general system, the solution is nontrivial only if it is possible, within the constraint of the limited resource, to construct more than one "satisfactory" system. The approach is applicable, for example, to the allocation of spares for the elements in a large communication network where maximum reliability is desired and a fixed amount of money is available. There are some minor but annoying errors and awkward grammatical constructions in the translation which make the paper rather difficult to read.

R67-13077 ASQC 824
Joint Publications Research Service, Washington, D. C.

SYNTHESIS OF RELIABLE SYSTEMS FROM UNRELIABLE ELEMENTS BY FEEDBACK METHOD

V. B. Georgiyevskiv *In its* Res. in Cybernetics 9 Dec. 1965 p 1–7 refs (See N66-14476 05-10) CFSTI: $3.00
(N66-14477)

This article studies the synthesis of reliable systems by feedback methods with error indication by time doubling–the introduction merely of time redundancy. Because the method of synthesis with different methods of error indication requires the insertion of structure and time, the concept of generalized redundancy for the detection and correction of malfunctions is utilized for the total characterization. Different methods of synthesis and error indication are compared for economy by the use of generalized redundancy. An expression is obtained which theoretically demonstrates the minimum necessary redundancy by using feedback methods. Either individual elements of a system or whole groups may be covered by feedback. The effect of the number of feedback connections in the system on its reliability and redundancy is explained. The results obtained are a generalization of the known results of element-by-element and unit duplication. Author

Review: Anyone interested in using the results in this paper will find it desirable to go over (essentially rework) the derivation carefully. The case considered is that in which a single given type of malfunction occurs with probability p during any trial. Hence, summations at the top of page 2 should have an upper limit of m-1 rather than 2m-1. But then (1), which is fundamental to the development, is not true. For P(a) is given by the formula at the top of page 2 (with upper index m-1) which is not less than $2^m p^m$ for $m = 3$ and p near zero.

R67-13078 ASQC 824; 831
Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

ON THE RELIABILITY OF SINGLE-CYCLE CIRCUITS BUILT FROM ELEMENTS WITH SYMMETRIC ERRORS

M. K. Chirkov *In its* Herald of Leningrad Univ., Issue 3, no. 13
13 Apr. 1965 p 199–204 refs (See N66-17406 08-23)
CFSTI: HC$6.00/MF$1.25
(N66-17418)

A method is presented for analysis of switching circuits reliability. The dependence of switching circuit reliability on component reliability was investigated and general approximations are given for determination of the circuit operation for any degree of component reliability. E.E.B.

Review: The ideas in this paper may have value to those concerned with reliability theory. However, it is extremely difficult to decipher them because of difficulties with the notation. Perhaps the author's first reference (presumably in Russian) may help explain things. It seems likely, however, that anyone interested in the problem would obtain more useful results for time invested by tackling the problem himself instead of trying to make sense of this translated work.

R67-13079 ASQC 824; 412; 421
National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.

PROBABILITY THAT STRESS IS LESS THAN STRENGTH AT PRESCRIBED CONFIDENCE LEVELS, FOR NORMALLY DISTRIBUTED DATA

E. L. Bombara *In* Army Res. Office Proc. of the 9th Conf. on the Design of Expt. in Army Res., Develop. and Testing Dec. 1964 p. 111–189 refs (See N65-15451 06-19)
(N65-15457)

This paper presents methods for estimating probability that stress does not exceed strength, with a prescribed level of confidence. Tables are provided to simplify calculations of such probabilities. Input data are the mean and standard deviation of operating stress from n_{ss} tests, and the mean and standard deviation of strength from n_{th} tests. Precision of these methods, based on approximate results by Welch and Aspin, is indicated vs sample sizes and ratios of variances. Comparisons of analytical results with computer simulations were made to illustrate the amount of bias and the method when the number of tests is very small; say, 5. Author

Review: This paper is in the same general subject area as the one covered by R67-13073. In fact the two papers were written in coordination, this one serving the purpose of analytically complementing and supporting some of the Monte Carlo conclusions in the other. Practically all of the points raised in the review R67-13073 are treated analytically in this paper. The analytical techniques are preferable to the sampling approach because of the existence of these solutions or adequate approximations.

83 DESIGN

R67-13039 ASQC 832; 844
Minneapolis-Honeywell Regulator Co., Minn. Aeronautical Div.

STUDY OF PILOT-CONTROLLER INTEGRATION FOR EMERGENCY CONDITIONS

G. Cole, M. Bender, R. Shoquist, R. Santella, D. Lovinger et al
Wright-Patterson AFB, Ohio, Res. and Technol. Div. (1963)
193 p refs
(Contract AF 33(657)-7601)
(RTD-TDR-63-4092; AD-438820; N65-36724)

The objective of this program was to develop a design concept which will minimize catastrophic flight control failures through appropriate pilot-controller integration. This report describes a systematic procedure composed of techniques within the field of flight control design, reliability, and human factors which yields a practical approach for effective design of an integrated pilot-controller system. Application of the procedure was made to an advanced vehicle mission phase as an aid to the study group in determining practicality of the approach. Areas where further advances of the study are limited by the state-of-the-art are pointed out as recommendations for future investigation. Author

Review: An extensive study of pilot-controller integration is summarized in this report, which makes an important contribution to the literature on the reliability of man–machine systems. The man–machine relationship is a critical factor in the design of flight control systems for future spacecraft use. This report presents a design technique by which man–machine integration can be evaluated in regard to reliability and failure potential. Also suggested are areas which require further study. The bibliography, which lists 121 items and gives brief abstracts for most of them, is a very useful feature.

R67-13046 ASQC 831; 824; 844
Sperry Gyroscope Co., Carle Place, N. Y.

DEVELOPMENT OF LAUNCH VEHICLE MALFUNCTION EFFECTS MODEL

Washington, NASA, Aug. 1965 104 p refs
(Contract NAS8-11229)
(NASA-CR-288; N65-31573) CFSTI: HC $4.00/MF $0.75

Mathematical relationships relating malfunction and remedial actions to their effects on crew safety and mission success were derived and are presented as a series of mathematical models and computational procedures. The application of these techniques to the Saturn V launch vehicle has demonstrated that the large volume of reliability and failure effects data, typical of a complex multistage launch vehicle, can be assimilated, processed, and used effectively to assure that the Rocket Engine Analyzer and Decision Instrument system design considers these data in a proper perspective. R.N.A.

Review: This is a comprehensive and detailed report concerned with the Rocket Engine Analyzer and Decision Instrumentation (READI) concept as applied to the Apollo Manned Lunar Landing Mission and the Saturn V launch vehicle, with special attention to the J-2 engine subsystem. It serves to illustrate the development of a set of malfunction effect models applicable to a real mission-vehicle-engine combination. An available dynamic mathematical model of the J-2 engine, modified to permit its use for malfunction analysis, was used in this study. Analog computer simulation was used in evaluating the utility of the model to the READI design procedure. This is a reasonable approach, since the *engine mathematical model is too complex for rigorous theoretical* analyses of malfunction effects. The report is well illustrated with graphs and tables.

R67-13049 ASQC 831; 612
NETWORK ANALYSIS BY DIGITAL COMPUTER.
F. F. Kuo (Bell Telephone Laboratories, Inc., Systems Research Dept., Murray Hill, N. J.).
IEEE, Proceedings, vol. 54, Jun. 1966, p. 820–829. 65 refs.
(A67-10462)

The article gives a brief survey of various methods for network analysis by digital computer. Topics discussed include methods and programs for ladder networks, *mesh and nodal* analysis, network topology, electronic circuit analysis, state-variable analysis, n-port hybrid matrix analysis, and nonlinear circuit analysis. Also given is a brief discussion concerning algorithms for inverse Laplace transformation, and methods for obtaining magnitude, phase and delay responses in the frequency domain. Author (IAA)

Review: This survey article performs a useful function for *reliability engineers and designers in describing existing* computer programs which perform network analysis. Apparently only two of the programs described, ECAP and HYBRID, provide parameter variation for sensitivity and tolerance studies. The extensive bibliography given should be of considerable assistance to anyone wishing to dig deeper into the general area or to investigate specific programs in detail.

R67-13062 ASQC 838; 817; 870
RAND Corp., Santa Monica, Calif.
THE EFFECT OF MAINTAINABILITY ON THE MISSION RELIABILITY OF TWO-ELEMENT REDUNDANT SPACECRAFT SUBSYSTEMS
C. G. Vandervoort Dec. 1965 61 p refs
(Contract AF 49(638)-1700; Proj. RAND)
(RM-4824-PR; AD-627602; N66-25857) CFSTI: HC $3.00/ MF $0.75

The memorandum presents a technique that will assist the designer in assessing the effect of maintenance on the reliability of spacecraft systems with two-element redundancy, i.e., where the prime system element is backed up by a redundant secondary. TAB

Review: The technique described in this report should be useful in preliminary system optimization studies, as it is concerned with the effect of maintenance on subsystem mission reliability. Some of the underlying assumptions, which are spelled out in the report, are rather restrictive from a practical viewpoint. However, they serve the purpose of facilitating a solution to the problem, and refinements, if considered necessary, may be introduced later. An important feature is the introduction of an index of repairability, expressing the probability that a breakdown can be repaired. The presentation is clear and straight-forward, and the examples have good illustrative value. The more complex mathematics is relegated to an appendix.

R67-13067 ASQC 838; 824; 844
Illinois Univ., Urbana. Graduate College.
LIFE SPAN AND SELF-REPAIR IN COMPLEX SYSTEMS
Shei-Mei Cheng (Ph.D. Thesis, 1964) Ann Arbor Mich., Univ. Microfilms, 1965 54 p refs
(N67-80781)

Statistical nature of failure, intrinsic and extrinsic life span, redundant systems, and self-repair are considered in relation to complex systems. Difficulties arising in the construction of complex automata are pointed out, and an attempt is made to realize an ideal system by investigating the nature and origin of errors. Expressions are formulated for both intrinsic and extrinsic causes of failure of elements, the latter type resulting from the interaction between these elements and their environment. For simple systems, it is shown that the intrinsic life span is always shorter, but for complex systems the extrinsic life span is the shorter. Redundancy techniques are introduced to increase the extrinsic life span; and failure probabilities and life spans are considered for these redundant systems, with attention given to both series and parallel redundancy. Self-repair is considered a special form of redundancy; and it is concluded that redundancy is best applied at the lowest level, while self-repair has greater merit at higher levels. Error detection, cost, and weight limit the incorporation of self-repair into a system. M.W.R.

Review: The first part of the thesis contains introductory material and does not treat the subject well. Many of the statements are questionable, not clear, wrong, or inadequate. Some of the difficulty *may very well be a language problem but this* does not ameliorate the situation. Some parts of the latter half of the paper dealing with Markov chains may be of some use to theorists but by now they probably appear elsewhere in the literature in a more usable form. A major point of concern in redundant systems is that the author considers that failure is more likely due to an unexpectedly severe environment than to a known and constant environment (at least this is what he seems to say). It should be noted that in this case *the benefits of redundancy are severely reduced and in the limit* the minimum probability of failure cannot go below the probability of an extremely severe environment.

84 METHODS OF RELIABILITY ANALYSIS

R67-13029 ASQC 843; 553
General Electric Co., Philadelphia, Pa. Missile and Space Div.
RELIABILITY TABLES
E. Fritz, A. Sternberg, T. Weir, and J. Youtcheff Washington, Navy Dept., 15 Apr. 1965 300 p refs
(R62SD135; NAVWEPS-OD-30668)

Tables that assume testing is truncated according to best time are presented for determining reliability to four significant figures with either one or two tail confidence limits. These tables provide both the lower and upper bounds at the various confidence levels; and formulas used in obtaining the values are given. The tables are based on the *principle that* the reliability figure implies a specified fixed time of operation or survival; and that the components under consideration exhibit an exponential failure time distribution. Values of the descending exponential ($e^{-\lambda}$) for values of λ from 0.000 to 2.4999 are given, and the application of the tables to specific reliability problems is discussed. M.W.R.

Review: The tables presented in this report will be useful *to reliability analysts who have a frequent need to determine* reliability confidence limits from observed data. They apply to situations involving an exponential distribution of times to failure, and in which testing is truncated by test time. However, they can also be used for situations in which testing is truncated by failure, as explained on page 3 of the report. The underlying mathematics is clearly and concisely explained in the introduction and two examples given in the Appendix illustrate the use of the tables.

R67-13033 ASQC 844; 775
Naval Air Station, Pensacola, Fla. Materials Engineering Div.

EFFECTIVENESS OF THE SPECTROMETRIC OIL ANALYSIS METHOD FOR MONITORING AIRCRAFT MECHANISMS

B. B. Bond 26 Jun. 1964 10 p ref.
(OA-20-64; AD-609746; N65-22928)

An investigation of the potentialities of the spectrometric oil analysis method for monitoring aircraft engines and other aircraft mechanisms is reported. The reliability of the method for detecting abnormal wear in oil lubricated aircraft mechanisms such as metal parts in frictional contact, is discussed. The applicability of the oil analysis technique to turbojet engines was also evaluated. Results of a study on seven discrepant jet engines showed these facts: (1) Oil analysis provided preindications of failure in six of the seven engines. Other evidence of failure was found in only two of the seven. (2) Oil analysis provided warnings in time to avert inflight failures in four of the engines. Delay in transit time of oil samples for two of the remaining three engines prevented a more thorough study. (3) Two of the three inflight failures resulted in total loss of the aircraft. Oil analysis is credited with the detection of two of the discrepant engines that did not fail in flight. S.C.W.

Review: These two papers (R67-13033 and R67-13034) show the effectiveness of analyzing the oil for wear metals and some of the troubles involved in trying to establish such a program for failure prevention. The two papers contain some overlapping material. The reliability of equipment can be considerably enhanced by a nondestructive monitoring process which gives an early indication of potential failure. The oil analysis method cannot indicate incipient catastrophic failures such as those due to fatigue but only those failures due to excessive wear. This type program is also in use on some commercial airlines, especially in connection with jet engines. These papers would be useful mainly to those involved in trying to set up such a program. They contain little information of value to the design engineer. Efforts of this kind which take advantage of what is already known in our technology for the purpose of improving the reliability of equipment and machines should be encouraged.

R67-13034 ASQC 844; 775
Naval Air Station, Pensacola, Fla. Overhaul and Report Dept.

TRECOM TECHNICAL REPORT 63-55; REVIEW OF

B. B. Bond 14 Sep. 1964 12 p
(OA37-64)

The feasibility of an aircraft spectrometric oil analysis system for operational use in the field is reviewed. Since statistical studies did not prove that oil analysis is either a good or bad method of detecting incipient failures in aircraft engines, additional studies were undertaken to measure the effectiveness of oil analysis with reciprocating engines. The approach was to test the soundness of the laboratory recommendations to the operating activities. Over the four-year period from October 1, 1959 through October 1, 1963, a reliability factor of 53.45% is given for the 350.15 samples analyzed per discrepant engine detected; while for the last year of the study a 76.92% reliability factor is given based on 202.13 samples per engine. Over the four-year period, 53 discrepant engines were detected, 24 of which were during the final year. Some typical case histories are outlined. M.W.R.

Review: See R67-13033.

R67-13037 ASQC 844; 775
Martin Co., Orlando, Fla.

INFRARED TESTING OF ELECTRONIC COMPONENTS
Final Report, 5 Apr. 1965–5 Jun. 1966

W. R. Randle, G. Chadderdon, and T. L. Hartman, Jr. Jun. 1966 115 p
(Contract NAS8-20131)
(NASA-CR-76080; OR-8347; N66-29973) CFSTI: HC $4.00/MF$0.75

The feasibility of developing an infrared radiation nondestructive test technique for electrical/electronic devices was investigated. The phases included are (1) a state-of-the-art survey of industry and government organizations, (2) testing conformal coating materials to standardize surface emissivity, and (3) determining the use of infrared in various actual applications. A relationship between infrared radiation and life expectancy was established. It was found that increased operating temperature has a deleterious effect on transistor life expectancy, but also design and process variables may have a significant effect. Infrared fingerprinting of the operating components on a printed circuit board for thermal derating analysis and for troubleshooting was proven to be feasible, and was successfully employed in: (1) locating the hotter components on a printed circuit board, (2) evaluating the effects of relocation, and (3) accurately evaluating a variety of heat sink configurations and transistor mounting techniques. The requirements for application on infrared technology and its limitations are identified. N.E.N.

Review: This is a comprehensive and detailed report based on a 14-month study of infrared technology for the nondestructive testing of electrical/electronic devices. As such it will be of interest to anyone using these techniques or planning programs involving their use. Phase I of the study was a state-of-the-art survey based on questionnaires, personal interviews, and a review of pertinent literature. Phase II was concerned with testing conformal coating materials to standardize surface emissivity. These two phases were covered in more detail in separate earlier reports, which are referenced in this final report. Phase III dealt with the feasibility of using infrared in various applications. This report makes an important contribution to the literature on infrared technology, and includes some recommendations regarding work which should be done in this field.

R67-13040 ASQC 844; 775

CHOLESTERIC LIQUID CRYSTALS AND THEIR APPLICATION TO THERMAL NONDESTRUCTIVE TESTING.

Wayne E. Woodmansee (Boeing Co., Seattle, Wash.).
Materials Evaluation, vol. 24, no. 10, Oct. 1966, p. 564–572. 4 refs.

The unique properties of cholesteric liquid crystals are described, and applications involving the use of these materials to visualize small thermal gradients are shown. Mixtures of liquid crystals are discussed which respond rapidly to temperature changes of 1°C or less by reflecting visible light of different colors. Examples of the detection of surface and subsurface flaws in metals and nonmetals, measurement of the surface temperature of electronic components, identification of circuit board interconnections having excessive resistance, and inspection of adhesively bonded honeycomb sandwich materials with liquid crystals are shown. Author

Review: This method of detecting surface thermal gradients should prove to be a useful nondestructive testing technique. It has apparently an advantage over the use of infrared radiometers in the ease with which it can depict a distribution of temperatures over a surface. The paper is a concise and clear description of the method and some of its applications; more details will be found in the references which are cited.

R67-13041 ASQC 844; 775

RADIOGRAPHIC INSPECTION OF SEMICONDUCTORS AND COMPONENTS.

L. D. Clark and R. E. McCullough (Texas Instruments, Inc., Dallas, Tex.).

Materials Evaluation, vol. 24, no. 10, Oct. 1966, p. 577–582.

Procedures are described for accomplishing radiographic nondestructive inspection of semiconductors and similar components, and problems inherent in such analyses are reviewed. An in-plant laboratory was organized to accomplish the necessary inspection procedures despite the fact that an outside laboratory had the advantages of complete equipment and trained personnel. Factors which influenced the laboratory site selection were capital equipment, facility cost, available effort, schedules, manpower, location, and existing facility. Operation of the in-plant facility is described, with emphasis on a penetrometer suitable for semiconductors. Techniques for obtaining optimum resolution are considered. M.W.R.

Review: Radiographic inspection has proven to be a valuable nondestructive testing method for semiconductors and components. Perhaps its earliest application was in the detection of contaminants in semiconductors–see R65-12230. As pointed out in the present paper, the method has potential applicability to potted modules, ceramic-coated inductors, soldered connectors, etc. Further development work is needed, and this paper indicates some of the needs. The bulk of the paper is devoted to a description of the set-up and fixturing of a radiographic inspection facility. It could serve as a guide for those interested in setting up a similar operation.

R67-13042 ASQC 844; 775

A TRANSISTOR SCREENING PROCEDURE USING LEAKAGE CURRENT MEASUREMENTS.

George T. Conard, Jr. and Donald C. Shook

Journal of Research, NBS, vol. 69C, no. 4, Oct.–Dec. 1965, p. 319–330.

A study of the aging behavior of low-power germanium alloy switching transistors has revealed a relationship between small changes in junction leakage current, induced by a brief aging stress, and later deterioration in performance. This relationship may provide the basis for a nondestructive screening procedure which would serve to identify germanium alloy transistors likely to deteriorate through excessive growth of junction leakage current. The proposed screening procedure involves the determination of relatively small changes in junction leakage current, increases of the order of 15% or more, associated with 1.000 hr. of aging at a shelf (bake) stress of 100°C. Because the leakage current changes of interest are small, relatively high demands are placed upon measurement repeatability. There is evidence that transistors bearing identical type numbers, but of different manufacture, respond differently to the same screening procedures and would, therefore, require different screening limits. Author

Review: The results in this paper indicate a valuable screening method for further reducing the failure rate of "high-reliability" germanium alloy transistors by eliminating potential failures. The authors have shown an appropriate regard for the steps necessary to insure the integrity of the data taken in such component testing. Further exploration of the screening method is in progress; it is hoped that this work will slow applicability of the method to other types of transistors. Up to now an effective method to screen out a potential transistor failure before actual "failure" has been conspicuously absent. The article should be of value to reliability engineers and designers of high-reliability electronic gear. A condensation giving the highlights of the results appears under the title "Transistor failures set by Bureau" in *Quality Assurance*, vol. 5, July, 1966, p. 30–31. Another short descriptive article summarizing the experimental findings and conclusions is found in *Electronics World*, vol. 75, June, 1966, p. 27.

R67-13043 ASQC 845

MEETING R AND D REQUIREMENTS FOR RELIABILITY AND QUALITY CONTROL DATA.

R. J. Smurthwaite (General Electric Co., Philadelphia, Pa.).

Journal of the Electronics Division, ASQC, vol. 4, no. 4, Oct. 1966, p. 3–12.

Overall objectives that must be established to meet reliability and quality control data requirements must consider both customer and company data requirements, the scope of data reporting, available data processing methods, and degree of integration among operational procedures of the groups using the data. A data reporting system should include the recording, collecting, processing, and filing of all inspection data and test data from vendor through flight; and the following four major data systems categories are suggested: performance, discrepancy, configuration verification, and records and retention. Various reporting forms and quality scorecard–sheets are included. M.W.R.

Review: A data system serving the mutual needs of reliability and quality control in one organization in the missile industry is described. The discussion of the underlying considerations and the illustrations should prove useful to those responsible for data systems on similar programs.

R67-13048 ASQC 840; 770; 837

Grumman Aircraft Engineering Corp., Bethpage, N. Y.

INVESTIGATION OF RELIABILITY MEASUREMENT BY VARIABLES TEST-TO-FAILURE

J. J. Bussolini May 1964 98 p refs

(ADR-09-14-64.1; N65-36450)

This report describes the results of an investigation to determine the feasibility and validity of using overstress test-to-failure techniques as a means of reliability measurements or as a reliability indicator for electronic equipment. The conclusions drawn from the program contained in this report indicate the usefulness of test-to-failure techniques as a tool for quantitative reliability measurement, weak link analysis and as a method for determining safety margins and performing pre-qualification reliability tests. The purpose of the test is to provide an indication of a product's ultimate strength early in its development stages. This program represents an advancement in the state-of-the-art in reliability testing in that a concept which had previously only been discussed and written about was studied, analyzed, and actually implemented in the form of an actual test on an item of modular electronic equipment taken from the E-2A aircraft. An unexpected proof by implication was developed from test results showing that the environmental limits anticipated in the aircraft were below those actually experienced. Author

Review: A detailed report of a test program and the analysis of the results is presented. However, the reader interested in following it closely will have difficulty in using a STAR copy of the document, as the reproduction is very poor in places (although clearly this is no fault of the author). The organization of the report is no help either, as all of the graphs are collected at the end of the text, calling for much flipping of pages. The discussion is rather tedious on points which should be familiar to reliability analysts (parameter estimation using Weibull paper, confidence limits, and interpretation of test results). There are typographical errors in the expression for $P(F) = Q$ appearing in two places on page 31; it should be $P(a) + P(b) - P(a)P(b)$. There appears to be some confusion regarding the use of the word "random" as applied to failures. On page 8 it is implied that the term is synonymous with the existence of a constant failure rate (a misuse which occurs frequently in reliability literature). On page 31 a "definition" of a random failure is not really a definition at all. The reader is left in doubt as to what the author does mean when he refers to a random failure. The program on which this report is based may have been good, but this description of the results leaves much to be desired from the standpoints of conciseness and clarity. (An earlier report on this program was covered by R66-12454, but it presented no quantitative results.)

R67-13050 ASQC 844; 771; 814; 817

RAND Corp., Santa Monica, Calif.

IMPACT OF EQUIPMENT LIFE CHARACTERISTICS ON MISSILE TEST PLANNING

L. T. Mast May 1964 19 p refs

(Contract AF 49(638)-700; Proj. RAND)

(RM-4102-PR; AD-620646; N64-26199)

Two conflicting bodies of opinion hold that the R&D missile and space system success rate can be improved by less prelaunch testing, or that the reliability of missiles can be enhanced by longer, more thorough testing and more extensive prelaunch operations. This paper presents data on both sides of this debate and examines the tradeoffs involved in finding the optimum point of operation to minimize the effect of both the wearout and infant mortality phenomena. From the conclusions drawn from the data, a test plan is proposed that would require all electronic and electromechanical subassemblies to be operated over long periods prior to use in the vehicle; the mechanical, hydraulic, and pneumatic booster subsystem to be operated for approximately one-tenth of their estimated mean life in order to have minimum risk during their short period of use; and a minimum of ground operation to be applied to the spaceborne pneumatic, hydraulic, and mechanical subsystems, unless their mean time between failures is very long. Author

Review: This report about equipment reliability is based on actual data. More of these are needed in reliability. Analysis of the data shows distinctly different failure patterns for three classes of equipment: airline electronic, airline mechanical, and helicopter mechanical. The mechanical equipment has the classical "bathtub" curve, but the electronics curve tapers off after a lengthy "burn-in" and does not show an increasing failure rate with age. The report is short, and the data used are dated. Even so, the report is of interest because of the tendency in reliability to assume without substantiation that certain failure patterns exist, such as the pertinence to electronic equipment of the short burn-in period and a constant failure rate. Some teesting guidelines are presented; these are sensible conclusions based on the data. These guidelines, which are for the three broad classes of equipment noted above, might be improved upon by further breakdown within each class, since most failures are usually caused by a small percentage of the types of parts which comprise an equipment.

R67-13055 ASQC 845

AN "INSIDE" LOOK AT THE ECRC DATA CENTER.

Robert A. Yereance (Battelle Memorial Institute, Reliability Coordination Div., Columbus, Ohio).

Evaluation Engineering, vol. 5, Nov.–Dec. 1966, p. 37–40.

Technical memoranda presenting data in chart form, data summaries describing test results, and an index listing parts' data are discussed as integral parts of the ECRC Data Center, a program sponsored by both government and industry to provide reliability information on electronic equipment to the sponsoring groups. Mention is made of some of the problems faced by the center, including completeness validation, and obsolescence of data. Parts identification and classification, computation of failure rates, and selection of parts from parameter ranges are also mentioned as problems. M.W.R.

Review: This is a short article which probably presents as good a description of the ECRC Data Center as can be provided in the available space. In general these brief descriptions are of little use to a non-user of systems since to the non-user all the systems tend to sound rather good. One who has used a data center can interpret what is written in terms of his own experiences and see where his needs would be better met and where not so well met. The description of some of the ECRC forms is probably incomplete. For example there appears to be no place on a Technical Memorandum for describing the calendar time of manufacture or purchase of any of the items tested. (In a private communication the author has stated that "Tech Memos include data from many reports and thus the information you suggest cannot be given.") It should be emphasized that none of the results are available to non-participants, i.e., they are available only to those who have provided financial support. No discussion is given of the cost of supporting this program nor whether it is open to new members. The author would probably be willing to provide such additional information.

R67-13057 ASQC 844; 612; 813

Autonetics, Anaheim, Calif.

STATISTICAL ANALYSIS OF ELECTRONIC PARTS RELIABILITY TEST DATA

J. L. Bekkedahl and F. R. Maiocco 8 Jun. 1964 50 p Presented at Conf. on Reliability of Semicond. Devices and Integrated Circuits, Jun. 1964

The data processing system and the statistical analysis methods and programs developed in connection with the Minuteman reliability improvement program are treated. Based on results from life testing of approximately 300,000 parts for extensive periods of time, the analysis used graphic presentations to show trends with time and stress for the various parts. Both failure and electrical parameter data were used to develop two statistical analysis systems. System I, developed to process unlimited amounts of test data, consists of programs to control the analysis, statistical programs to perform the analysis, and magnetic history file types with the data to be analyzed. System II has the same analytical capabilities as the first one, but is limited to 5500 bits of data at any one point in time. Input data are on cards or tape instead of the history files with specialized format. These systems as well as the other techniques developed are considered applicable to the majority of engineering test data collected in the electronic industry today. M.W.R.

Review: This paper accomplishes its purpose of presenting an approach to the analysis of electronic parts data. The author states that the analysis is complete, efficient, and flexible, but it is not possible to tell whether this is so from the description. The description is adequate to convey an idea of the outline of the program. Some specific examples are given which are quite helpful. The part of the analysis that enables one to look at the tails only of the distributions can be most helpful since in many situations the tails are not adequately represented by an assigned frequency distribution. Yet to a large extent they determine the failure behavior. This paper would be of little help to design engineers but could be of considerable value to those whose function it is to plan analyses of test data. It is well written and easy to read.

R67-13058 ASQC 844; 711; 714
Texas Instruments, Inc., Dallas. Semiconductor-Components Div.
CHEMISTRY AND PHYSICS OF RELIABILITY
S. S. Baird [1964] 31 p Presented at Conf. on Reliability of Semicond. Devices and Integrated Circuits, 18 Jun. 1964

Electrical behavior of semiconductors as a function of impurity content and temperature is discussed, and methods of distributing impurities within the device to meet design requirements are treated. Purification, crystal growth, and cutting procedures are mentioned; and various epitaxial techniques are considered. The process for fabricating an all-diffused oxide-stabilized transistor is detailed, including (1) relationship between deposition time and sheet resistance for a typical base process using boron, (2) selection of materials for contact design, and (3) bonding of wafers. Ball bonding, chisel bonding, welding, sonobonding, and pulse fusing techniques are considered; cleaning and washing procedures are discussed; and the effects of water, oxygen, and other surface contaminants are described. Stabilization of the atmosphere to which the device is exposed, dissipation of heat within the device, and protection of the device are considered the most important functions of the semiconductor package; and various classes of soft and hard glass packages, use of whiskers or metal plugs as second leads, encapsulating polymers, and ceramics are discussed. M.W.R.

Review: The first part of this paper deals with the physics of semiconductor devices. The second half deals with the behavior of devices as it is related to some of the processing steps and processing materials. The influence of the package is also considered. This paper is largely for the newcomer to the semiconductor field and could be of considerable value. Even though some of the material is several years old, it is still basically good. There is little concern in the paper with the measurement of lifetime of the devices; it is largely concerned with physics of failure.

R67-13061 ASQC 844; 770; 813
Radio Corp. of America, Camden, N. J. Communications Systems Div.
MICROMODULE LIFE TEST PROGRAM Final Report
F. E. Farmar Aug. 1966 64 p
(Contract DA-36-039-AMC-01462(E))
(AD-637675; N66-39645) CFSTI: HC $3.00/MF $0.75

Based on over 26 million micromodule hours, the observed MTTF for micromodules is approximately 300,000 hours with continuous operation +65 or 75°C. Handling of modules and the physical movement of the test setup during test had a dramatic effect on the reliability of the modules. There is a learning curve or familiarization period associated with new operators and test facilities. There was a positive or upward drift in center frequency of the analog modules. This coupled with the fact that Modules which are tunable should receive periodic center frequency adjustments. On the other hand, if modules are to be completely sealed, they should be tuned to a center frequency slightly below the specified center frequency to allow an upward frequency drift. The variable capacitor used with the DM-3 micromodule is inadequate to withstand the stresses imposed on it in this test. Inadequate mechanical strength may have been a contributing factor to many failures. Improved protection against mechanical stress should be provided. Environmental testing was not effective as a screen to eliminate potential failures. The reliability of the micromodules tested is probably a function of the amount of experience each vendor had accumulated prior to the production of material for this test. Reliability estimates for the Vendor A modules are probably most nearly representative of what one would achieve in the long run. Analog modules are more subject to degradation failures than digital modules. Author (TAB)

Review: This report on life testing of micromodules is especially interesting for two reasons: 1. The practical problems involved in running a life test appear to have had a drastic influence on the results; for example, the number of failures increased appreciably for new operators or when the facilities were moved. There was also the possibility of operator error and operator-caused failures during the insertion of the devices after testing. 2. After a long and extensive development and testing program, some reasonably good life test results have been obtained; that is, the MTBF for circuits is over one quarter million hours. But, the micromodule concept is now virtually obsolete. It has been replaced by various kinds of integrated circuitry. This shows the importance of drastically accelerated testing as a means of proving out a concept before something else comes along to replace it. The practical problems described in this report should be of interest to reliability engineers and to designers of tests (as well as to users who may want to learn how to quibble with test results).

R67-13063 ASQC 844; 711; 712
Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.
ABOUT HYSTERESIS ENERGY AS THE MAIN CRITERION OF DESTROYING METAL AT CYCLIC MONOAXIAL STRESS
G. S. Pisarenko and M. S. Mozharovs'kiy 23 Feb. 1966 7 p refs Transl. into ENGLISH from Dopovidi Akad. Nauk Ukr. RSR (Kiev), no. 7, 1964 p 893–896
(FTD-TT-65-1433; TT-66-62112; AD-637439; N66-39521) CFSTI: HC $1.00/MF $0.50

The basic regularities of thermal fatigue are discussed in this article. It can be asserted that the basic criterion of metal failure with cyclic thermal loading should be considered as the value of the specific irreversible absorbed energy, which simultaneously takes into account both the stresses and strains. Author (TAB)

Review: This is an unedited rough draft translation and certainly reads as such, as it is at times difficult to make sense of the arguments. The concern is with low-cycle thermal fatigue and the thesis is that failure will occur when the hysteresis energy has reached a certain value. It is not clear whether the increment of hysteresis energy remains constant from cycle to cycle or not. The idea perhaps has some merit in that certainly some of the hysteresis energy is going into the mechanism of fatigue damage. Anyone interested in this mechanism of failure or who is involved in physics of failure studies for reliability might be interested in trying to take some of the ideas in this paper and making something of them. By itself the paper is too difficult to read to be of much value otherwise.

85 DEMONSTRATION/MEASUREMENT

R67-13047 ASQC 851; 522; 541; 844
Hughes Aircraft Co., Fullerton, Calif. Ground Systems Group.
ACCELERATED RELIABILITY TEST METHODS FOR MECHANICAL AND ELECTROMECHANICAL PARTS Technical Report, Dec. 1963–Jan. 1965
William Yurkowsky and R. E. Schafer Jul. 1965 246 p refs
(Contract AF 30(602)-3268)
(RADC-TR-65-46; AD-621074; N66-10843)

This study is addressed to the development of accelerated reliability test methods for long lived mechanical and electromechanical parts. The parts studied were a subminiature snap-action switch, a crystal can relay, a mechanical seal, and a rubber timing belt. The failure times of all parts fit Weibull distributions. Failure analysis data is presented. Several mathematical models are presented as tentative representations of the failure laws operating under conditions of combined stresses. The merits of each are investigated in relation to the data generated during this study. Author (TAB)

Review: There is a good blending in this study of parts engineering, reliability modeling, and the engineering and statistical design of tests. It can be thought of as an attempt to develop a more solid foundation for terms and concepts which are widely bandied about. The tests on the four parts which were conducted are similar to those tests which parts engineers have traditionally performed for evaluating parts or for formally qualifying them to a specification (such as those reported in IDEP), except that the parts engineers do not typically bring in very much of reliability models and statistical design of experiments. Rather, they rely more on engineering judgment. The more or less positive results presented in this report are some general conclusions of the engineering judgment sort typically made by parts engineers. The results with respect to quantitative reliability acceleration models are somewhat inconclusive, with the old (and correct) story that more test data are needed in order to develop firm conclusions about all of the variables which thus far appear to be significant. Thus the frustrations set in. Two of the items tested were electromechanical parts, a snap-action switch and a crystal can relay. Now one of the likely results of the tests which have been conducted is that they will prompt and assist the manufacturer in making changes in the parts which hopefully will improve their reliability. Even without these particular test results, the manufacturers may be contemplating changes in material, design, assembly, or quality control. If additional testing is conducted, then a question which arises is the degree of similarity of the newly tested parts to the ones which were tested earlier. The same point is pertinent to other manufacturers who may supply devices which are functionally and physically interchangeable and which meet the same procurement specification as the type tested, but which are physically different beneath the surface. The report acknowledges this point without emphasizing it, and it will be interesting to see what the next phase of the study produces in response to it. In the final analysis, either thoughtful studies of the sort reported here must be conducted, or the reliability discipline must stop bandying about words which sound great but which lack technical basis. The fact remains that the areas of reliability models and statistical design of experiments have yet to become an accepted feature of the large amount of parts testing which is occurring. One thought which could assist in allevating the economic problems would be the utilization of more of the traditional parts testing efforts for making rigorous studies on reliability acceleration models as well as for conventional purposes, and vice versa. In this connection, this report seems amiss in not identifying more specifically the manufacturers and part description, as this detracts seriously from the value of the test results to parts engineers for conventional purposes. Otherwise, this report does a good job of describing the test procedures and reporting the test results. Regarding specific references to the names of the manufacturers whose parts were studied, the first author in a private communication has commented as follows. "This information was omitted at the request of the RADC Project Office because it was felt that the specific parts studied were merely vehicles used in the development of a test methodology and the specific results on those given part types were not one of the major objectives of the study. If there is interest in the part manufacturers' names these can be requested from:

Mr. D. W. Fulton
RADC Project Manager
EMERR
Rome Air Development Center
Griffiss Air Force Base, New York"

R67-13068 ASQC 851; 770; 782
Texas Instruments, Inc., Dallas.
COMBINED RANDOM VIBRATION AND EXTREME TEMPERATURE TESTING OF INTEGRATED CIRCUITS
James C. Burrus *In* NRL Shock and Vibration Bull., no. 35, pt. 2 Jan. 1966 p 197–202 (See N66-17786 08-32) CFSTI: HC$6.00/MF$1.50
(N66-17803)

In the never-ending quest to supply the most reliable semiconductor devices possible, a series of special, extreme-environmental programs have been established and conducted under controlled laboratory testing conditions. One of these programs involved an integrated circuit, or semiconductor network. This test represented our first attempt to perform random vibration under extreme temperatures on a device of recent design. Another requirement of the test was to detect any device discontinuity while undergoing vibration. The special nature of the test required several modifications, principally in existing facilities. A temperature chamber had to be modified for piggyback operation over an existing exciter. Simultaneously, the shaker had to be modified to allow full shaker capability with no thermal loss. Several methods were devised and tested before the required test specification were met. Since the device itself had to be operated during the test, it was necessary to design and fabricate a method for holding the device under these conditions. Check-out procedures were taken to assure that the device was properly vibrated.

Review: This short paper shows some of the difficulties involved in testing an integrated circuit at high vibration levels and low temperatures at the same time. As such, it will be of interest to test engineers and perhaps to design engineers who request such tests without realizing all of the consequences. The tests themselves are presumably quite useful in determining potential failure modes of the device under more realistic conditions of operation. An interesting sidelight is that most of the failures, experienced at high vibration and low temperatures, were intermittent and the cause was difficult to pinpoint. This kind of outcome is typical of many engineering endeavors and the author is to be commended for not trying to cover it up.

R67-13070 ASQC 851; 770; 782; 844
Frankford Arsenal, Philadelphia, Pa.
PHILOSOPHY OF ENVIRONMENTAL TESTING Final Report
David Askin Apr. 1966 36 p refs
(M66-21-1; AD-633577; N66-33815) CFSTI: HC $2.00/MF $0.50

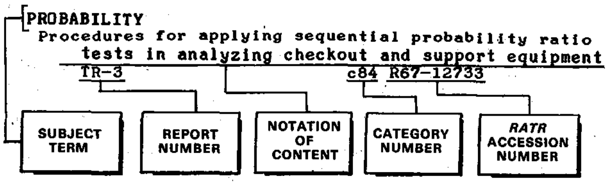
This report discusses the philosophy of environmental testing, gives definitions of the more commonly used terms, classifies the various types of environmental tests, describes some effects of environmental stresses on military equipment and briefly discusses the derivation of environmental criteria and test standards. Author (TAB)

Review: The great variety of environmental conditions which exist around the world are aptly highlighted in this short report. It is mainly word discussion with a general orientation. A portion of the report is devoted to tables which indicate for different types of items the failure modes which are caused by various environments and offers recommended remedies and design precautions therefor. These tables could serve as check-off lists in failure mode and effects studies. A moderately long bibliography is given.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7, NUMBER 3

Typical Subject Index Listing

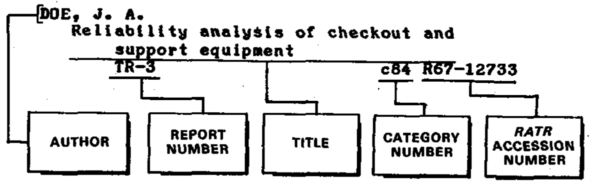


The Notation of Content, rather than the title, is used to provide a more exact description of the subject matter. The category number and *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

PERSONAL AUTHOR INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 3

Typical Personal Author Index Listing



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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 3

List of Report Numbers

This may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number preceded by the category number for locating the abstract-review in the abstract section of *RATR*. For purposes of this index, AD, N, and A numbers (accession numbers from *TAB, STAR,* and *IAA,* respectively) and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 3

List of *RATR* Accession Numbers

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NASA-Langley, 1967

Reliability Abstracts and Technical Reviews

APRIL 1967

Volume 7
Number 4

R67-13082—R67-13128

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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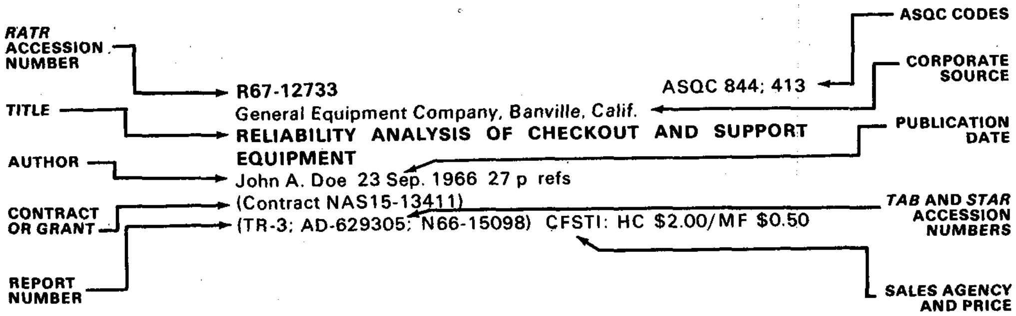
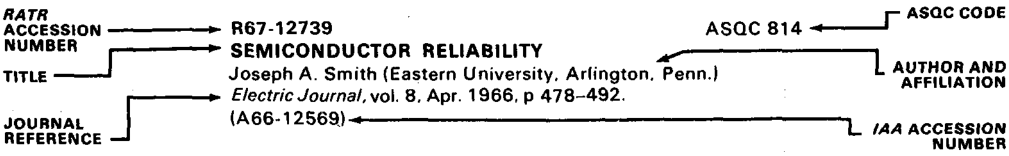
The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

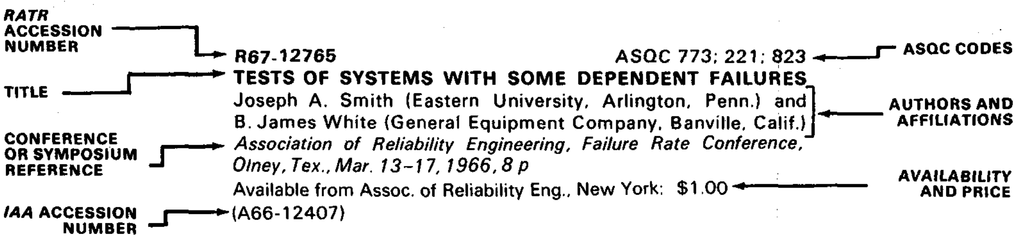
EXAMPLES OF CITATIONS IN *RATR*



R67-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N66-15098) CFSTI: HC $2.00/MF $0.50



R67-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478-492.
(A66-12569)



R67-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13-17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A66-12407)

VOLUME 7 NUMBER 4

Reliability Abstracts and Technical Reviews

A Monthly Publication
of the National Aeronautics and Space Administration

April 1967

80 RELIABILITY

R67-13125 ASQC 800
SAFETY AND RELIABILITY.
Hartley Soule
Astronautics and Aeronautics, vol. 4, Oct. 1966, p. 16, 19.

Differences in approaches to reliability by aircraft and rocketry personnel are considered; with emphasis on safety, which the aircraft industry considers as a contributor to safety rather than as an independent factor. On the other hand, safety during use has never been a factor in weaponry; the primary contribution of rocket-reliability developments is considered to be a systems approach during design. Such an approach is based on probability theory, and provides numerical procedures for arriving at an overall system reliability from the total number of components and the failure rates for individual components. It is concluded that such an approach might be of value to the aircraft industry in further improving aviation safety. M.W.R.

Review: This is a brief, well-written paper which describes the distinction between the objectives of safety in the aircraft industry and reliability in the missile industry. It is clear that assurance of one of these objectives does not automatically imply assurance of the other. However, for the success of manned space-flight programs, both are necessary. The author concludes by suggesting that those who are concerned with aircraft safety should learn everything that the rocket and space industires have to offer on reliability, and then apply the applicable knowledge to their work. The converse of this admonition is equally worth considering.

81 MANAGEMENT OF RELIABILITY FUNCTION

R67-13128 ASQC 802; 810; 830; 840; 870
General Dynamics/Astronautics, San Diego, Calif.
RELIABILITY AND MAINTAINABILITY TRAINING HANDBOOK
C. S. Winlund and C. S. Thomas 11 Dec. 1964 655 p refs
(NOBS-90331)
(NAVSHIPS-0900-002-3000; N67-81247)

A textbook for use in Bureau of Ships top management, intermediate level, and technician courses on reliability and maintainability is presented. Emphasis is placed on contract management and methods to design for required reliability; rather than to predict, control, and measure reliability. Cost effectiveness analysis approaches are presented in some detail; as are quantitative treatments to determine component reliability. Both a requirements and system definition are given; and chapters are devoted to probability, reliability prediction, apportionment, stress–strength analysis, maintainability, data acquisition, statistical techniques, and verification methods. Failure modes and effects analysis are considered, as are failure diagnosis, human factors, parts engineering, and various aspects of contractor and manufacturing operations. M.W.R.

Review: A Naval orientation with much material on predesign and design considerations characterizes this voluminous handbook. Little detail is presented on post-design considerations. This handbook is aimed at those without previous reliability experience. Reliability workers will want to go deeper than the level presented here, and references are cited at the end of each chapter. A tone of experience exists relative to the frustrations of attempting to implement the tasks and techniques which make up the contents. An attempt is made to show the practical limitations of each technique, so that the reader will not be led into false expectations. Generally there is good continuity throughout the handbook and a consistency in the style and level of presentation. Some exceptions exist, such as the re-introduction of material which has already been introduced and the inclusion of material in inappropriate chapters. For example: Most of the quantitative material presented prior to Chapter 10 is probabilistic (a priori), but a few statistical techniques have also been cited, such as using the "t" distribution for acceptance sampling in Chapter 8 and the Chi-square goodness-of-fit test in Chapter 9. Then comes Chapter 10, entitled "Statistical Techniques," which includes three sections on "statistical techniques" and one section on Boolean Algebra. This sort of organization can hinder the reader without prior familiarity with the topics and who is trying to get straight in his mind the very basic distinctions between deterministic, a prior probabilistic, and a posteriori statistical considerations. However, these organizational nuances are not really a serious problem. This handbook hangs together better than most reliability handbooks, where the discontinuity usually comes from many different authors being involved. At a cost of $5 from GPO this handbook is a bargain relative to other reliability handbooks available through private sources. Apparently reliability handbooks are now becoming as numerous as reliability specifications became some years ago.

R67-13122 ASQC 810; 230
RELIABILITY MANAGEMENT–A SURVEY.
Marv Freedberg (Arma/American Bosch Arma Corp., Garden City, New York).
Industrial Quality Control, vol. 23, Nov. 1966, p. 224–226.

Organization, responsibilities, training, activities, and current problems related to reliability management are covered by the results of questionnaire answered by 56 randomly selected electronics companies in the United States; replies were not received from 44 businesses who had also received the ten-question survey. Forty of the respondents said they had separate reliability and quality departments, with 16 companies employing less than 500 persons reporting that the two functions were combined into one department. All companies reported their reliability groups in operation more than two years, and 42 reported more than five years. Reliability managers generally report to top executives, with only 11 firms having their reliability managers report to second-level management. Large component-oriented businesses have reliability reporting to top operating executives more than do large systems-oriented businesses. Recommendations for improving the effectiveness of reliability programs are included in the areas of budgeting, specifications, management, and data collecting and reporting. M.W.R.

Review: This survey provides some insight into the organization, responsibilities, training, activities, and problems of reliability departments in the electronics industry in the U.S. Since it is based on a 56% response to questionnaires sent to a random sample of 100 comapnies, the author has not attempted to draw inferences, but has merely tabulated the results. Reliability managers may find it worthwhile to compare these tabulations with their own response to the questions.

R67-13124 ASQC 810
ZERO DEFECTS: IT PAYS.
William P. Wood (Martin Co., Reliability, Test, and Evaluation Div., Orlando, Fla.).
Mechanical Engineering, vol. 88, Nov. 1966, p. 45–47. 8 refs.

Individual responsibility is considered the most important factor in achieving zero defects (ZD) during the design of aircraft. A ZD program in production quality control resulted in a 54% reduction in manufactured hardware defect rates during the first year of its operation, an addition 25% the second year, and another 7% the third year. Since this program stressing individual responsibility was so successful on the production line, it was carried over to the concept and design stages. Reliability is considered inherent in the design, and the most effective reliability engineer is the designer who is responsible for his design throughout the life of the product. Designers are given reliability training, and the need for additional reliability engineers is eliminated. The engineers are easily won over to ZD programs when specific methodology is provided, and mention is made of ZD incentive awards and their total cost. Storage-mode failures and the price of defects are also discussed. M.W.R.

Review: The ideas in this paper merit the thoughtful consideration of anyone concerned with management of the reliability function in a hardware-producing organization. The main point is that the human factor is vital in designing and producing reliable products. Any program which promotes individual responsibility and personal integrity–whether it be called Zero Defects or something else—is based on recognition of this vital factor. Problems of implementation are subtle and involve much more than exhortations to do the job right. Some useful thoughts will be acquired from a reading of this paper.

82 MATHEMATICAL THEORY OF RELIABILITY

R67-13083 ASQC 821; 824
Naval Postgraduate School, Monterey, Calif.
CONDITIONAL DISTRIBUTION OF TRUE RELIABILITY AFTER CORRECTIVE ACTION
Harold J. Larson Jan. 1966 18 p ref
(TR-61; AD-629084; N66-22509) CFSTI: HC $3.00/MF $0.65
(TR-61; AD-629084; N66-22509)

Attempts are made to correct those failure modes that occur; the probabilities that these attempts are successful are assumed known. The conditional distribution of the resulting true reliability is derived and used to construct observable limits which will include the true reliability with a known probability. Author (TAB)

Review: The task of finding confidence intervals based on the conditional distribution referred to in the title of this report is an ambitious one. The author has actually accomplished it for the case in which the true failure probabilities are known. For the case in which the failure probabilities are unknown, the author has indicated a way of deriving lower bounds for a class of confidence statements. The report should serve as a stimulus to further work on this practical problem. (See also an earlier paper on estimating reliability after corrective action covered by R67-13091.)

R67-13086 ASQC 820
Authority Health and Safety Branch, United Kingdom Atomic Energy Authority, London (England).
RELIABILITY CONSIDERATIONS FOR AUTOMATIC PROTECTIVE SYSTEMS
A. E. Green and A. J. Bourne 1965 18 p refs
(AHSB(S)-R-91; N65-33270) CFSTI: HC $3.00/MF $0.65

Automatic protective systems are provided for nuclear reactors to initiate shut-down should certain specified reactor fault conditions arise. In the safety assessment of these systems, aspects of performance such as response, accuracy and efficacy are considered. However, a system analysis is never complete without giving consideration to reliability. The report discusses briefly the definition of reliability and indicates a method by which a reliability model for an automatic protective system may be derived on the basis of such a definition. Some applications of this simple model are described together with the corresponding limitations to its use. The general usefulness of the techniques is underlined in the context of the work of safety assessment. Author

Review: This is a very elementary simple introduction to some theory of probability in the mathematics of reliability. The exponential assumption is introduced and the idea of adding failure rates of components to get the failure rate of equipment is explained. Very little of it has to do with automatic protective systems per se. Generally speaking, at this introductory level, the explanations are satisfactory. Three problems, however, do exist. In one of the examples, operating vs. non-operating failure rates could profitably have been introduced. The word "random" is used to imply the constant failure rate portion of the bathtub curve; while this is very common practice, it is also very poor practice. Independence of failures is defined essentially as physical independence; the failures must be statistically independent, which is more far-reaching than physical independence.

R67-13091 ASQC 824

ESTIMATING RELIABILITY AFTER CORRECTIVE ACTION.

W. J. Corcoran (United Technology Corp., Sunnyvale, Calif.), H. Weingarten (Center for Naval Analysis, Washington, D. C.), and P. W. Zehna (Naval Postgraduate School, Monterey, Calif.).

Management Science, vol. 10, Jul. 1964, p. 786–795. 3 refs. (Contract NOW 61-0153-c)

A proposed model accounts for the corrective action that takes place during the improvement of reliability in the final development stage of an expensive component. Probabilities for correcting a number of failure modes are assumed to be known, and a multinomial sampling procedure is discussed. Mean reliability is then defined as a function of the unknown probabilities attached to the failure modes. Formulation of the model is detailed, as is the estimation problem. Properties are discussed for a number of estimators that are applicable to the model; and some degree of versatility is provided with regard to the various criteria that are usually adopted for point estimation. M.W.R.

Review: This is a mathematical paper addressed to an important practical problem in reliability estimation. Several estimators are presented for the mean reliability after corrective action has been taken. The questions as to which estimator is optimum and why are left open, although the properties of the estimators are discussed. The lack of distribution theory prevents the estimation of confidence intervals. (For an attack on the distribution theory problem see the report covered by R67-13083.)

R67-13092 ASQC 821; 844; 711; 712

THE ODDS AGAINST FRACTURE.

Ralph L. Barnett, James F. Costello, and Paul C. Herman (IIT Research Institute, Chicago, Ill.).

Machine Design, Nov. 10, 1966, p. 184–191. 4 refs.

Although ordinary stress analyses cannot predict performance of materials such as cermets, ceramics, and refractory metals because they are so brittle, statistical fracture theory can define their loading ability in terms of probability of failure. Relationships can be established between groups of specimens, and cumulative distribution curves can be used to test one group of samples and to predict the probable distribution of strengths of another group of the same material. Strength can be traded off against reliability, so that the permissible probability of failure becomes a design parameter that determines the allowable loads. Predictions based on scale models and on test specimens are discussed separately; and the substitution of cheaper test materials is considered. Design analysis is described, and the reliability of a circular plate is determined. Failure strengths of typical brittle tensile specimens are tabulated, and a failure-distribution curve and various parameter curves are graphed. M.W.R.

Review: The mathematics in this paper appears to be quite satisfactory, but the article as a whole gives an unwarranted feeling of precision and accuracy in calculating *absolute* failure probabilities for brittle structures. For example, the three-parameter Weibull distribution is introduced for the probability density function of strength as if there were no question of its adequacy over the entire probability range from zero to one. Furthermore, it is introduced in a particular form which implies the weak link concept of failure. Both these assumptions are inadequate especially in the region of very low failure probabilities and very high ratios of volume between the model-specimen and the full-scale structure. The equation given for non-axial stresses is quite unusual. Statistical independence seems to have been presumed among the principal stresses. The overall tone of the article is exemplified by the final sentence: "...Thus, in this example, the partitioning of the plate into five subvolumes produces a fairly accurate estimate of the overall reliability." It is certainly easy to infer from this that the calculation of reliability is quite accurate in an *absolute* sense, which of course is not so. The method if self-consistent and should give good answers insofar as the assumptions are true. The qualms are not about the arithmetic, but about the correspondence with the real materials.

R67-13093 ASQC 820

RELIABILITY CONSIDERATIONS FOR AUTOMATIC PROTECTIVE SYSTEMS.

A. E. Green and A. J. Bourne (Authority Health and Safety Branch, United Kingdom Atomic Energy Authority, London, England).

Reprint from *Nuclear Engineering,* Aug. 1965, 4 p. 12 refs.

A method is presented for the development of a mathematical reliability model for the automatic protective devices that are provided for the shut-down of nuclear reactors when faulty conditions arise. Reliability is emphasized from both the cost and maintenance point of view, as well as from safety considerations. Equipment failure rates are discussed, and average failure rates are tabulated for electronic components that are applicable to land-based nuclear installations. The assumptions used to formulate the proposed reliability tool are that failures are random and independent, there are no compensating failures, testing time is negligible, and repair of devices is perfect. Based on these assumptions and the average failure rates, predicted failure rates are tabulated for some equipment used in British nuclear installations. M.W.R.

Review: This is a publication based on the report covered by R67-13086. It presents the same information as in the report, but gives a better explanation of the expression "Failures are random."

R67-13094 ASQC 822

Washington Univ., Seattle. Lab. of Statistical Research.

A STOCHASTIC CHARACTERIZATION OF WEAR-OUT FOR COMPONENTS AND SYSTEMS

Z. W. Birnbaum, J. D. Esary, and A. W. Marshall (Boeing Co.)

25 Jan. 1966 26 p refs Also issued as DI-82-0460 by Boeing Co.

(Contract Nonr-477(38))

(TR-46; DI-82-0460; N66-25768)

It is well known that the future life distribution of a device *remains the same regardless of the time it was previously* in use, if and only if the life distribution of that device is exponential. For this reason exponential life distributions are accepted as characterizing the phenomenon of no-wear. The problem of finding a class of life distributions which would similarly reflect the phenomenon of wear-out has been under investigation for some time. In answer to this problem we introduce in this paper the class of IHRA (Increasing Hazard Rate Average) distributions and show that it has, among others, the following optimal properties: (i) it contains the limiting case of no-wear, i.e., all exponential distributions, (ii) whenever components which have IHRA life distributions are put together into a coherent system, this system again has an IHRA life distribution, i.e., a system wears out when its components wear out, and (iii) the IHRA class is the smallest class with properties (i) and (ii). Author

Review: This report gives an excellent derivation of a class of distributions (those with increasing hazard rate average—IHRA) which may be said to characterize "wear-out." By contrast with such distributions, the exponential characterizes the phenomenon of no-wear. The material is well motivated and high readable. Ten references to pertinent earlier work are given.

R67-13095 ASQC 824; 431

CHARACTERISTIC FUNCTIONS OF STOCHASTIC INTEGRALS AND RELIABILITY THEORY.

Gordon Antelman (Chicago University, Ill.) and I. Richard Savage (Florida State University, Tallahassee).
Naval Research Logistics Quarterly, vol. 12, Sep.–Dec. 1965, p. 199–222. 7 refs. Supported by Office of Naval Research. (AD-637546)

This paper concerns reliability theoretic problems involving systems of n components subject to stochastic hazard rates with independent increments. General methods are given for finding the probabilities of service at specified times and the joint characteristic function of the system failure time and the component hazard rates at the time of failure. TAB

Review: Even though the proofs given in this paper are only "formal" proofs, the paper is still highly mathematical and it is doubtful that most reliability engineers could make use of the results. As far as practitioners are concerned, more down-to-earth examples need to be given before the theory will be usable. The results are certainly of interest to the more mathematically-inclined reader and hopefully the practical applications will be exploited further in papers yet to come.

R67-13096 ASQC 822; 424

Boeing Scientific Research Labs., Seattle, Wash. Mathematical Research Lab.

A MULTIVARIATE EXPONENTIAL DISTRIBUTION

Albert W. Marshall and Ingram Olkin (Stanford Univ.) Mar. 1966 38 p refs *Its* Math. Note No. 450 Also issued as TR-23 by Stanford Univ. CFSTI: HC $3.00/MF $0.65 (D1-82-0505; AD-634335)

A number of multivariate exponential distributions are known, but they have not been obtained by methods that shed light on their applicability. This paper presents some meaningful derivations of a multivariate exponential distribution that serve to indicate conditions under which the distribution is appropriate. Two of these derivations are based on 'shock models', and one is based on the requirement that residual life is independent of age. It is significant that the derivations all lead to the same distribution. For this distribution, the moment generating function is obtained, comparison is made with the case of independence, the distribution of the minimum is discussed, and various other properties are investigated. A multivariate gamma distribution is obtained by convolution, and a multivariate Weibull distribution is obtained through a change of variables. Author (TAB)

Review: This report presents a very interesting new multivariate probability distribution with the property that all marginal distributions are of the negative exponential type whereas the random variables involved are *not* independent. The derivation of the distribution is motivated by reliability considerations which in turn can serve to indicate situations where the distribution is appropriate. The material is presented quite clearly with the bivariate case being given first for ease in exposition.

R67-13097 ASQC 840; 824; 860

Army Electronics Labs., Fort Monmouth, N. J.

TECHNIQUE USED IN DETERMINING FIELD OPERATIONAL RELIABILITY

Joseph W. D'Oria May 1966 18 p ref
(ECOM-2709; AD-634385; N66-34173) CFSTI: HC $3.00/ MF $0.65

The report depicts several of the problems involved in conducting an investigation to determine the operational reliability of an Army radio set utilized under actual field conditions. A reporting form was distributed to the troops prior to the exercise commencement. The form was designed to require little time for its completion and yet yield sufficient information for meaningful analysis. Three different monitoring techniques were studied to determine which would provide the most accurate and informative data with the manpower and facilities available. The technique employed was to visit each operating site twice daily, checking the reporting form against the operator's daily log; in the event of a system failure occurrence, interview both the operator and maintenance man, recording all data pertinent to the failure. Due to the lack of manpower, accurate maintenance information could not be obtained after failed equipment was sent from the operating site. Analysis of the data revealed the presence of a bias. The equipment had been used regularly at least several months prior to the exercise commencement; however, approximately thirty percent of the failures occurred in the first 420 hours. Potential causes of this bias are discussed in the body of the report. Author (TAB)

Review: This paper again illustrates the well-known problems of getting adequate field reporting for reliability analysis. It is a subject for which the "ideal solution" is often presented. The large effect of operators on reliability shows that the concept of "inherent" reliability is not useful, and in fact may be detrimental. More care needs to be taken in the specification phase to be realistic about the amount of training the operators will receive. The design can then be modified (easier said than done) to account for "poor" operators. Even though there are recommendations for planning the next test better, the world probably will pay little attention to them. Somewhere, somehow, the systems people need to learn how to include these mundane, gross problems of reliability and reliability assessment in their overall conceptual models.

R67-13098 ASQC 824

Aberdeen Proving Ground, Md.

RELIABILITY ESTIMATION FOR MULTI-COMPONENT SYSTEMS

James R. Kniss Jan. 1966 21 p refs Presented to the 9th Conf. on Design of Expt. at Redstone Arsenal, Ala.
(BRL-MR-1727; AD-633163; N66-30662) CFSTI: HC $3.00/MF$0.65

A system for obtaining point estimates and confidence interval estimates for very complex multi-component systems has been developed. This method was developed specifically to be used to estimate reliabilities of nuclear warheads where the redundancy of circuits and components complicate normal procedures of reliability estimation. However, the system is highly adaptable to any similar situation where access to high speed electronic computers is available. Author (TAB)

Review: This report is directed to the practical reliability worker. However the discussion is not clear, and it is doubtful that the ideas can be used in their present form by others. Judging by the numerical results, the technique seems to work rather well and it is hoped that a better explanation of the method will be forthcoming.

R67-13101 ASQC 824; 412
RAND Corp., Santa Monica, Calif.

MAXIMUM LIKELIHOOD ESTIMATION AND CONSERVATIVE CONFIDENCE INTERVAL PROCEDURES IN RELIABILITY GROWTH AND DEBUGGING PROBLEMS

Richard E. Barlow, Frank Proschan, and Ernest M. Scheuer Jan. 1966 51 p refs
(Contract NASr-21(11))
(NASA-CR-70633; RM-4749-NASA; N66-18323) CFSTI: HC$3.00/MF$0.65

This study examines two problems. The first deals with estimating the reliability of a system that is undergoing developmental testing for the purpose of increasing its probability of successful operation, or increasing its time-to-failure, or decreasing its failure rate. Three models of reliability growth are formulated, and appropriate maximum likelihood estimates and conservative confidence bound procedures are derived for them. The second problem treated here deals with the "debugging" of a new complex system during the initial period of its total life. During this period failures and errors are corrected as they occur, with resulting improvement in subsequent performance of the system. Maximum likelihood estimates are obtained for relevant failure rate functions and for the end of the debugging period. A conservative upper confidence bound on the stable failure rate is obtained. Author

Review: This report has been written in such a way that it may be used by two different classes of readers. The mathematical details may be omitted by those interested primarily in the numerical procedures which are given in a separate somewhat self-contained section. The overall presentation is excellent with all assumptions and limitations being carefully pointed out.

R67-13103 ASQC 824
Naval Postgraduate School, Monterey, Calif.

ESTIMATING MEAN RELIABILITY GROWTH Progress Report, Jun.–Dec. 1965

Peter W. Zehna Jan. 1966 27 p refs
(TR-60; AD-629381; N66-22515) CFSTI: HC $3.00/MF $0.65

A model is defined wherein corrective action may be accounted for in improving the estimation of reliability over the usual nominal success ratio. Probabilities for correcting any one of K failure modes which may arise are assumed known within the structure of a multinomial sampling procedure. Mean reliability is defined as a function of the unknown probabilities attached to the failure modes, the problem being to estimate this mean. Other measures of current reliability are defined. Three different estimators of mean reliability are defined and analyzed from the point of view of unbiasedness. Explicit expressions for the bias are derived and compared numerically for a wide variety of choices for the unknown parameters. Several problem areas for further research are identified and partial formulations of some of these are discussed. Author (TAB)

Review: This report will be quite accessible to most reliability engineers. Several different measures of reliability, after attempts to eliminate failure modes have been carried out, are discussed. Maximum likelihood estimation procedures are developed and the bias of the estimates are obtained numerically in several cases. Probably the greatest drawback of the method is the assumed knowledge of the probability of removing the i-th failure mode given that corrective action is taken. The report closes with some remarks on topics for further study.

R67-13107 ASQC 824; 711; 712; 844
Ohio State Univ., Research Foundation, Columbus.

LIFE ESTIMATE OF FATIGUE SENSITIVE STRUCTURES Technical Documentary Report, Jul. 1, 1963–Jul. 31, 1964

A. M. Freudenthal Wright-Patterson AFB, Ohio, AF Mater. Lab., Sep. 1964 13 p refs
(Contract AF 33(657)-8741)
(ML-TOR-64-300; AD-608073; N65-11965)

By defining fatigue failure as an "ultimate load failure" of a structure damaged in fatigue by operational loads, the estimate of fatigue life can be reduced to that of a "mean return period" of an ultimate load type of failure for which statistical methods of safety analysis have already been developed. By applying such methods in conjunction with a simple fatigue damage function, the fatigue sensitivity of a structure can be evaluated in terms of the ratio of the return periods of fatigue failure and ultimate load failure. Author

Review: The work in this document appears to be accurate and more in the nature of defining fruitful concepts than in producing startling results. As such the report would be of more value to those engineers who are engaged in research than to those who are working on a specific design. The many misprints, some extremely long sentences, some incomplete sentences, and the poorly-defined unfamiliar notation, all make the report rather difficult to read.

R67-13111 ASQC 824
Joint Publications Research Service, Washington, D. C.

APPLICATION OF THE COINCIDENCE METHOD TO ANALYSIS OF RELIABILITY OF TECHNICAL SYSTEMS WHICH OPERATE IN THE STATIONARY CONDITION

N. M. Sedyakin *In its* News of the Acad. of Sci. USSR 9 Jul. 1965 p 10–24 refs (See N65-27975 17-34) CFSTI: $3.00
(N65-27977)

A method is proposed for analysis of reliability of technical systems based on the mathematical apparatus of the theory of coincidence of pulses from a series of sources. Some relationships are found which characterize the reliability of the system for the case of stationary condition of its operation. Author

Review: This Russian translation is a highly mathematical paper which relates the theory of reliability of physical systems to the theory of coincidence of pulses from a number of pulse sources. Although the viewpoint on system reliability given here is an interesting one, the reliability results are not new. According to the author, the reference on the theory of coincidence of pulses, on which this paper is based, presents a more general theory applicable to reliability. This reference is: N. M. Sedyakin, "On the Theory of Coincidence of Pulses of Dependent Flows," *News of the Academy of Sciences USSR, Technical Cybernetics,* No. 4, 1963. Reliability engineers who have access to this reference may find results of value there.

R67-13115 ASQC 821
Joint Publications Research Service, Washington, D. C.

THE DETERMINATION OF PROBABILITY AND RELIABILITY OF OPERATION OF A SYSTEM DURING A GIVEN TIME INTERVAL

V. S. Zaritskiy *In its* News of the Acad. of Sci. USSR Dept. of Tech. Sci. Tech. Cybernetics no. 1, 1966 6 Jun. 1966 p 72–78 refs (See N66-28428 16-10) CFSTI: $3.00
(N66-28435)

The problem of determination of probability that the random function u(t), the correlation function of which during the time T does not go beyond the limits which provide for normal operation of the system, is investigated. The formulae, graphs and tables are presented with the help of which it is possible to obtain an approximate solution of this problem without awkward calculations. Author

Review: This paper provides a theoretical treatment of the determination of the probability that a random function u(t), with specified correlation function, does not cross certain limits. An expression is provided for the desired probability for a random starting point u_0, having a normal distribution. It will not be very easy for readers to follow the mathematical derivation because referenced papers are in Russian journals. However, similar and more extensive problems are treated in [1] and [2].

References: [1] Leadbetter, M. R., and Cryer, J. D., On the Mean Number of Curve Crossings by Non-stationary Normal Processes, *Annals of Mathematical Statistics,* vol. 36, Apr. 65, p. 509–516. [2] Leadbetter, M. R., On Crossings of Arbitrary Curves by Certain Gaussian Processes, *Proceedings of the American Mathematical Society,* vol. 16, Feb. 65, p 60–68.

R67-13116 ASQC 821
Joint Publications Research Service, Washington, D. C.

ON THE RELIABILITY OF LOGICAL CONTROL SYSTEMS OF THE CYCLICAL TYPE WITH PERIODIC CONTROL OF STATE OF REPAIR

A. M. Gurevich *In its* News of the Acad. of Sci. USSR Dept. of Tech. Sci. Tech. Cybernetics no. 1, 1966 6 Jun. 1966 p 79–89 refs (See N66-28428 16-10) CFSTI: $3.00
(N66-28436)

The reliability of cyclical logical control systems with a limited number of operating states is investigated. Formulae are presented for the upper and lower values of the probability of breakdown free operation of the system. Author

Review: This paper gives a theoretical treatment of the reliability of logical control systems with repair. The assumptions made are clearly stated. They include the typical ones of complete statistical independence and exponential failure-time distribution. The paper should be of interest to reliability mathematicians and the results might be helpful to the designer of control systems. However, the results for the monitored systems would not appear to be useful for real-world situations due to the restrictive assumptions. The translation seems to be good although some of the terminology is differenct from that ordinarily used in the reliability literature.

R67-13117 ASQC 821; 872

DERIVATION OF THE TIME DEPENDENT PROBABILITY THAT A SUBSET OF IDENTICAL UNITS IS OPERATIONAL.

E. G. Enns (Northern Electric Research and Development Labs., Ottawa, Canada).
Proceedings of the IEEE, vol. 54, p. 986–987.

The time dependent probability is derived for a system containing *N* identical units with at least *N* identical repair facilities, and whose failure and repair probability density functions are exponential. The probability of a failure of an operating unit or the repair of a failed unit is, therefore, constant within each small time interval. The probability is reduced to a simple binomial form where all units are initially operating, or all units are initially under repair, or the system itself is in a stationary state. M.W.R.

Review: The results given in this paper are indicative of the kind of closed form solution to the problem of system reliability with repair that may be obtained when the system parameters are sufficiently restricted. In the principal result given–equation (7) in the paper–the last factor in the equation is a binomial coefficient using noninteger arguments. This notation is not standard and will confuse most engineers. This notation is not standard and will confuse most engineers. A definition (probably in terms of the Gamma functions usually used) or a reference would have been most helpful. One restriction specified in this paper is that there be at least as many repair facilities as operating units. This restriction may well not be met in practice. For a treatment of reliability with repair, using a less restrictive number of repair facilities, see R64-11482.

R67-13118 ASQC 824; 412
Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.

ON THE DETERMINATION OF A SAFE LIFE FOR CLASSES OF DISTRIBUTIONS CLASSIFIED BY FAILURE RATE

Sam C. Saunders Jun. 1966 29 p refs *Its* Math. Note No. 469
(D1-82-0540; AD-640136)

Using a lower tolerance bound as the derated life provides a guaranteed service period with the confidence level as a measure of safety in situations where mass production is contemplated. However, when only a limited number of items are to be produced, the probability of no failures among the fleet of specified size provides a better measure of assurance. Assuming that the life distribution is one of a specified set of subclasses of those distributions which have increasing failure rates we find those derating functions which can be used to provide lower tolerance bounds of given confidence, or a safe service life with specified fleet assurance. A method of finding such derating functions is exhibited and the calculation of a lower bound for the probability of no failure in the fleet is carried out when such derating functions are used. The confidence in the tolerance bound and the assurance of no fleet failure are compared when using bounds obtained from these derating functions. Author (TAB)

Review: This is largely a theoretical paper. Not all the mathematics was checked, but it appears to be of high quality. Reliability and design engineers are not likely to get much from the paper unless they are very mathematically inclined. There are a few examples, but they will not be meaningful to engineers. It definitely seems as if the work contained here would be worth popularizing, so that it could be readily used.

R67-13126 ASQC 824
RELIABILITY ESTIMATES IN THE EXPONENTIAL CASE.
E. G. Enns (Northern Electric Company, Ltd., Ottawa, Ontario, Canada).
Operations Research, vol. 14, Sep.–Oct. 1965, p. 945–946.
1 ref.

The best reliability estimate from a finite sample of time intervals taken from an exponential distribution is derived by dividing an interval of fixed length in a random fashion, and considering the result as subinterval statistics. In the analogy used, choosing the points at random becomes equivalent to choosing the interval lengths from an exponential density.
M.W.R.

Review: This brief mathematical note provides an alternative way of obtaining the result given in the paper covered by R63-11103. It rests on an analogy between choosing a finite sample of time intervals from an exponential distribution and choosing points at random over an interval (O,L). The assertion that "the length of each interval is distributed according to the probability density $f_n(t)$" is not formally established, but the results given are correct, and brevity is to be expected in a "letter-to-the-editor" type of paper. While the result is not new, the approach is novel and may well be of interest to theorists.

83 DESIGN

R67-13099 ASQC 838
William (Clyde) and Co., Columbus, Ohio.
RELIABILITY AND REDUNDANT CIRCUITRY
P. R. Dennis and Sundarum Seshu Washington, NASA, Oct. 1964 34 p refs
(Contract NASw-778)
(NASA-CR-128; N64-32832) CFSTI: $3.00

Within the complex field of reliability, there are many technical disciplines which are large and complicated efforts in themselves. These subfields of reliability encompass virtually all technologies and touch every phase of product development from the initial design concept through final product production and ultimate product use. This report "Reliability and Redundant Circuitry" is concerned with only one area within the overall field of reliability, viz., the use of redundancy techniques to improve the reliability of systems. One way to make a system more reliable is to improve the reliability of each of its parts. Unfortunately, in many cases product reliability has been pushed so close to its limits that further improvement may be uneconomical or even impossible. In cases of this type, it may be found necessary to design the system so that it functions properly even when some of its parts fail. To overcome malfunctions caused by failed parts, redundant (or extra) parts must be used in the system–parts which would be quite unnecessary if no failures ever occurred. Many interesting and complex theories have been built up around the basic redundancy concept. Some of these theories have direct practical application–some, as yet, do not. The report is not a "textbook" on redundancy theory and applications, but rather pulls together diverse work in the field of redundancy involving both NASA and non-NASA contributions to indicate the state-of-the-art. The references used in the report and listed in its bibliography comprise an excellent cross section of work accomplished in the field of redundancy. They include both report and open literature for the 10-year period 1954–63. Individual references are discussed, their unique contributions are noted, and some comments are made on the validity and practical aspects of the individual works. The report also delineates various types of redundancy and the applications of each type. Author

Review: This is a useful supplement for those who are concerned about reliability and have a working knowledge of redundancy. While the report can be helpful, it should be read carefully. Some of its difficulties are as follows. (1) "Random" is used to imply a Poisson (exponential) distribution. While it is commonplace to do this, it is poor practice. (2) The curves which compare the reliability for redundancy vs. no redundancy cross. For most kinds of reliability, the redundant equipment will always have a higher reliability, regardless of mission length. (This is especially true of parallel redundancy in the usual simple analysis.) (3) Some redundancy methods are asserted to be useful only if the malfunction is intermittent. The need for the restriction is not apparent in many cases. (4) On pp. 12–13 it is asserted and "proved" that one kind of switched redundancy is poorer than none at all. If the switching is assumed to be perfect (as in the text) the two systems should have exactly the same reliability if the exponential assumption is made (as in the text). An important point only very briefly touched upon is that virtually all such analyses assume statistical independence of failures and that this is more restrictive than physical independence. For example, if the environmental profile is uncertain, there can be no statistical independence.

R67-13110 ASQC 838
Joint Publications Research Service, Washington, D. C.
PRACTICAL ALGORITHMS OF SEARCHING FOR OPTIMUM REDUNDANCY
B. T. Belov, V. A. Ovchinnikov, and L. V. Surkov *In its* 22nd All-Union Sci. Session Devoted to Radio Day. Sect. on Electron. Computer Tech. 3 Aug. 1966 p 59–66 (See N66-34328 20-08) CFSTI: $3.00
(N66-34339)

Optimum redundancy is discussed in terms of increasing the reliability of digital computers. The three methods described for solving the problem of obtaining optimum redundancy are: (1) arbitrary extremum, (2) linear programming, and (3) steepest descent. It is noted that a program for solving the optimum redundancy problem was developed for the Minsk-2 computer, and block diagrams illustrate the routines for solutions by methods (1) and (3). Further development of the program may be carried out by compiling subroutines for calculating failure-free redundant sections for the various redundancy methods, as well as compiling ordered search routines for the subroutines. It is stated that the method of steepest descent has the advantage of producing multiples of redundancy in complex form. M.W.R.

Review: This is a quick summary of the following three methods for optimizing the number of parallel redundant elements for each part of a series system: (1) finding an extremum with conditions–by Lagrange multipliers, (2) linear programming, (3) steepest ascent. These are all covered well in the American literature; thus there is no point in trying to wade through the poor copy and unfamiliar notation.

R67-13112 ASQC 838; 431
Joint Publications Research Service, Washington, D. C.
ON THE PROBLEM OF RELIABILITY OF TECHNICAL SYSTEMS WITH REGULARLY RENEWABLE RESERVE
A. L. Paykin, A. F. Rubtsov, and V. S. Penin *In its* Tech. Cybernetics, No. 4, 1964 10 Nov. 1964 p 14–21 refs
(See N65-10754 01-19) CFSTI: $3.00
(N65-10756)

A reserve system over equal intervals τ, which comes to the stage of technical service where the faulty blocks in a negligibly small time are replaced by reserve blocks, is investigated. A procedure is given for the determination of reliability of this system at the end of an arbitrary interval of time (0,t) under the condition of a finite number of n reserve blocks. Author

Review: This report is concerned with redundancy, in the special case wherein there are a fixed total number of elements available; certain of them are carried along on each mission. Only one of them is required for satisfactory operation during the mission; the spares are provided in case of failure. A constant hazard function is presumed for the elements but it is different during operation than non-operation. It is not feasible to check all of the mathematics since many of the equations are virtually non-readable. (This is due to the reduction in size and lack of resolution in the reproduction process. The value of reproducing reports in this manner is highly questionable). From the equations that can be checked it appears that the algebra is good and that the model is probably analyzed correctly. Two graphs are also included; they are not impossible to interpret, only difficult. Similar results are probably available in the literature in this country since the analysis appears to be a straight-forward application of Markov chains.

R67-13121 ASQC 831; 838; 844
THE EFFECT OF ACTIVE FAILURES ON RELIABILITY.
Raymond Goldstein (Litton Systems, Inc., Guidance and Control Systems Div., Woodland Hills, Calif.).
The Electronic Engineer, Oct. 1966, p. 50–53.

Unscheduled active failures can create operational problems so serious that it is safer to stop operations rather than to risk the consequences of a maximum output failure, defined as the abrupt cessation of system operation passively in a "zero output" sense. Minimizing active failure modes is discussed, and the addition of redundant components or paths is considered. Examples of synchronous switches are used to show that circuits most prone to active failure have the following deficiencies: (1) critically balanced components, (2) high level excitation voltage that is component-balance dependent to achieve a low output null, and (3) tight effective coupling between excitation source and signal path. It is noted that a failure in a signal limiter may not be recognized until the limit is exceeded, since its attenuation is constant up to the limit level. A method for testing for active failure ratio index is presented, and parameters of system design are mentioned. M.W.R.

Review: The thesis of this paper is that good circuit design must take into account potential active failure modes and their effects in producing spurious system output. It is clearly and concisely presented and well illustrated. Designers of electronic circuits should find it to be worthwhile reading.

84 METHODS OF RELIABILITY ANALYSIS

R67-13082 ASQC 844
Battelle Memorial Inst., Columbus, Ohio.
PREINDICATIONS OF FAILURE IN ELECTRONIC COMPONENTS
J. W. Klapheke, B. C. Spradlin, and J. L. Easterday Redstone Arsenal, Ala., Redstone Sci. Inform. Center, 31 Jul. 1965 56 p refs
(Contract DA-01-021-AMC-11706(Z))
(RSIC-445; AD-472738; N66-23146)

This report discusses state-of-the-art information and techniques concerned with indications of potential degradation and catastrophic failure in electronic components. The objective of this survey is to present a comprehensive description of past, present, and future planned work on preindicators of failure for certain electronic components. This study is intended to provide basic information for future development in automatic checkout equipment. The following electronic parts were covered in the survey: semiconductors (transistors, diodes, and microcircuits), resistors, capacitors, inductors, computer cores, other items used in a computer, and vacuum tubes. Such items as wire, insulation, lamps, relays, and rotary devices were not considered. Precursors of failure have been investigated for electronic components but few have been identified at the present time. Most of these investigations were undertaken as part of programs directed at physics of failure, screening, or accelerated testing. The results of this study show that predictors of failure for semiconductors (transistors, diodes, and microcircuits) have received more attention than other types of parts. Current noise (l/f noise) and infrared emission profiles show promise as precursors that would apply to all types of semiconductors. Apparently computer cores and inductors are the least considered. Author (TAB)

Review: This is a comprehensive and clearly-presented report which will be of value to those interested in automatic checkout as a means of enhancing the reliability of electronic equipment. It has relevance also to the related areas of screening and physics of failure. In addition to providing state-of-the-art information, it gives some indication of planned future work and needed research. A total of 93 references are given; many of these will provide more detail on specific points.

R67-13084 ASQC 844; 851
Curtiss-Wright Corp., Caldwell, N. J. Curtiss Div.
RESEARCH ON ACCELERATED RELIABILITY TESTING METHODS APPLICABLE TO NON-ELECTRONIC COMPONENTS OF FLIGHT CONTROL SYSTEMS Final Report, May 1, 1963–May 1, 1964
W. F. Johnson, Jr. *et al* *Wright-Patterson* AFB, Ohio, AF Flight Dyn. Lab., Mar. 1965 199 p refs
(Contract AF 33(657)-11080)
(AFFDL-TR-64-181; AD-617567; N65-30137)

This study is concerned with the development of techniques for the testing of electromechanical components in time compressed form. The motivating basis for this work is that presently used statistical testing methods require large numbers of samples and long testing periods to compile meaningful MTBF data. The approach employed herein included: system failure mode analysis; classification and ranking of failure modes in terms of influence and frequency of occurrence; and physics of failure analysis at part and material levels. "Measured weakening" (pre-cracking) technique was developed and applied to the most predominant failure parts to generate failures in reasonably short test times. In addition, extraneous or unwanted failures were not produced, which is frequently the case when "over load" testing is employed. An all mechanical position servo unit was selected as a typical energy conversion flight control system component on which tests were conducted to verify the developed techniques for accelerating reliability testing. The tests results indicated that "measured weakening" of mechanical parts can be employed to reduce the number of samples required and the test time involved to perform reliability testing. Author

Review: This is a detailed report on testing a particular mechanical device namely the nozzle-actuation system power unit for the after-burner exhaust-nozzle of a jet engine. Thus the report is much more limited than the title suggests. The report is quite intensive—it includes a discussion of the problems encountered, even those which were not solved. The testing methods which were developed are described along with their application to the mechanical device. The application of these principles is very specific; a knowledge of the unit and its function, a knowledge of the language involved in talking about it are all necessary to really understand the report. It is doubtful that the principles enunciated here could be extended to other mechanical units with much saving of time over the original project. The authors have included tips on what to do and what not to do and the order in which they should and should not be done; these are most helpful. The largely chronological nature of the description makes it rather difficult to extract the knowledge which can be applied to other projects. It should be noted especially by electronics engineers who may not be familiar with the technique that the accelerated nature of the test is by compression of time rather than by increased stresses. The compression of time is accomplished by eliminating non-damaging portions of an operating cycle and by eliminating the time required to produce an initial predicted amount of damage. This is not generally the case in electronics accelerated testing. Two comments, certainly not inclusive of the problems but typical of difficulties that might be encountered in reading the report are the following. (1) It is not clear why the probability of system failure given part failure does not include the factor C.I. which accounts for the number of ways in which a part appears in logic diagrams for system failure. Offhand one would suspect that this is included implicitly in the probability of system failure given part failure. (2) The items are ranked for criticalness with respect to their effect on mission success. It is easy to infer that one should start to correct these items from the worst on down. For a fixed amount of resources, it is possible that one should allocate the resources in such a manner that the biggest improvement in reliability is achieved by them, rather than necessarily attacking the most critical item first. This naturally involves an estimate of the amount of resources necessary to make each reliability improvement. All in all this is a good report. Reliability engineers can learn from it but they will have to study it—not just read it, and they will have to be familiar with the mechanical system in this particular application.

R67-13085 ASQC 844; 711; 712
National Aeronautics and Space Administration. Langley Research Center, Langley Station, Va.

A COMPARISON OF FRACTURE MECHANICS AND NOTCH ANALYSIS

Paul Kuhn [1965] 18 p refs Presented at the Am. Soc. for Testing and Mater., Spec. Comm. on Fracture Testing, Washington, 13 Jan. 1965
(NASA-TM-X-56206; N66-22254) CFSTI: HC$3.00/MF$0.65

This paper presents a general comparison of fracture mechanics and notch analysis with respect to fundamentals and to scope. This is followed by a more detailed comparison using test results. The study showed a notable difference in scope for the two methods. The variation of the notch toughness constant K_c with specimen dimensions was serious, since this variation amounts to a factor of about three precisely for those aluminum alloys which are in greatest need of having their notch toughness well defined and controlled. Since the variation is due to the use of the Griffith proposition, a reappraisal of this proposition appears to be in order for any material which is expected to develop more than about one-tenth of its tensile strength.

Review: A knowledge of the ways in which metals are considered to fail is important for the analysis of aerospace structures. In some cases there are several ways of treating a type of failure. This paper deals with two such methods. It is a well-prepared discussion and comparison of phenomena (fundamentals and scope) and test results for fracture mechanics vs. notch analysis. Notch analysis is confined to applications and static strength problems related to sheet-metal parts; therefore, engineers working in these general areas of fracture analysis should be familiar with the contents of this paper for an insight into each technique. The bibliography of appended references can assist the reader in obtaining more complete information regarding the pros and cons of fracture mechanics and notch analysis. The author makes a strong point of the fact that materials are frequently compared on the basis of notch toughness constants, which are strongly dependent upon specimen dimensions. (An error in symbols—Fig. 4—was detected, but it does not detract from the paper.)

R67-13087 ASQC 844; 711; 712; 715

THE STRESS–CORROSION CRACKING OF METALS.

Hugh L. Logan (National Bureau of Standards, Washington, D. C.).
(National Metals/Materials Congress, Philadelphia, Pa., Oct. 21, 1964, Paper.) Metals Engineering Quarterly, vol. 5, May, 1965, p. 68 refs.

Intercrystalline cracking, discontinuous crack propagation, and the relation of cracking to crystallographic structures are discussed in terms of stress corrosion phenomena in metals. Environments for various alloy systems in which stress corrosion cracking most frequently occurs are listed. Transcrystalline cracking is considered, along with the effects of plastic deformation and chemisorption of corrodents. It is postulated that specific corrodents form protective films on the surfaces of alloys, as well as reduce energy to form new surfaces at the crack tip. Small anodes are formed at grain boundaries or faces that either rupture the protective film and/or produce a heterogeneous condition in the grain boundary or face. The unstrained material forms a large cathode, and cracking proceeds by an electrochemical process until the stress causes fracture. Means of mitigating stress corrosion are briefly mentioned, including removal of residual stresses, changing the environment and designs, and using protective coatings. M.W.R.

Review: Stress–corrosion of metals is not a well-known failure mechanism among non-metallurgists. It is, nevertheless, quite important; and this paper is a well-referenced review of the published literature on stress-corrosion cracking. The mechanisms and causes of stress-corrosion failure are discussed with a minimum use of unfamiliar language, but yet in an authoritative manner. Means for mitigating the effects of stress-corrosion cracking are included so that the paper can be especially useful for design engineers. The paper is directly oriented toward the research engineer, but experienced designers will find that a study of it can be most helpful.

R67-13088 ASQC 844; 711; 714

STRESS CORROSION–CAUSES AND CURES.

Henry Suss (General Electric Co., Philadelphia, Pa.).

Materials in Design Engineering, Apr. 1965, p. 102–105, 146, 148.

Environments that can produce stress corrosion in common alloys and means of eliminating stress corrosion are considered. It is noted that stress corrosion occurs under the combined influence of a susceptible material, a specific environment, tensile stress, and time of exposure; and if one of these factors is eliminated, stress corrosion is eliminated. Since change in material or design modification may be difficult to accomplish, threshold values can be established below which a material is not susceptible to stress corrosion failure in a certain period by (1) determining safe limits on chloride content in bulk water in contact with the stressed metal or (2) by operating the equipment so that the applied stress will be less than the safe limit. The following, however, are considered more practical: (1) use alternate corrosion resistant materials, (2) design parts to eliminate or minimize factors that produce stress corrosion, (3) eliminate applied or residual surface tensile stresses, or (4) protect the surface by use of protective layers or inhibitors. M.W.R.

Review: Stress corrosion is an important failure mechanism in mechanical parts, but it is not readily recognized by mechanical engineers; therefore, it needs to be emphasized. This paper is directed toward the practical engineering aspects of stress-corrosion failure rather than toward the physics of failure and failure mechanism approach. In general, the paper is recommended as background and introductory reading for design engineers. It is well written and easy to read.

R67-13089 ASQC 844; 711; 714

STRESS-CORROSION FAILURE.

Peter R. Swann (United States Steel Corp., Edgar C. Bain Laboratory for Fundamental Research, Monroeville, Pa.)

Scientific American, vol. 214, Feb. 1966, p. 72–81.

(A66-19601)

Examination of the phenomena related to stress-corrosion effects in metals. Surface energy and elastic energy are explained in terms of the relative energies possessed by surface atoms and atoms at the tip of a crack which have been displaced from their normal position by stress. Adsorption phenomena are discussed as an explanation for the fact that fractures can occur under very small stresses; the adsorbed ions lower the binding energy between surface atoms so that crack propagation can occur. The alternative pit and tunnel theory for explaining stress-corrosion is described. Transgranular fractures have been investigated by transmission electron microscopy. A method for directly observing the chemical activity of slip steps is described. The mechanism by which a corrosion tunnel forms at an active slip step is investigated. IAA

Review: This paper presents an informative discussion on the physics of stress-corrosion failure. In general, the philosophical approach to the problem is presented rather than the engineering or structural approach. Consequently, the paper does not contain numerous tables of engineering or test data. It is, however, an excellent starting point for a general introduction into the basic understanding of stress corrosion and the techniques for overcoming it (but it will not be a good technical reference). The paper, is interesting, easy to read, and well illustrated with graphics, but there are no appended literature references. This is an important failure mechanism for metals and an example of the synergism that can exist in combined environments.

R67-13090 ASQC 844; 711; 712

THE ENERGY REQUIRED FOR FATIGUE.

G. R. Halford (Illinois University, Dept. of Theoretical and Applied Mechanics, Urbana, Ill.).

Journal of Materials, vol. 1, Mar. 1966, p. 3–18. 42 refs.

(A66-29070)

Fatigue data were compiled from 36 previous investigations; 190 sets of data encompass more than 1400 tests on four classifications of ferrous metals and six classifications of nonferrous metals under a variety of conditions. Plastic strain hysteresis energy, stress range, plastic strain range, and fatigue life are tabulated for tests spanning the range from 1/2 cycle (monotonic tension) to 20,000,000 cycles to failure. When available supplementary information–test temperature, cycling condition, cyclic strain-hardening exponent, hardness, ultimate tensile strength, and modulus of elasticity–is included. The plastic strain hysteresis energy to fatigue failure at 500,000 cycles is about 100 times that required for failure by monotonic tension. Plastic strain hysteresis energy (fatigue toughness) was plotted versus number of cycles to failure. The fatigue toughness of all metals increases approximately as the 1/3 power of fatigue life. Fatigue toughness values are low for metals that: (1) are cast, (2) have a low modulus of elasticity, (3) are thermal cycled, or (4) are strain cycled about a relatively large tensile mean strain. A brief review is presented of the unifying relationships between stress range, plastic strain hysteresis energy, and fatigue life. A consistent set of simple fractional values is suggested for the various exponents that relate their quantities. Author (IAA)

Review: Many metallic parts fail by fatigue; in fact it is considered by some to be the most important failure mechanism for structural materials. A paper which summarizes much of previous experience with fatigue by means of formulas can be an important contribution to good design. This paper is such a compilation and mathematical analysis of fatigue data from several previous fatigue investigations (all the data are not presented but they are available). The author does an excellent job of arriving at a consistent set of fractional exponents for the unifying relationships between stress range, plastic strain range, plastic strain hysteresis energy, and fatigue life. The paper is well written and thoroughly documented; consequently, the author's argument is easily followed. Each anomaly, discrepancy, or deviation is pointed out and discussed. The explanations of strain, the strain hysteresis loop, and their application to fatigue analysis are well done. In general, the paper should be of value to research and design engineers.

R67-13100 ASQC 844; 220; 824

Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

RELIABILITY ANALYSIS OF A HIGH-SPEED, EXTRA HIGH-PRESSURE AIRCRAFT TIRE

Stanley O. Smith (M.S. Thesis) Aug. 1964 61 p refs
(GRE/MATH/64-11; AD-610772; N65-27776)

Failure distribution model and reliability function are derived for the B-58 tire. The model results in a combined chance failure (exponential) and wearout (normal) failure distribution. The method used is general and may be applied to any aircraft tire. The areas of contractual specification, inspection procedures, and reporting of failures are analyzed. An operating characteristic curve for the acceptance sampling plan is constructed, showing the plan offers little protection for the consumer. A plan from MIL-STD-414 is selected and recommended. Deficiencies are found to exist in the reliability demonstration method and the area of failure data collection. Author

Review: This is a good report. It deals with the subject at an unsophisticated level, and this is precisely where the effort should be put. The cumulative function for failures appears to fit the data reasonably well. Since it was the only one shown, there is no way of knowing how much better it is than some other likely functions. The use of the word "chance" to describe some failures and not others is poor practice. A random variable was used to describe both the "non-wearout" failures and the wearout failures; thus both are subject to the "laws of chance." It would be interesting to pursue the ratio of non-wearout to wearout failures in terms of improving the tires and in terms of safety. While the present sampling plan was shown to be very poor, it would probably be helpful to consider a greater variety of kinds of new plans to give better protection and to improve the tires. All such studies as this one take time, money, and qualified, interested people. This is why progress is so slow. There is no point in considering more sophisticated reliability techniques until the "quick and dirty" ones have been used up.

R67-13102 ASQC 844; 775
Navy Electronics Lab., San Diego, Calif. Engineering Test Div.

A HIGH-SPEED INFRARED MAPPING SYSTEM FOR RELIABILITY ASSESSMENT OF MINIATURE ELECTRONIC CIRCUITS

H. F. Dean and R. M. Fraser 15 Mar. 1965 21 p
(NEL-1272; AD-615018; N65-27172)

A system consisting of a cryogenically cooled infrared detector, a scanning mechanism, electronic circuitry, and a modified facsimile machine was developed. The infrared energy maps produced proved the feasibility of high speed thermal mapping of miniature electronic circuits. It is shown that useful maps can be produced at environmental temperatures of 60° to 70°C. This range is below the temperature normally considered destructive for most electronic materials. A mapping speed of one-in. sq of surface area per 30-minute period is possible. R.R.D.

Review: This is one of many papers on the subject. Although the title does not indicate it in any way, this is apparently a six-month progress report. The idea, of course, is very good and should be pursued. Nothing much for external use is given here except the feasibility. The scan mechanics causes the mapping time to be larger than necessary and distorts the image. Improvements are under way—perhaps consideration will be given to a spiral scan of some sort which can eliminate the "return trace."

R67-13104 ASQC 845; 846
George Washington Univ., Washington, D. C. School of Engineering and Applied Science.

ANALYZING SELECTED UNITED STATES AIR FORCE DATA SYSTEMS AND DETERMINING SUITABILITY OF DATA FOR RELIABILITY MEASUREMENTS OF AIRCRAFT ENGINES

Thomas Bennett McHugh (M.S. Thesis) Feb. 1964 36 p refs
(AD-608350; N65-21011)

The primary concern was to determine whether present Air Force data systems provide a suitable basis for computing aircraft engine reliability. Certain elements of reliability theory and practice are discussed. Three separate data systems, whose data suggest a usefulness for reliability computations, are evaluated. Both retrospective and prospective testing is considered for testing the accuracy of reliability estimates made from presently available data systems. The exponential function for reliability probability is included. E.E.B.

Review: The essence of this thesis is a recommendation to piece together data from several existing AF data systems in order to obtain engine reliability estimates. Some knowledge of the AFM-110, AFM 66-1, and AFR 65-20 data systems can be gleaned from the descriptions in the thesis. No actual data or examples are given to illustrate the proposal. A generous amount of space is devoted to the importance of reliability and to coin-tossing explanations of probability. Oddly, nothing is said about statistical inference even though this is appropriate. The familiar Poisson assumption in between the burn-in and wear-out periods is assumed to apply to aircraft engines. No data are cited to support this assumption, which may or may not be applicable to this equipment. The DDC copy which is available is apparently made from a carbon copy and is difficult to read.

R67-13105 ASQC 840; 824; 831
California Univ., Berkeley. Inst. of Engineering Research.

MALFUNCTION DETECTION AND DIAGNOSIS

J. M. Alcone, R. L. Osborne, H. R. Ramanujam, D. Rao and J. L. Costanza Aug. 1965 108 p refs
(Contract W-7405-ENG-8)
(UCRL-13186; MD-65-7; N66-23242) CFSTI: HC $3.00/MF $0.65

Techniques are sought and analyzed for detecting and diagnosing the causes of malfunctions in arbitrary systems. A computational approach is used. The particular areas of study include the nature, extent, and distribution of malfunction sensors on the system to be monitored; the requisite data processing operations; and feasibility of the malfunction-detection system. NSA

Review: Some of the concepts developed in this study are possibly pertinent to the area of performance variation analysis. The material is more of a theoretical nature rather than something which is ready for routine application. A flavor of communications theory exists. Apparently no experimental applications have been conducted. A good bibliography on failure detection and isolation is given; it includes some related reliability publications. The copy of this report (and most reports) available through STAR is annoying to read because of the method of reproduction; this is particularly distracting with "heavy" material such as presented in this report. Readers interested in obtaining a copy of this report for detailed reading might try requesting one from the original source.

R67-13108 ASQC 844; 822
National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.
DISTRIBUTION OF FAILURE TIMES IN STRESS CORROSION TESTS
J. B. Gayle 1 Nov. 1965 16 p refs
(NASA-TM-X-53355; N66-14066) CFSTI: HC $3.00/MF $0.65

The results of stress corrosion tests on aluminum alloys have been analyzed with respect to the statistical nature of the distribution of failure times. The analyses indicated that the data were represented adequately by a three-parameter Weibull distribution in which the induction period amounted to 85 percent of the time of the first observed failure and 55 percent of the time required for failure of half the specimens. Author

Review: This paper refers mostly to a specific test. The three-parameter Weibull distribution was found to fit the data reasonably well and the magnitudes of the parameters are considered reasonable. The characteristics of the failure time distribution and their possible relation to the mechanism of the stress corrosion process are discussed. No model of failure is used to derive the distribution, so the fitting is quite empirical. With three adjustable parameters, one would be surprised not to have a good fit. The paper will be of most use to those doing engineering research; designers will find little of value in it.

R67-13109 ASQC 844; 775
General Motors Corp., Kokomo, Ind. Delco Radio Div.
NON-DESTRUCTIVE RELIABILITY SCREENING OF ELECTRONIC PARTS Final Report
J. R. Bevington and L. V. Ingle Griffiss AFB, N. Y., RADC, Sep. 1964 245 p refs
(Contract AF 30(602)-2972)
(RADC-TDR-64-311; AD-608137; N65-11928)

An extensive study of the relationship of a large number of parameters to later failure was made for germanium, high-power, pnp, alloy junction transistors. The relative effectiveness of several screening approaches was tested and applications to several related device types were made to extend the applicability. A reliability screening technique that uses the time response characteristic after step application of rated diode voltage was developed. A study of the mechanism of collector diode degradation failure resulted in the establishment of a model for the mechanism of failure. A computer program was developed and is described. Author

Review: This is apparently the final contract report for the work on which the paper covered by R64-11524 was based. That review should be consulted as the comments apply as well to this report. The effort appears to have been a good combination of engineering, physics, and statistics—especially in regard to not having statistics be the tail that wagged the dog. Several different preindications of failure were found which were rapid and non-degrading to good units. This kind of success requires a good knowledge of the physics of the part, much hard work—both mental and laboratory, and a little luck. This report can be of use to anyone planning similar programs.

R67-13113 ASQC 844
Joint Publications Research Service, Washington, D. C.
ON CALCULATION OF RELIABILITY OF SYSTEMS TAKING INTO ACCOUNT THE PROBABLE CONDITION OF USE OF THEIR ELEMENTS
S. Yu. Ruderman *In its* Tech. Cybernetics, No. 4, 1964 10 Nov. 1964 p 51–53 refs (See N65-10754 01-19) CFSTI: $3.00
(N65-10759)

An analysis is carried out of the reliability of a system of K individual elements, where each element is used by the system only from time to time. The special case where the elements are usually operated for a short time and can go out of order only by remaining on is considered. If the element usually is turned on for a short time, then the basic influence on its reliability is often not the total time of operation, but the number of switchings into the operating state. For a system i consisting of K statistically independent elements, each of which is characterized by its own parameters λ_i, p_i, the reliability of the system is subject to an exponential law, and the average time of its trouble-free operation will be equal to:

$$t = 1/\sum_{i=1}^{n} \lambda_i p_i.$$

P.V.E.

Review: This is a short note translated from the Russian. Unfortunately, the reproduction at reduced size does not permit the reading of the equations. Therefore, this translation will be of little use. It is concerned with failure of an element wherein it both degrades while it is on and has a limited number of turn-ons available. The special case of exponential arrival times of calls is considered and the average time of trouble-free operation is calculated. The work does appear reasonable but could be worked out from scratch faster than the equations can be deciphered.

R67-13114 ASQC 844; 711; 712
American Power Jet Co., Ridgefield, N. J.
RELIABILITY PREDICTION FOR MECHANICAL AND ELECTROMECHANICAL PARTS Final Report
George Chernowitz, Samuel J. Bailey, Angelo W. Castellon, and Gerald L. Geltman Griffiss AFB, N. Y., RADC, May 1964 291 p refs
(Contract AF 30(602)-2991)
(RADC-TDR-64-50; AD-601784; N64-25231)

The reliability of selected parts is investigated from the viewpoint of materials behavior throughout parts—materials history, including process, fabrication, test handling, and early operation. The parts studied are mechanical (bearings and gears) and electromechanical (brushes and contacts). Failure mechanisms were examined on the basis of a SCWIFT taxonomy: S—stress—creep rupture; C—corrosion; W—wear; I—impact; F—fatigue; and T—thermal. Dominant among the mechanisms of failure were wear and fatigue phenomena. A multistage process was developed for organizing analytical and empirical investigation of part failure causes in the broader sense, based on materials influences that may be statistically related to part survival. The definition of a retrospective part survival function was proposed. Data and relationships covering flaw propagation, fracture, corrosion, surface fatigue, and the influence of materials and manufacture are given for the parts studied. Author

Review: A very large portion of the document is the editorial review of the state of the art. Perhaps the major finding is that wear is the most common mode of failure for anti-friction bearings, for gears, for contacts, and for brushes. It does not deal with structural elements wherein fatigue is one of the most common causes of failure (although the wear in anti-friction bearings is due to fatigue). Much of the material on metals would appear in a reference such as the Metals Handbook published by the American Society for Metals. Most of the material on bearings is quite familiar to bearings engineers; the material on contacts to engineers who design and manufacture contacts; etc. Thus this work is not for the specialists but for the general engineer. The report fulfills its objectives of "the analysis of those factors which, at the part or material level contribute to the failure of mechanical and electromechanical assemblies." Most of the presentation begins at a rather elementary level and gradually works its way up; thus it is certainly a suitable introduction for those who know absolutely nothing about the subjects. After reading the entire report one gets the uneasy feeling that it would be very good material for those who spoof the jargon and obfuscation in engineering and government documents. Consider, for example, the final paragraph of Chapter I, which is not atypical of the style of the entire report. "Finally, conclusions are reached and recommendations made to extend these research results in advancing this important branch of engineering science. This report should not be regarded as final in the sense of presenting a fully developed and exhaustive statement: rather it should be seen as a series of demonstration of areas in which fundamental insights have been obtained as the key to further progress." The following comments are perhaps on minor points, but they illustrate the level at which the report is written. (1) On p. 20 a random process is equated to the Poisson process where the failure rate is constant. This is very poor practice. It is also worth noting here that the wear-out region of the bathtub curve may not involve mechanical wear per se. (2) On p. 29 it is pointed out that many bearings fail due to improper assembly. A good designer should take into account the fact that the bearings may be improperly assembled, especially with regard to alignment. Formulas for considering misalignment have appeared in such publications as Machine Design. The actual operating life can then be estimated much better. (3) On p. 50–53 it is easy to infer that the inverse cube law on the load for anti-friction bearings is reasonably universal; the references for this are quite old. The exponents appearing in catalogues these days are somewhat different from three. Later in the paper this point is clarified to show the considerable variation that does exist. (4) For small samples of bearings the logNormal is often used and is generally indistinguishable from the Weibull. (5) On p. 65 the discussion of fatigue limit is not at all clear. (6) On p. 67 the chi-square test for exponential behavior is not very sensitive to the alternatives. Other tests should be used. (7) On p. 66–68 where the Weibull distribution is fitted to bearing life for several loads, it is pointed out that for loads in general the failure rate decreases with increasing life, while for high loads the failure rate is a constant and for low loads the failure rate increases with time. Further on, different things are said. While the authors are trying to show what happens with specific data and in localized regions, the result is confused at best. (8) The model $f = \mu N$ is used in the discussion of friction. One must be careful not to presume that μ is a constant. In many mechanical situations the coefficient of friction is proportional to the speed or even the square of the speed. (9) Discussions for bearings and gears refer only to metals; the discussion is not applicable to plastics. Plastics are coming into more and more use especially for bearing retainers and for some gears. (10) On p. 185 a non-uniform Poisson (and exponential) distribution is introduced. While it may be clear from context what the authors mean by this, it seems to be a poor choice of terminology and could be misleading. Also, the form shown is applicable to any continuous cumulative distribution. The entire discussion on distributions seems unconventional and unnecessarily complicated. The report will be most useful to beginners who want an overall view of the situation, who are not concerned with the specific details, and who enjoy this particular style of writing. It will be of little use to the specialist in any of the particular fields discussed in the text.

R67-13119 ASQC 844

Clevite Corp., Palo Alto, Calif. Shockley Research Lab.

FAILURE MECHANISMS IN SILICON SEMICONDUCTORS *Final Report, 1 Mar. 1963–31 Aug. 1964*

W. Schroen and W. W. Hooper, ed. Griffiss AFB, N. Y., RADC Mar. 1965 311 p refs

(Contract AF 30(602)-3016)

(RADC-TR-64-524; AD-615312; N65-27300)

This Final Report is divided into two major sections: The first part is concerned with investigations of thermal instability in silicon power transistors, and the related phenomena of hot spots and second breakdown. The theory of the thermal instability problem is presented. A rather extensive investigation of the damage which occurs in silicon power transistors as a result of hot spots and second breakdown is included, and finally, special transistor structures are studied which serve to confirm earlier theories on thermal instability and shed new light on possible methods by which the failure mode of second breakdown can be minimized. The second portion of this report concerns an investigation of the surface properties of oxide covered silicon and silicon p–n junctions. In particular, the program of charge motion on the outer surface of the oxide covering silicon and silicon p–n junction is studied, with relevance to the current-voltage characteristics of reverse biased silicon p–n junctions. These investigations are directed at a better understanding of the physics of failures which occur in oxide covered p–n junction devices. Author

Review: This is a long detailed report about two failure mechanisms in silicon semiconductors. The work is of high quality as is the report itself. The first half of the report deals with the relation of thermal instability to second breakdown failures in power-transistors. Experimental results generally confirm the theory that second breakdown results from lateral thermal instability and the resulting formation of hot spots. Although a solution to the problem is not given, it is expected that this more complete understanding will enable a solution to be found. The mechanism of charge transfer for silicon dioxide over p–n junctions is investigated in the second half of the report. This mechanism relates to the deterioration of reversed biased p–n junctions which are protected with silicon dioxide and hence to the reliability of integrated circuitry in general. Excellent verification is given of the theory that charge motion occurs only on the surface of the oxide. This report is recommended to reliability engineers and others who wish to keep abreast of research on failure mechanisms in semiconductors. It will be of little direct use to circuit designers.

R67-13120 ASQC 840; 850

RELIABILITY PREDICTION TECHNIQUES: A QUICK-REFERENCE GUIDE.

Richard E. Shafer

Electronic Procurement, vol. 7, Jan. 1967, p. 36–39.

Reliability prediction is regarded as a tool for both design and management decisions, and factors to be considered in selecting the appropriate techniques for determining reliability are briefly discussed. The six basic sources of reliability prediction information are reviewed: (1) Mil-Std-785, (2) Mil-Std-756, (3) Mil-Std-217, (4) Mil-R-26474, (5) NavShips-93820 that includes four methods, and (6) RADC Reliability Notebook methods. Consideration is given to cutting costs while predicting and making predictions work. M.W.R.

Review: This paper does give a quick reference guide to reliability prediction techniques which are spelled out in military documents; the major portion is given over to a quick summary from six such documents. It is probably at a level which is satisfactory for procurement personnel to whom it is directed. It might be of value to management or to anyone else who wants to get a very superficial knowledge about prediction methods. Reference to the documents listed will, of course, provide information of considerably greater depth which will assist engineers and management or configuration personnel who require data of broader scope, including tradeoff parameters. There are some helpful hints on why one might want to make a prediction, on how not to be extravagent while predicting, and on how to make predictions effective. The accuracy of these methods is described realistically but qualitatively–in terms such as "ball park." For the newcomer it is worthwhile pointing out that "ball park" may mean up to a factor of 10 uncertainty in MTBF or failure rate with an occasional surprise where it is even worse. While there are reports that predictions come within 10% or 20% of the measured value, in general one is lucky to come within a factor of 2. If the equipments from which the source data were generated are very similar in nature and use to the ones being estimated, then occasionally closer results can be obtained. Even this rough guide is controversial–some insist that it is much too optimistic, and others that it is too pessimistic.

R67-13123 ASQC 840; 851; 864

COMPONENT RELIABILITY IN TELECOMMUNICATIONS EQUIPMENT–PARTS 1 AND 2.

G. Mattana (Telettra, S.P.A., Milan, Italy).

Electronic Components, vol. 7, Aug. 1966, p. 737–745. 7 refs.; Sep. 1966, p. 825–830. 7 refs.

Methods employed and results obtained by accelerated testing of electronic components in complex telecommunications equipment are discussed. Philosophy of these accelerated tests is based on the assumption that the failure rate is both constant and below the wear-out point. The Arrhenius and Eyring models for accelerated testing are included, along with a definition of the accelerated test and its duration. Accelerated component testing results are given for aluminum electrolyte capacitors and carbon layer resistors, which serve as examples of degradation research concerning an entire population, and tantalum capacitors, as an example of correlation between failure rate and stress severity. Mention is also made of germanium and silicon transistors. Some of the results, covering a period of more than five years, concern failures that occurred during field operations of as many as 10^{11} component hours. M.W.R.

Review: The discussion of reliability techniques in this two-part paper consists (except for some criticism) of rather standard material familiar to reliability analysts. For those not familiar with it, the paper will provide only a rather sketchy picture. Of more interest, perhaps, are the results of some 'accelerated' tests on resistors, capacitors, and transistors, made with small acceleration factors and prolonged for up to five years. These are presented mainly in the form of graphs in Part 1. Part 2 is concerned with field data, and serves to illustrate the approach taken in some particular investigations. Conclusions are given only in rather general terms.

R67-13127 ASQC 844; 774; 775

INTEGRATED CIRCUITS IN ACTION. PART 4: POST-MORTEMS PREVENT FUTURE FAILURES.

Seymour Schwartz (NASA, Electronic Research Center, Cambridge, Mass.).

Electronics, vol. 40, 23 Jan. 1967, p. 92–106. 10 refs.

A step-by-step analysis is presented for determining the cause of a typical integrated circuit, specifically for the Minuteman 2 program. The use of proper tools and correct sequence is stressed; and a chart details the instruments available for testing physical, chemical, mechanical, and electrical abnormalities. For each instrument, related failure modes and probable failure mechanism are given. Forced failures, electrical stressing, individual tests, and metallography are discussed; and tools for determining integrated circuit failure are tabulated for physical, electrical, and chemical properties. In addition to listing the instrument and procedure and the specific property, the sensitivities of the tools are given as to resolution and power. Mention is made of atomic probes, uses of X-ray diffraction, and chemical examination of integrated circuits. M.W.R.

Review: This is a good popular article on the failure analysis of integrated circuits. It describes some of the failure mechanisms and failure modes and the uses of various analytic tools. The paper will be useful to reliability engineers, management, and others who wish a quick survey rather than a detailed description. The references support the text rather than show where more detailed knowledge may be obtained. The analysis of failed parts is, of course, essential to the attainment of high reliability, and this article can serve a good purpose by encouraging more people to believe in it and by providing them an opportunity to learn about it. There are relatively few case histories, so that the article is not spectacular in that sense. Two points not brought out by the author are (1) small-quantity users probably do not have the means to have their own laboratories and may not receive a sympathetic ear from the manufacturer in these days of low prices and very large volume, and (2) to do a complete failure analysis on all failed parts is usually prohibitively expensive and time-consuming, however desirable it may otherwise be.

85 DEMONSTRATION/MEASUREMENT

R67-13106 ASQC 851; 770; 844

National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.

A COMPARISON OF BURN-IN AND BAKE AS SEMICONDUCTOR SCREENING TECHNIQUES FOR THE NIMBUS SPACECRAFT PROGRAM

Irving J. Ross Mar. 1965 49 p refs

(NASA-TM-X-55206; X-650-65-105; N65-21669) CFSTI: HC $3.00/MF $0.65

This report summarizes and compares the relative effectiveness of high temperature storage (bake) and high temperature operating burn-in as screening techniques for semiconductor devices used in the Nimbus spacecraft program. Data were accumulated for summaries of burn-in and bake screening performed. Results are presented for 162 different

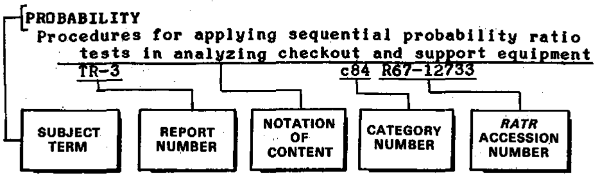
types of semiconductor devices, with an overall sample size of 70300 for an aggregate of 49 million device hours for both screening techniques. Results indicate that burn-in is superior to bake for every class of semiconductor device and for every manufacturing process used in the fabrication of the devices. Correlation is shown between rated power dissipation and burn-in effectiveness. Statistical significance of the data is evaluated when comparability of types is possible, i.e., where the types were both burned-in and baked.
Author

Review: This paper fails to present a completely convincing case for the superiority of burn-in over high-temperature bake of semiconductor devices as a method for reliability screening. The most important element lacking is demonstration of equivalent test conditions for the two different types of tests. For example, the high-temperature bake test specification for silicon devices was 1000 hours at 100°C. The corresponding burn-in test was 300 hours at 100°C, with sufficient power applied to each device in this environment to bring junction temperature to 80% of its maximum allowed operating value. Although not stated in the paper, this typically raised junction temperatures to 140°C. The exponential failure rate dependence on junction temperature makes the 1000-hour test at 100°C *roughly* equivalent in severity to 300 hours at 140°C. It must be admitted that no claim is made in the paper that the test conditions are equivalent. Doubtless the test conditions were beyond the author's control and he could only use the resulting data. A word of explanation to this effect and an indication of the rough equivalence shown here, would have made his results more convincing. Given that the test conditions are roughly equivalent, the results do strongly favor the burn-in test in that this test produces significantly more failures in a wide variety of semiconductor devices. The author gives what is undoubtedly the correct reason for this superiority: applying power to a device allows the detection of electrical failure mechanisms, such as the formation of hot spots in nonuniform junctions, which temperature tests alone cannot do.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 4

Typical Subject Index Listing



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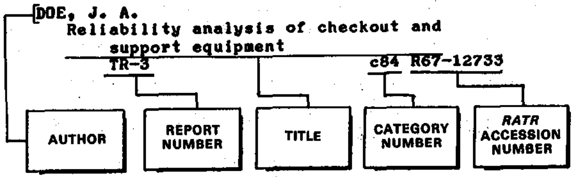

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 4

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This may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number preceded by the category number for locating the abstract-review in the abstract section of *RATR*. For purposes of this index, AD, N, and A numbers (accession numbers from *TAB, STAR,* and *IAA,* respectively) and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

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NASA-Langley, 1967

Reliability Abstracts and Technical Reviews

MAY 1967

Volume 7
Number 5

R67-13129—R67-13181

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

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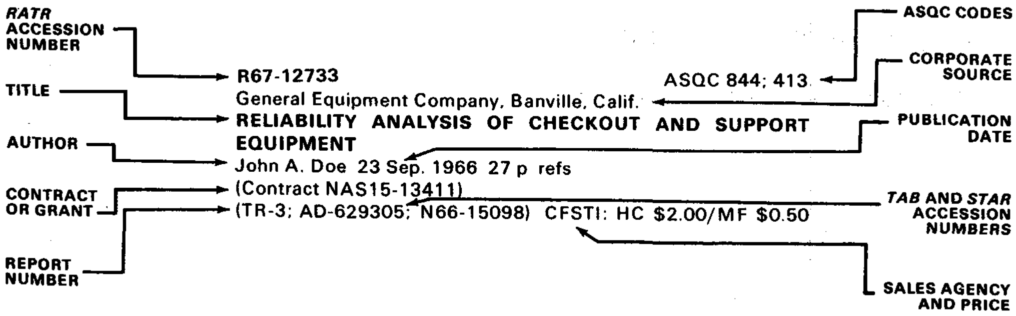
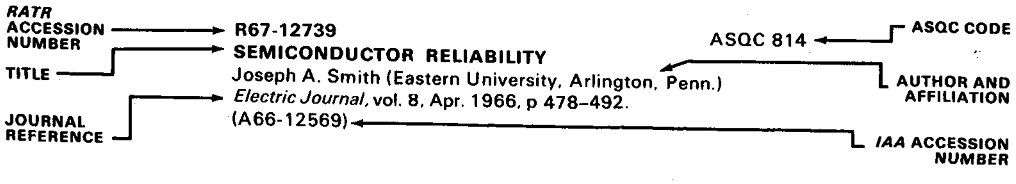
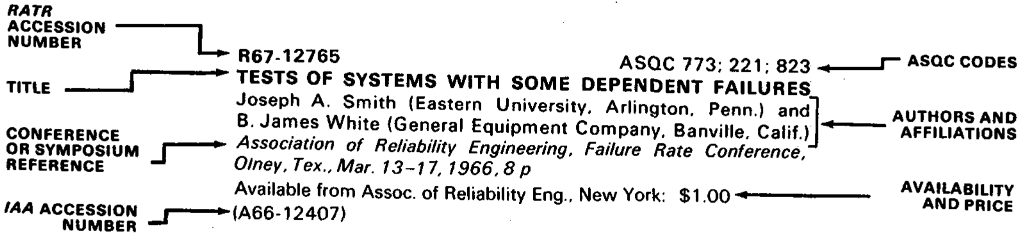


R67-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N66-15098) CFSTI: HC $2.00/MF $0.50



R67-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A66-12569)



R67-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A66-12407)

VOLUME 7 NUMBER 5

Reliability Abstracts and Technical Reviews

A Monthly Publication
of the National Aeronautics and Space Administration

May 1967

80 RELIABILITY

R67-13144 ASQC 800; 810; 840
THE MEANING OF RELIABILITY.
R. Woodcock (Marconi Co., Ltd., Basildon, England).
Electronic Components, vol. 5, Oct. 1964, p. 829–832. 2 refs.

Practical reliability assessments are stressed in a general review that points to some of the difficulties incurred during reliability testing programs. Source of and conditions under which the data are accumulated must be assessed, as well as the relationship of the component reliability data to the specific system on which the components are to be used. An example is given to show that although the same failure data can be used in two tests, different confidence limits for failure rate can result from different test conditions. It is, therefore, necessary for the data user to understand the limitations of any theoretical estimate of reliability; and in this regard both the manufacturers' and customers' points of views are considered. M.W.R.

Review: This is a short, practical article which cautions the reader about the pitfalls in failure-rate estimation and in reliability testing. The author accomplishes his purpose of "...pointing out a few of the many and varied difficulties, not to discourage those on the fringe, but rather to encourage them to look deeper into what is an interesting and diverse subject." It could be of help to both management and design engineers.

R67-13176 ASQC 800
PANEL ON MAJOR DEVELOPMENTS IN RELIABILITY DURING THE NEXT FIVE YEARS.
Charles W. N. Thompson
In: National Electronics Conference, Proceedings, Chicago, Ill., Oct. 3–5, 1966. Vol. XXII. Sponsored by the Illinois Institute of Technology, the Institute of Electrical and Electronics Engineers Region IV, Northwestern University, and the University of Illinois. Chicago, Ill., National Electronics Conference, Inc., 1966, p. 1023–1025.

Brief summaries are presented of part of a panel session devoted to trends in the development of reliability procedures during the next five years. Mention is made of the information explosion, new technologies, progress in related areas, and human safety factors that may influence the future of reliability; and consideration is given to the role of the reliability engineer in the overall design and production picture. One of the panelists stresses that reliability must become a staff function at a high management level in order to integrate the work of the many departments concerned in maintaining high quality. M.W.R.

Review: Of the five panelists only two have an abstract of their talks in this paper, in addition to the chairman, whose introductory remarks are included. While the actual presentation and ensuing discussion may have been exciting and informative, the panelists' abstracts are of little value to read except for idle curiosity. The chairman's introductory questions are the most interesting. They indicate the likelihood that reliability will go in many directions in the next five years—some good, some bad, some indifferent—and the likelihood that some of the basic problems will probably be bypassed rather than solved.

81 MANAGEMENT OF RELIABILITY FUNCTION

R67-13129 ASQC 815; 814; 825
Air Force Inst. of Tech., Wright-Patterson AFB, Ohio.
ESTABLISHING RELIABILITY REQUIREMENTS FOR MILITARY WEAPON SYSTEMS AND EQUIPMENT
Robert L. Mc Call (M.S. Thesis) Dec. 1965 63 p refs
(GRE/SM 65-2; AD-628100; N67-81292)

This study was made to investigate the hypothesis that an economic analysis can be used as the basis for establishing reliability requirements. The economic basis for such an analysis is established and the AGREE reliability cost model and the WSEIAC reliability allocation model are reviewed. The problem of determining cost reliability relationships because of the lack of historical data and the problem of representing the value of reliability in an analysis are discussed. Finally, an economic analysis is made of the APN-159 radar altimeter, using historical data. The conclusion is that an economic analysis can be used as the basis for establishing reliability requirements of military weapon systems and equipment. Author (TAB)

Review: The difficulties of attempting to implement the cost-effectiveness viewpoint are illustrated by this thesis, which essentially concludes that the idea is promising but that procedures and a data-base are needed. The interesting part of the thesis involves the use of some loose data on times between failures, acquisition costs, and operational costs for a radar altimeter. These data are used to obtain some points on the total cost versus MTBF curve. The sensitivity of the relationship to the acquisition and operational costs is checked by developing a number of the curves for several acquisition and operational costs. The curves are all "U" shaped with a relatively flat bottom over a moderately broad MTBF range. Now the acquisition cost data points were mainly based on actual operational times between failure and actual costs plus contractors bid costs for improved reliability. The latter was not procured. The total cost curves which are developed indicate that not buying the improved reliability is costing the Air Force a small fortune. This conclusion holds for the various sensitivity tests, including one of doubling the contractors bid costs for improved reliability. These curves generally indicate that somewhat too much reliability costs essentially nothing because decreased operational costs offset increased procurement costs, but that too little reliability results in tremendous costs. Some operational data from radar altimeters is presented and analyzed in order to obtain an MTBF estimate. The data are checked graphically and statistically (Kolmogorov–Smirnov) for an exponential fit. Now the altimeter is a repairable equipment, and the interest with respect to the exponential distribution is as it relates to the Poisson distribution or the flat part of the familiar bathtub curve. Lumping all the data as was done here does not check the time-ordering of the time between failures. As the data were from new equipment, it is possible that the equipment reliability might have been improving with age. The time-ordering point is often not cited when data are being analyzed in similar situations, and the author is doing what is usually done. Another statistical analysis which is shown apparently uses the "t" distribution for estimating the confidence interval for the mean of the exponential distribution. A more appropriate estimating technique involving the chi-square distribution is widely cited and used in reliability analysis.

R67-13130 ASQC 815

RAND Corp., Santa Monica, Calif.

A NOTE ON INCENTIVE FEE CONTRACTING

Robert M. Thrall Aug. 1965 5 p

(P-3191; AD-619998; N67-81318)

A hypothetical incentive fee contract for a missile is considered that includes factors of cost, time, weight, and reliability; the missile is to be assembled from 10 components, each of which is to be manufactured under a subcontract. The main desire is to learn whether the incentive fee contract can reasonably be extended to the subcontractors. The following features are stressed as of importance in extending the incentive fee concept to subcontracts: (1) If individual components have a strictly additive effect on the total project, then the incentive fee concept can be safely extended to subcontractors although for a weight case this may lead to some minor inequities. (2) If the performance of the total project is measured by that of the poorest of the components, then one must beware of substantial magnification effects. (3) If the performances of the components combine like independent probabilities to determine overall performance, the range of variability for individual components is severely restricted. TAB

Review: Several reasonable guidelines are developed in this short note for extending the incentive fee concept to subcontractors. The author illustrates with a simplified example that such extensions are not at all straightforward. Reliability is one of the factors which are to be related to profit. Only a limited scope of incentive contracting is covered here, and those interested in further notions about reliability and incentive contracting could refer to R65-12015, R65-12263, R65-12264, andR66-12611.

R67-13148 ASQC 817; 838

AEROSPACE POWER SYSTEMS—MAXIMIZING RELIABILITY WITH RESPECT TO WEIGHT.

Rajnikant B. Thakkar and Roy C. Hughes (Allis-Chalmers Manufacturing Co., Milwaukee, Wis.).

(International Conference and Exhibit on Aerospace Electro-Technology, Phoenix, Ariz., Apr. 20–23, 1964.) IEEE Transactions on Aerospace, vol. AS-2, Apr. 1964, p. 528–534.

(A64-18144)

Presentation of a procedure for determining the optimum arrangements of components in a system under weight or reliability constraints. It is based on reliability improvement through the use of functional redundancy. The mathematical background is briefly presented. General steps of the procedure are logically deduced and then applied to the components of an aerospace system. It is concluded that the procedure presented gives the design or reliability engineer an effective way to evaluate the degree of redundancy and types of components to be used in redundanization. It is visualized that for large complex systems, such as space vehicles, the procedure outlined could be used extremely advantageously, through computer programs, especially in the early design stages. IAA

Review: The first part of the paper gives the solution for maximizing reliability for a given weight, as derived by the method of Lagrange multipliers. It requires that the elements be statistically independent, logically in series, and have a known differentiable probability of failure vs. weight. The mathematics is the same if weight is to be minimized and reliability held constant. These are the only constraints put on the system. It is important to realize that the parameters recommended by the formulas may then not be physically realizable. For example, some of the weights may be negative. The system so analyzed is completely determined, although this is not clear in the paper. That is, given the differentiable formulas for the weight of each element vs. its failure probability, the Lagrange multiplier can be determined, however tedious the process may be. Then, using this value of the multiplier, the exact weight and failure probability of each element in the system is determined. The statement "It is apparent that moving the curve in Fig. 1 to the left without vertical movement would be ideal...," is misleading since the total weight is what fixes the position of the line. Obviously small deviations from the optimum weight of each element will cause little change in system reliability since the reliability is at a stationary point. This brings up another factor: although it is likely that the extremum is the desired maximum of reliability there is nothing in the Lagrange derivation that guarantees it; similarly for the case of fixed reliability and minimum weight. If the optimum weights are negative or otherwise below the absolute minimum obtainable, the elements should be considered fixed in weight, those weights subtracted from the total weight and the remaining portion of the system optimized with respect to the new weights. Whether the approach used by the authors for systems in which the weight is changed in discrete amounts is valid is not obvious on its face. Their criterion in Equation 15 is not justified in the paper. It should be pointed out that the method of solution they tend to use was handled by Sasaki (see R62-01496 and R63-10978), whose work was put into a more usable form by Webster (see R64-11267 and R65-12023). In it the method of Lagrange multipliers to find the optimum solution is not necessary and not used; it is not even necessary to have a continuous function for the relationship of failure probability to weight.

R67-13158 ASQC 810; 833; 844

PARTS RELIABILITY PROBLEMS IN AEROSPACE SYSTEMS.

Welfred M. Redler (NASA, Office of Reliability and Quality Assurance, Washington, D. C.).

In: Electronic Reliability, Annual Conference, 6th, New York, N. Y., May 21, 1965, Proceedings. Sponsored by the Metropolitan New York Chapters of the IEEE Professional Technical Groups on Reliability, Components Parts, Product Engineering and Production, and Basic Science, and the Society for Advancement of Management. 11 p. 3 refs.

Available from S. Houck, Grumman Aircraft Engineering Corp., F-111 Maintainability Group, Plant 15, Bethpage, N. Y.: IEEE Members: $4.00; Nonmembers: $6.00.

Component reliability and quality control are discussed in terms of mission success of NASA programs. The greatest problem is considered that of attaining sufficient quality control and care in the production, handling, storing, testing, fastening, and application of spacecraft parts and associated materials. Another critical problem is availability of parts and materials with higher performance and life characteristics. Electronic parts appear to have inherently low failure rates, while mechanical and electromechanical components are apt to provide limiting factors in space system reliability unless more attention is paid to their analysis. Parts management problems are discussed, Saturn pre-flight failure reports are analyzed, and a breakdown of representative failure rates for space parts is included. Attention is given to personnel training, specifications, procurement policies, and data exchange. Space parts reliability status is reviewed for the Mariners, parts versus soldered joints, Lunar Orbiter failure rates, and DoD and NASA spacecraft. M.W.R.

Review: This paper is very similar to the one by the same author covered by R66-12527.

R67-13181 ASQC 815; 824

North American Aviation, Inc., Downey, Calif. Space and Information Systems Div.

RELIABILITY ASSESSMENT GUIDES FOR APOLLO SUPPLIERS

B. L. Amstadter and T. A. Siciliano

Sep. 1965 103 p refs revised Supersedes SID-64-1447

(Contract NAS9-150)

(NASA-CR-83055; SID-64-1447A; SID-64-1447; N67-2098)

The requirements, criteria, and methods to implement appropriate paragraphs in referenced specifications are defined for those suppliers not required to have formal reliability program plans. In addition to general requirements and criteria for determining the type of assessment, techniques are provided for assessing the reliability of systems and components using data from actual tests and inspections subsequent to firm design release. Reliability–confidence relationships are established so that reliability can be assessed at any desired confidence level, or, given the reliability, the corresponding confidence level can be determined for the applicable sample size. Criteria for the selection of applicable methods are given, required data are indicated, appropriate equations are defined, and tables and graphs are provided. Author

Review: A collection of formulas and charts essentially comprises this guide. The contents are the type found in introductory statistics books and in much of the reliability literature. No examples or real-world data are presented to illustrate applications. This guide would be of some help to suppliers (or anyone) new to reliability assessment, but such a person should proceed cautiously with applications. It should be noted that these remarks pertain to this issue of the guide (SID 64-1447A), which is an improvement over the original issue (SID 64-1447).

82 MATHEMATICAL THEORY OF RELIABILITY

R67-13132 ACQC 820

Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

ON THE OPERATIONAL RELIABILITY OF ELECTRONIC EQUIPMENT

Petre Sipos 18 Apr. 1966 23 p refs Transl. into ENGLISH from Telecomunicatii (Bucharest), v. 8, no. 2, 1964 p 73–78 (FTD-TT-65-1166; TT-66-62523; AD-641112; N67-16172) CFSTI: HC $3.00/MF $0.65

Conclusions: (1) Knowledge of probability calculations and mathematical statistics is necessary for successful solution of problems in operational reliability. In general, statistical methods do not present especially difficult problems in the study of reliability. Usually, the difficulty consists in logical statement of the given problem. In the same way, statistics provide the theoretical basis for many practical solutions, which are purely intuitive in most cases. (2) Standardization and miniaturization of components is an important means for increasing the reliability of electronic equipment. Additionally, when it is economically and technically reasonable, it is recommended that components that have a high failure risk be kept as spares. To increase reliability further it is also necessary to choose reliable components, adequate operating conditions, and finally, to make failure predictions. (3) It is absolutely necessary to establish reliability standards for the various types of electronic equipment. For this it is necessary to use one of the most complete reliability characteristic, such as the average duration of normal operation. These reliability standards must be introduced in the early design stages. (4) It is necessary to establish an adequate terminology for reliability theory; the terminology used in this article is not to be considered definitive. (5) As the quantities and complexity of electronic equipment increase, it is absolutely necessary that reliability be considered as one of the most important parameters of the equipment. Author (TAB)

Review: This is a translation of a Rumanian document. It is written on the level at which several terms such as "hazard rate," "mean life," and "failure rate" are defined and that is all. In some cases they are implicitly defined for a sample and in other cases for the population. The failure of any part is presumed to cause failure of the system. The need for high reliability is also mentioned. This kind of material is readily available in journal articles, government reports, and published books. There is no need to go to this document to get any of it.

R67-13134 ACQC 824; 413

Ford Motor Co., Dearborn, Mich.

SOME TEST FUNCTIONS FOR THE PARAMETERS OF THE WEIBULL DISTRIBUTIONS

Satya D. Dubey Repr. from Naval Res. Logistics Quart., vol. 13, no. 2, Jun. 1966 p 113–128 refs

(NAVSO-P-1278; AD-636552; N66-38208) CFSTI: HC $3.00/MF $0.65

Test functions, based on various types of censored and noncensored data, for testing several hypotheses about the location, the scale, and the shape parameters of the Weibull distributions are proposed. The exact sampling distributions of these test statistics are derived and their properties in special cases are discussed. A numerical example is considered to illustrate the application of the test functions. The results of this paper possess good possibility of wide application in view of the fact that hosts of real data arising from diverse fields of human endeavor are adequately described by the Weibull distribution. Author (TAB)

Review: The statistics listed in this paper can be obtained by χ^2 and F transformations from the exponential distribution on noting that an exponential distribution is a χ^2 with 2 degrees of freedom. Just having a particular distribution under null hypothesis does not constitute a "good" test criterion. In cases where the Weibull shape parameter (m) is known, the theory can be reduced to the test for the exponential distribution (see References 2, 3, 4, and 7 in the paper). In the cases in which we are concerned with the hypothesis $m = m_0$, the tests as suggested are likely to be biased and in some cases useless (in the sense of power being less than significance level) against the alternatives $m \neq m_0$. Unless some properties of these test functions under the alternative $m \neq m_0$ are derived, these test functions will remain mere exercises for the student of probability on transforming Weibull to exponential.

R67-13136 ASQC 824; 410

Boeing Scientific Research Labs., Seattle, Wash.

THE CONCEPT OF MONOTONE FAILURE RATE IN RELIABILITY THEORY

Frank Proschan *In* Army Res. Office Proc. of the 9th Conf. on the Design of Expt. in Army Res., Develop. and Testing Dec. 1964 p 17–71 refs (See N65-15451 06-19)

(N65-15453)

It is shown that in the analysis of reliability problems, an error in the original assumption of the underlying failure distribution may be greatly compounded at the final conclusion. A reliability analysis based on a conditional failure rate, i.e., increasing failure rate (IFR) which might correspond to wearout, or a decreasing failure rate (DFR) which might correspond to work hardening, is discussed. The bounds on the quantities of interest are determined for IFR and DFR distributions, and a number of reliability models are presented that illustrate how the assumption of IFR(DFR) distributions simplifies the solutions. Operations under which a monotone failure rate is preserved are also discussed. D.S.G.

Review: This paper is one in a series that the author and his colleagues have been writing on this subject. Many references to earlier papers are made; some of these have been reviewed in RATR (see, for example, R62-10401, R63-11049, R65-12062, R65-12237, R66-12428, R66-12531, and R66-12583). The paper is largely in the form of theorems and proofs which would make it difficult for an engineer to follow. The work is important enough so that is deserves more popularization than it has received. This means that engineers should be exposed to some of the results which have been prepared in simplified form for the trade magazines. Most of the results are in the form of inequalities, which may be a disadvantage, but the fact that the distribution function is so general tends to balance out this disadvantage. The article is long and would be tedious to follow; therefore it will be of use largely to those doing research in this field or to one who wishes to popularize the results. (The work was not checked for typographical or mathematical accuracy, but it is expected to be of the same high quality that has characterized other papers by this author.)

R67-13137 ASQC 824; 837

Picatinny Arsenal, Dover, N. J. Nuclear Reliability Div.

UNBIASED ESTIMATES OF RELIABILITY WHEN TESTING AT ONLY EXTREME STRESS LEVEL

A. Bulfinch *In* Army Res. Office Proc. of the 9th Conf. on the Design of Expt. in Army Res., Develop. and Testing Dec. 1964 p 73–91 refs (See N65-15451 06-19)

(N65-15454)

Based on the stress–strength concept of reliability for "one-shot" items, it is assumed that an item cannot fail until the stress equals or exceeds the strength. From this premise and the following additional assumptions, methods are given for calculating unbiased estimates of nontime-dependent reliability: (1) The relation between the stress and strength standard deviations is known approximately. (2) A single-stress level is applied during testing at approximately three standard deviations from the average stress level. (3) The stress and strength distributions are normal. Calculations are included to show the effect of errors in the assumptions concerning the standard deviations, applied stress level, and rounding-off errors. This approach further reduces the sample size required to demonstrate high non-time-dependent reliability in laboratory testing. It has the added advantage of obtaining unbiased estimates of reliability with the simplest of testing methods. Author

Review: The paper is difficult to read and the statistics, per se, are not of the best, although the arithmetic itself may very well be correct. The author introduces an interesting concept—at least one can think of an interesting concept by reading the paper. The statistical assumptions are not clearly spelled out. The sampling distribution of the variable being estimated from the experimental data is not really considered in a formal sense. The discussion of whether two numbers are approximately correct or not is poor. For example, it is easy to infer that the author thinks that reliabilities of 0.99998 and 0.99632 are approximately the same, whereas, in fact, the unreliabilities have a ratio of about 1/200. An interesting statistical model can be developed from what the author has written: both stress and strength are presumed to have Gaussian distributions; the ratio of variances (m^2) is presumed known; the absolute variance is unknown; tests are run at a particular stress level and the fraction of items failing is recorded; it is presumed that the reduced Normal variate Z_1 (of the stress distribution) corresponding to the actual stress used is known; and it is desired to estimate the reduced Normal variate Z_2 of the actual stress (for the strength distribution). The fraction of items failing the test will have a binomial distribution with a true parameter p corresponding to the area in the tail of the strength curve below the test stress. If that parameter is estimated by the fraction failing the test, p, the value of Z_2 can be found from Gaussian tables. This is plugged into the easily derivable formula: safety margin = $(Z_1 - mZ_2)/(1 + M^2)^{1/2}$, Z_2 will ordinarily be negative. The sampling distribution of Z_2 is not available in the literature. If Z_1 and Z_2 are about the same and m is fairly close to 1, the safety margin is relatively insensitive to the value of m (if $Z_1 = Z_2$ the value of the safety margin for $m = 3$ or $m = 1/3$ is only 11% less than it is for $m = 1$). It might be of interest to investigate statistically the sampling distribution of the safety margin. The safety margin itself is much more likely to be robust with regard to non-Normality than is a calculation of the reliability from that safety margin.

R67-13143 ASQC 822; 711; 712; 714; 844

STATISTICAL DISTRIBUTION OF ENDURANCE IN ELECTROCHEMICAL STRESS-CORROSION TESTS.

F. F. Booth and G. E. G. Tucker (Aluminum Laboratories, Ltd., Banbury, England).

Corrosion, vol. 21, May, 1964, p. 173–177. 5 refs.

Based on anodic stress corrosion testing, endurances of aluminum-5% magnesium alloy specimens are found to be log-normally distributed; and the geometric mean is considered the best representative value of endurance. Both intensiostatic and potentiostatic control are used during the testing, and other types of statistical distributions are investigated. Although fairly good agreement with experimental data was found for the normal distribution, it was rejected because of the difficulty in attributing physical significance to negative endurances. The experimental procedure and the statistics employed are described, and probability plots and histograms of endurance are included. M.W.R.

Review: This is a continuation of the work reported in a previous article by the same authors (see R65-11929) and comes to similar conclusions. The main emphasis appears to be on the general shape of the curves as opposed to what happens on the short-lived tail end. The authors' reluctance to use the Normal distribution because of the awkward physical interpretation of negative values of endurance is not well founded since none of the common tractable distributions would be expected to represent the situation that far out in the tails when data are taken in a region relatively near the center. For example, the probability level to get a negative endurance on the Normal scale is probably less than 10^{-8} to 10^{-10} (if those probabilities were greater than 10^{-3}, then it might well be sufficient reason for rejecting the Normal distribution). The chi-square tests, although not known for their discriminating power, do appear to reject the Normal distribution and to render the hypothesis of the log-Normal quite tenable. Work such as this is valuable for reliability considerations in that use is often made of the density function. For reliability purposes, however, the short-life tail is of more interest than the measure of central tendency. Others have found a good fit by the three-parameter Weibull distribution. This is not surprising since many life data are equally well fitted by the log-Normal and the Weibull distributions.

R67-13154 ASQC 824; 837

UNBIASED ESTIMATES OF NON-TIME DEPENDENT RELIABILITY.

Alonzo Bulfinch (Picatinny Arsenal, Dover, N. J.).

In: Basic Failure Mechanism and Reliability in Electronics, Annual Conference, 5th, Newark, N. J., Jun. 15, 1964, Proceedings. Sponsored by the Metropolitan New York Section of IEEE Basic Science and Professional Group on Reliability, and the Society for the Advancement of Management. 26 p. 8 refs.

Available from Stevens Institute of Technology, Hoboken, N. J.: IEEE Members: $5.00; Nonmembers: $8.00; Student Members: $4.00.

A safety factor approach to reliability is taken that assumes a component will not fail until the stress exceeds the strength, and that reliability is created by building in a margin of safety during the development stage. The model for non-time dependent reliability is considered good for "one shot" items that will have only one chance to operate. Reliability values obtained by numerical integration, Z-formula, and Monte Carlo sampling of simulated flight conditions are in close agreement with a non-time dependent model. Single and multiple stress level testing procedures are described, as are methods of testing to failure. The latter discusses the T-formula, and characteristics of available methods. The two-stimuli method is described and compared to an up-and-down method and a flight condition method; and is considered accurate for determination of reliability at any level with only small samples. M.W.R.

Review: This paper has severe deficiencies which drastically limit its usefulness. It is difficult to follow and much of the statistics is poor. Reliability is defined as a probability that strength exceeds stress; the simple stress–strength model of failure is presumed to hold; about six pages are taken to elaborate upon these two conditions. It is obvious on its face that if the distributions of stress and strength are considered unknown and to be determined by experiment, then any tests at a single stress level will not come close to estimating the reliability, and long, drawn-out examples are not needed to prove it. Some numerical integration is done and the results are compared to the exact value which could be obtained by closed-form integration; a calculation of the reliability was also made by a Monte Carlo sampling. The three answers were averaged for no apparent reason and each was compared to that average rather than to the correct answer obtained by the closed-form integration. The conclusions about this given by the author are, in fact, merely conclusions about the efficiency of some kinds of numerical integration and Monte Carlo sampling. In another section the author takes the same problem and runs a Monte Carlo experiment at a single stress level and then seems disappointed because it does not come out with the right answer, when obviously no one should expect it to come out with a right answer. A multiple stress-level method has been introduced and is not clearly explained, but it does come out with approximately correct answers. Whether this is fortuitous or not is difficult to determine. Two final methods are introduced: the "Bruceton up-and-down" ("Staircase") method and the "Churchman two-stimuli" method—but they are poorly explained. (In a private communication the author has stated that these are discussed in his References 1 and 2.)

Although only the latter is mentioned as requiring Normality, in fact both do. Very briefly, the most reasonable way to approach the problem presumably being attacked here is to estimate the two distributions as closely as possible from the experimental data; that is, the strength has to be estimated by testing samples and the stresses have to be estimated by sampling the expected environment. In calculating the reliability using the difference of stress and strength, if the difference between the means is more than two standard deviations, it is extremely unwise to depend heavily on the exact form of the distribution in the tail regions. The approach described in this paper should be ignored, as it serves to confuse rather than to elucidate. In a private communication the author has stated "... The empirical approach was used so that development engineers, not trained in statistics, could easily compare the results with their own experience." He has also indicated that much of his demonstration was intended to convince engineers who were unimpressed by statistical argument. (Essentially the same paper as this one was published by the author in Proceedings of the Eighth Conference on the Design of Experiments in Army Research Development and Testing; ARO-D Report 63-2, Dec 63)

R67-13155 ASQC 822; 420

USES AND MISUSES OF DISTRIBUTIONS.

G. Ronald Herd (Kaman Aircraft Corp., Bethesda, Md.).

In: Electronic Reliability Annual Conference, 6th, New York, N. Y., May 21, 1965, Proceedings. Sponsored by the Metropolitan New York Chapters of the IEEE Professional Technical Groups on Reliability, Component Parts, Product Engineering and Production, and Basic Science, and the Society for Advancement of Management. 7 p.

Available from S. Houck, Grumman Aircraft Engineering Corp., F-111 Maintainability Group, Plant 15, Bethpage, N. Y.: IEEE Members: $4.00; Nonmembers: $6.00.

The various probability distributions used by reliability and life testing engineers are described, and limitations of each method are mentioned. A statistical approach is taken to the interpretation of the binomial, Poisson, normal, log normal, exponential, gamma, and Weibull distributions. While each has been used successfully to describe reliability data, none of the distributions are considered to provide universally good results. Limitations are discussed for the constant failure rate concept, and preventive maintenance is considered a means of improving a constant failure rate system. M.W.R.

Review: This is a short, easy-to-read paper which can be of value to engineers. Mathematical formulations of the various definitions of failure rate and the uses and misuses of each of the common distributions are given. The statement that "the assumption of a constant failure rate implies that an old item which has not failed is as good as a new item" is not quite accurate. Whether the environment stays constant or has a random stationary nature or even perhaps something else, if the failure rate (i.e., hazard rate) is in fact known to be constant, then a new item is as *likely* to fail in a given time as is an old one. The new part may be the same as, better, or worse than the old one, but we have no way of knowing. It will turn out that, on the average, the failure times of the old and new parts will be the same. If this were not so, then the failure rate would not be constant. Parts may degrade under use even if the constant failure rate assumption is true, it is just that we have no way of knowing in advance what the endurance of a part is; and, again, the endurance of any new part will, on the average, be the same as that of old part known to be working. A most unpleasant implication of this assumption is that short times to failure are the most common, long times to failure are the least common. The question of preventive maintenance can also be expanded upon somewhat. The author suggests that preventive maintenance can improve a constant failure rate system if it actually removes the deteriorated items. The important point is that the new part be known to have a greater endurance than the old part which is to be removed. Otherwise, even though the deteriorated items are removed they may be replaced with something which has even less endurance. This would not decrease the failure rate. All in all the discussion is quite suitable for the level at which it is pitched and is on a subject about which both engineers and practicing statisticians in reliability should be more knowledgeable and concerned.

R-67-13156 ASQC 824; 312

STATISTICAL CONFIDENCE INTERVALS: THEIR USES AND MISUSES IN RELIABILITY ENGINEERING.

John H. K. Kao (New York University, Department of Industrial Engineering and Operations Research).

In: Electronic Reliability, Annual Conference, 6th, New York, N. Y., May 21, 1965, Proceedings. Sponsored by the Metropolitan New York Chapters of the IEEE Professional Technical Groups on Reliability, Component Parts, Produce Engineering and Production, and Basic Science, and the Society for Advancement of Management. 6 p. 6 refs.

Available from S. Houck, Grumman Aircraft Engineering Corp., F-111 Maintainability Group, Plant 15, Bethpage, N. Y.: IEEE Members: $4.00; Nonmembers: $6.00.

Various simple examples are used to explain the meaning of statistical confidence intervals and how they are obtained. Mention is made of one-sided confidence intervals that obtain either an upper or lower level, or the two-sided intervals that present both levels. Confidence intervals are then discussed in terms of hypothesis testing, the more common statistical distributions, and the difference between two parameters. Applications of the large sample and small sample methods are treated, and the necessary formulas are included. M.W.R.

Review: This paper gives the correct traditional meaning for confidence interval. The discussion is largely in terms of examples which will be helpful to some and a disadvantage to others. The evaluation of confidence intervals where the random variable is discrete can be extended to give upper and lower bounds on a particular confidence number. This is discussed in [1]. The author gives very few misuses of a confidence interval but does distinguish it from a tolerance interval and the specification interval. Bayesian intervals, wherein a parameter is presumed to have a probability distribution, are not discussed. The paper is pitched at a reasonably simple level, but there are many equations in it which will be unfamiliar to the average engineer. It will be difficult for him to read the paper.

Reference: [1] *Biometrika Tables for Statisticians, Volume I,* edited by E. S. Pearson and H. O. Hartley, Cambridge University Press, 1956, p. 74–77

R67-13165 ASQC 824; 431; 872

A NOTE ON THE ANALYSIS OF A TYPE OF RELIABILITY TRIAL.

D. R. Cox (Bell Telephone Laboratories, Inc., Murray Hill, N. J.).

Applied Mathematics, vol. 14, Sep. 1966, p. 1133–1142. 9 refs.

Analysis is made of a simple two-state stochastic system that is alternating between the states of being in operation and under repair, and long run efficiency is assumed to be the parameter of primary importance. Termination rules, estimates of system efficiency, and trend testing are discussed. A snap-round method for estimating system efficiency is described; maximum likelihood estimates are made assuming an alternating Poisson process continuous time model; and the combination of these two methods is considered. Asymptotic variances are discussed in comparing the different methods employed, and this analysis is considered applicable to systems with more than two states as long as the times spent in each state are not exponentially distributed. M.W.R.

Review: Some mathematical results pertaining to a simple system alternating between two states are presented in this paper. They have relevance to the design of reliability tests for systems such as computers. The concern is with the statistical properties of the tests, rather than with the engineering or physical aspects. Thus the paper will be of interest to theorists rather than to reliability or design engineers. The material is clearly and competently presented, and adequate references are cited to tie the work in with other relevant publications.

R67-13167 ASQC 824; 814; 815; 872

PROBLEMS IN THE SPECIFICATION AND ASSESSMENT OF ELECTRONIC-EQUIPMENT RELIABILITY.

J. C. Higgins (Brighton College of Technology, Dept. of Computing Cybernetics and Management, Brighton, Sussex, England).

Institution of Electrical Engineers, Proceedings, vol. 113, Sep. 1966, p. 1413–1419. 7 refs.

(A66-40961)

This paper is concerned with some of the problems involved in the specification and assessment of electronic-equipment reliability. The emphasis is on mathematical and statistical aspects of reliability, in particular problems involving the use of the exponential reliability formula and its derivatives, and the development of cost/reliability models to estimate the optimum reliability for an equipment type. The related problems of definition and measurement of reliability, involving choice of time base, redundancy and reliability testing, are also discussed. Author (IAA)

Review: The first half of this paper is a summary of some of the fundamental statistical aspects of reliability. These include the exponential model and related considerations, calculation of reliability for parallel and series networks, and sequential test procedures described in the AGREE Report. Presumably the intent was to present these concepts to an audience not already familiar with them. The presentation is substantially correct, although there are some instances of loose terminology. For example: "...when electronic equipment fails it does so randomly in time; hence the distribution of interfailure times is taken to be negative exponential, ..." This is an example of the all-too-common misuse of the term "random" in the reliability literature. The assumption of a constant failure rate is mentioned later in the discussion. Also, on p. 1416 the author mentions "reliability changes of an order of magnitude or more," after having defined reliability to mean the probability of nonfailure for a time t. These are clearly inconsistent statements, unless the initial reliability before change is less than 0.10. The second half of the paper is concerned with cost-reliability relationships for the various stages in equipment life. These are less familiar and could be quite useful for determining quantitative reliability requirements. They follow by straightforward algebra from the assumptions which are made. While the details were only spot-checked, the work appears to be of good quality. The user will need to follow through the derivations, be sure that he has the notation straight, and note the approximations in order to ensure correct application of the results.

R67-13173 ASQC 823; 822

LIFE TESTING BASED ON THE WEIBULL DISTRIBUTION.

Earl Yost (Defense Supply Agency, Quality and Reliability Div., Washington, D. C.).

Journal of the Electronics Division, ASQC, vol. 5, Jan. 1967, p. 5–13.

Mean life, hazard, and reliable life criteria (as specified in TR-3, TR-4, and TR-6, respectively) are considered in relation to life testing based on the Weibull distribution. Examples of calculations are included for each type of criterion, as well as for testing on the basis of MIL-STD-105D. The scale parameter of the three-parameter Weibull distribution is not required for the life testing sampling procedures described; the location parameter is assumed to be zero hours, meaning that there is some risk of product failure from the very start of life testing; and the shape parameter is assumed to be known for each of the procedures discussed. M.W.R.

Review: This is a good tutorial article on the analysis of life test data based on the Weibull distribution. It features eight examples, clearly and concisely presented. The tables used by the author are found in certain DoD Quality Control and Reliability Technical Reports authored by Goode and Kao at Cornell University. The author identifies these reports by number and title, but does not indicate where copies may be obtained. However, in a private communication he has indicated that they are available from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402 at the following prices: TR-3: $0.40, TR-4: $0.50, TR-6: $0.45, and TR-7: $0.30.

R67-13174 ASQC 822

HINTS AND KINKS.

Paul Gottfried (Booz-Allen Applied Research Inc., Bethesda, Md.).

Journal of the Electronics Division, ASQC, vol. 5, Jan. 1967, p. 15–16.

Limitations of mathematical models in reliability work are stressed, and specific mention is made of the exponential, normal, and Weibull distributions used in failure rate determinations. It is noted that most real-life phenomena do not conform to the degree of neatness required by a normal distribution; and that the exponential distribution has a tendency not to fit the data on hand because of its implied assumption of constant failure rate. Weibull distributions are limited because of unpredictable changes in parameters when stresses, materials, or processes change. M.W.R.

Review: This paper was covered by R65-11739.

R67-13176 ASQC 824; 831; 872

RELIABILITY OF A SEQUENTIAL SYSTEM WITH A FINITE REPAIR CAPABILITY.

E. G. Enns (Northern Electric Research and Development Labs., Ontario, Canada).

Proceedings of the IEEE, vol. 54, Nov. 1966, p. 1630–1631. 2 refs.

Arbitrary failure and repair distributions are calculated for a sequential system with finite repair capability. A Laplace transform is employed, and the reliability function is defined as the probability that the system survives throughout a specified interval. The transform of the reliability and the mean time to system failure are formulated for the case of unlimited repairs; and the formula is also given for the special case in which the failure density is exponential. M.W.R.

Review: This brief note derives the formula for the reliability stated in the title in terms of the Laplace transforms of various functions. It will be useful in mathematical analysis of the systems when the relevant Laplace transforms can be worked out. This work extends the results in the paper covered by R65-12118 by considering arbitrary failure and repair distributions.

83 DESIGN

R67-13133 ASQC 830

Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

CONSIDERATION OF INFALLIBILITY ASPECTS WHEN PLANNING BASIC SYSTEMS OF DIGITAL MACHINES

A. Kojemski and Z. Swiatkowski 6 Apr. 1966 9 p refs Transl. into ENGLISH from Przeglad Elektroniki (Poland), v. 5, no. 5, 1964 p 252–255

(FTD-TT-65-1654; TT-66-62441; AD-640306; N67-15062) CFSTI: HC $3.00/MF $0.65

Treatise on the necessity and method for attaining reliability in the circuits and components of computers. TAB

Review: This is a translation of a Polish article in rough draft form. It is difficult to read but is so general that a more adequate translation is unnecessary. Worst-case design of logic circuits is labeled somewhat wasteful since the worst-case is very unlikely and since more components will be needed. The latter may increase the catastrophic failure rate. Statistical methods are stated to be better than worst-case. It is apparently desired not to import anything for the manufacture of the digital elements although the relationship to reliability is not clear. All in all there is no need for anyone to read this paper except from general interest.

R67-13135 ASQC 838; 821

RELIABILITY OF RESERVE (REDUNDANT) SYSTEMS WITH PERIODIC MAINTENANCE.

V. V. Malev

Engineering Cybernetics, vol. 2, May–Jun., 1964, p. 46–49. 6 refs.

Reliability is considered for systems in which there is periodic maintenance whereby faults of individual components can be eliminated. A model is proposed that permits determination of the average time of system operation before a breakdown occurs, and the necessary formulas are derived. Average time of operation is considered in the case where the interval between maintenance is a random variable as well as when maintenance is regularly performed. M.W.R.

Review: This paper solves a rather specialized problem. The assumptions appear to be clearly stated, although they are not likely to be fulfilled in a practical system. Not all the mathematics was checked, but it appears to be good. The problem is of a type attacked quite often in the literature of this country. This paper appears to contribute nothing new, and thus need not be consulted except by a specialist in this area who wishes to be sure that he is on top of everything.

R67-13141 ASQC 831; 612; 851

FAILURE PREVENTION THROUGH DESIGN OPTIMIZATION.

J. I. Levine (Westinghouse Electric Corp., Aerospace Div., Baltimore, Md.).

In: Annual East Coast Conference on Aerospace and Navigational Electronics, 11th, Baltimore, Md., October 21–23, 1964. Technical Papers. Conference sponsored by the Institute of Electrical and Electronics Engineers, Baltimore Section, and Aerospace and Navigational Electronics Group. North Hollywood, Western Periodicals Co., 1964, p. 3.6.2-1 to 3.6.2-10. 59 refs.

(A65-14971)

Discussion of the problem of design deficiencies, considered to be one of the greatest causes of field failure of electronic equipment. The use of the Monte-Carlo simulation of circuit designs to minimize the number of these deficiencies and to ensure that the design has a high probability of meeting specifications each time it is produced is described. Author (IAA)

Review: This paper essentially decries design deficiencies that exist everywhere and that contribute so severely to unreliability; then suggests that the way to overcome this is by a Monte Carlo analysis. The major portion of the paper is given over to an explanation of the Monte Carlo process. While there is no doubt that Monte Carlo can often be most rewarding, it should be emphasized that getting the equivalent circuit to use in the Monte Carlo analysis and being certain that it applies in the regions of poor performance may be the most difficult task of all. This paper can be used as a good introduction to Monte Carlo analysis, keeping in mind the fact that getting the equivalent circuit involves more than a few lines in a checkoff list.

R67-13142 ASQC 830; 833; 870

RELIABILITY AND MAINTAINABILITY ADVANTAGES OF MODULAR STEERABLE ARRAY RADARS.

K. E. Portz (Bendix Corp., Bendix Radio Div., Towson, Md.).

In: Annual East Coast Conference on Aerospace and Navigational Electronics, 11th, Baltimore, Md., October 21–23, 1964. Technical Papers. Conference sponsored by the Institute of Electrical and Electronics Engineers, Baltimore Section, and Aerospace and Navigational Electronics Group. North Hollywood, Western Periodicals Co., 1964, p. 3.6.3-1 to 3.6.3-5.

(A65-14972)

Demonstration that, in the performance of many radar functions, modular steerable array radars are more reliable, have lower initial cost, and are more easily and more economically maintained than conventional radars designed to perform the same functions. This is particularly demonstrated in the case of multimode, multitarget radar functions. Author (IAA)

Review: The advantage in reliability enjoyed by some of the electronic vs. mechanical parts for radars may be transient in nature, but one of the big factors brought out by the author *is enduring, viz., the improvement in reliability* by using a large number of identical elements. The advantages of becoming accustomed to the system in production, the ability to investigate the design in detail, the concentration of Quality Control departments on a small number of parts, etc. can contribute significantly to reliability. The approach is being used more and more as time goes by even where performance compromises may be necessary. This is another example of the reduction in complexity of operations resulting in improved reliability.

R67-13147 ASQC 838

REDUNDANCY—A SPACE AGE RAINBOW.

George W. Emerson (Martin Marietta Corp., Martin Co., Denver Div., Systems and Advanced Design Dept., Denver, Colo.). *(International Conference and Exhibit on Aerospace Electro-Technology, Phoenix, Ariz., Apr. 20–23, 1964.) IEEE Transactions on Aerospace,* vol. AS-2, Apr. 1964, p. 524–527.
(A64-18143)

Definition of the redundancy concept, presenting the most common errors in the application of redundancy to designs, and exploring methods of optimizing the benefits of redundancy and *of avoiding the pitfalls. Included are practical* design techniques to reduce interdependency in the application of redundant items. Improved techniques are presented for more accurately predicting the reliability of redundant designs. IAA

Review: This is a good article; it decries much of the loose, misleading analysis of redundancy. If anything, the paper's only fault is that it is not severe enough. The independence assumption which is so necessary for the simple results is somewhat ambiguous to the average engineer. The correct, more exact term is statistical independence which is different from and more stringent than physical independence. Any correlations, due to whatever source, will cause statistical dependence. This article is recommended reading for all who make redundancy calculations. The problems are just a further example of the fact that engineers who use special purpose formulas without realizing the limitations involved get themselves and others into trouble.

R67-13150 ASQC 831; 824; 844; 851

LEARNING CURVE APPROACH TO RELIABILITY MONITORING.

J. T. Duane (General Electric Co., Erie, Pa.).
(International Conference and Exhibit on Aerospace Electro-Technology, Phoenix, Ariz., Apr. 20–23, 1964.) IEEE Transactions on Aerospace, vol. AS-2, Apr. 1964, p. 563–566.
(A64-18149)

Several different and complex electromechanical and mechanical systems are shown to have remarkably similar rates of reliability improvement during system development. These similarities provide the basis for a learning curve which can be used to monitor development progress, predict growth patterns, and plan programs for reliability improvement. IAA

Review: This paper presents another model for reliability growth. It is given in terms of failure rate rather than probability of success. The model seems to fit the author's data reasonably well and if applied to similar programs would *undoubtedly be satisfactory. The literature contains many* discussions of reliability growth models, some of which are different from this one. Success will generally be a matter of finding one that seems to fit the kind of work the company has been doing and hoping then that the new work will fit the same model.

R67-13159 ASQC 831; 612

APPLIED COMPUTERIZED RELIABILITY ANALYSIS METHOD (CRAM).

James B. Rivera and Harvey Ryland (ARINC Research Corp., Huntsville, Ala.).
In: Electronic Reliability, Annual Conference, 6th, New York, N. Y., May 21, 1965, Proceedings. Sponsored by the Metropolitan New York Chapters of the IEEE Professional Technical Groups on Reliability, Component Parts, Product Engineering and Production, and Basic Science, and the Society for Advancement of Management. 6 p. 5 refs.
Available from S. Houck, Grumman Aircraft Engineering Corp., F-111 Maintainability Group, Plant 15, Bethpage, N. Y.: IEEE Members: $4.00; Nonmembers: $6.00.

In order to predict the reliability and performance of manned space vehicle programs, a Computerized Reliability Analysis Method (CRAM) has been developed that combines the advantages of easy-to-use mathematical models with electronic computation and analysis. Reliability problems are thereby solved algebraically; and the probabilities are given for finding system reliability, confidence limits, and critical parts. The how, what, and why of CRAM are discussed; and its inputs, capabilities, and limitations are considered. An example details the use of CRAM in reliability analysis. In conclusion, it is noted that CRAM permits accurate and timely information with which to perform design tradeoffs and to overhaul the system in redundant or updated complexities. M.W.R.

Review: This paper will be of most value to an engineer who is already familiar with the computer aspects of a reliability analysis. CRAM analyzes the logic diagram of the system; it does not analyze the circuit diagram as do some other programs, such as NET-1 or ECAP. An example is given of how to use the method but, perhaps of necessity, it is somewhat tedious to follow not to mention the fact that in these Proceedings the papers are grossly misarranged. The statement that CRAM produces a mathematical model of the system is to be interpreted in the sense that the machine turns the crank when given the proper information for the model. It is not meant in the sense that, given the system, the computer will automatically and magically produce a correct model of the system. From the example given in the text, apparently the user must draw all of the logic diagrams that are involved and then the computer system will analyze them. Using a computer to perform analyses such as CRAM can be a tremendous time saver in terms of having faith in the lack of mistakes and reducing the man hours. The neophite, however, should be aware that there is little magic involved; that hard, detailed work is often necessary; that programs are written for one particular computer; that often computers even with the same model number, have personalities of their own; *that programs such as this one require the assistance* of computer personnel; that it takes a lot of hard work on someone's part to get any particular program working on one's own computer; and that if computer costs are directly billed, the first few will usually induce a mild heart attack. Notwithstanding all the disadvantages mentioned above, using a computer to assist in both circuit diagram and logic diagram evaluation is a very wise thing to do. It will often be economical and it certainly is the path to take to achieve systems of high reliability.

R67-13171 ASQC 830; 832; 838; 844

FAILURES OF SYSTEMS DESIGNED FOR HIGH RELIABILITY.

S. J. Ditto

Nuclear Safety, vol. 8, Fall, 1966, p. 35–37. 11 refs.

Three incidents illustrate that single failures can occur in subtle ways in reactor systems designed for high reliability. One failure is related to a single device that could not be tested, but was required for the system to operate. A visual checkout of the electrical connectors on the ML-1 reactor disclosed that a small coil spring to prevent activation during shipping or installation had not been removed. While no difficulty arose as a result of this faulty installation, the discovery pointed to the need for more careful surveillance and maintenance. Another failure involved the interconnection of redundant devices in such a way as to allow a single short circuit to prevent system operation. The third failure occurred when one of a pair of redundant components caused its counterpart to fail. A pair of redundant valves required a certain minimum differential pressure to seat, and the flow through the first was insufficient to develop the necessary pressure across the second. Corrective action included replacement of the valves, as well as changes in the procedure. M.W.R.

Review: While the three examples presented in this short paper pertain to nuclear reactor safety systems, the principles which they illustrate have applicability to the design and operation of a wider class of high-reliability systems. The fact that failures can occur in subtle ways means that designers, maintenance personnel, and operators must be continually on the alert for the presence of inherent design flaws. Comprehensive reporting and appropriate follow-up action are essential for the correction of fundamental deficiencies when they exist.

R67-13172 ASQC 831; 770; 873

DIAGNOSTIC PROGRAMS: GREAT EXPECTATIONS?

John E. Thron (Honeywell, Inc., Computer Control Div., Boston, Mass.).

Computer Design, vol. 6, Jan. 1967, p. 16, 18.

Major functions that might be programmed in the test and maintenance procedure for a computer system are: (1) exhibition of symptoms, (2) detection of failure, and (3) isolation of faulty components. Although a computer system exhibits the symptoms of its own failings, it cannot be programmed to exhibit all of these failings; and a realistic approach must be taken as to what the computer system can actually do. None of the three major functions can, therefore, be categorically assigned to a test and maintenance procedure. Determination must be made of which functions must be program-assisted and which will benefit the user. M.W.R.

Review: This is a brief, realistic discussion of the role of diagnostic programs in the testing and maintenance of computer systems. Its principal message is that unrealistic expectations for such programs must be avoided. They can be useful tools for the improvement of reliability in limited situations if their exact functions are properly specified. Their limitations, as well as the skills of the user, must be properly taken into account.

R67-13177 ASQC 837; 824

OPTIMAL WORST-CASE CIRCUIT DESIGN.

A. Brown and H. C. Yang (International Business Machines Corp., Systems Development Div., Poughkeepsie, N. Y.).

In: National Electronics Conference, Proceedings, Chicago, Ill., Oct. 25–27, 1965, Vol. XXI. Sponsored by Illinois Institute of Technology, the Institute of Electrical and Electronics Engineers, Northwestern University, and the University of Illinois. Chicago, Ill., National Electronics Conference, Inc., 1965, p. 737–742.

Linear programming techniques are shown to be applicable to worst-case design problems; and for the design of a transmission line receiver, these techniques lead to a complete determination of the tradeoff relations that characterize a class of feasible designs. The nonlinear optimal design problem is reduced to a linear programming problem via a transformation of variables; the resulting problem is solved with a standard linear programming subroutine, and this solution is transformed back to the original variables in order to solve the original problem. A system of nonlinear differential equations is derived to determine maximum tolerance; and these solutions, as functions of the common tolerance, are also solutions of the transformation equations. A singular point of these equations of motion is a solution of the maximum tolerance problem. Definitions and concepts from mathematical optimization theory are included, the associated worst-case design problem is formulated for a transmission line receiver circuit, and numerical results are included. M.W.R.

Review: This is essentially a mathematical paper although the authors might well feel that engineers "ought" to be able to follow it and to apply it. In principle the mathematics is reasonably simple but some of it is tedious to follow; it was not checked in its entirety but appears to be quite reasonable. The paper does not deal at all with the desirability of worst-case design but with how to solve some worst-case design problems. The approach seems appropriate and worthy of further pursuit. Most design engineers will not be able to apply the method as a result of reading this particular article although it might get them interested. They will undoubtedly need professional help for the mathematics and computer programming. The entire procedure would be reasonably expensive and thus not suitable except where extremely high production would justify this amount of effort on a single circuit or where the money is available to enforce very high reliability requirements. An example is given, but even following it will require some effort. (The indication that studying the article will require effort is not a value judgment on the paper, it just lets the reader know what to expect.)

R67-13179 ASQC 838; 822

SOME NOTES ON OPTIMUM RELIABILITY.

R. B. Rutledge (Emerson Electric Co., St. Louis, Mo., Southern Illinois University, Edwardsville, Ill.).

In: National Electronics Conference, Proceedings, Chicago, Ill., Oct. 19–24, 1964. Vol. XX. Sponsored by Illinois Institute of Technology, the Institute of Electrical and Electronics Engineers, Northwestern University, and the University of Illinois. Chicago, Ill., National Electronics Conference, Inc., 1964, p. 917–920. 5 refs.

A method for maximizing the reliability of a redundant system develops criteria to determine the optimum series or parallel redundant structure. A set of components having two identical failure modes is considered, and each component is assumed to have two mutually exclusive modes of failure. No restrictions are placed on the failure distribution functions of the modes, so that the results are useable for any failure distribution functions. It is shown that if each component has a finite probability of failing in each of two modes, then a finite number of components give the optimum solution. If failure occurs in only one mode, then the reliability of the redundant structure approaches one with the use of a sufficiently large number of components. Examples illustrate that the optimum structure is a function of the time interval over which the reliability is to be optimized; and, therefore, the optimum redundant structure often changes as a function of time. M.W.R.

Review: This paper is apparently an adaptation of a portion of its Ref. 4 which was covered by R66-12453. Some of the comments that appear there apply here as well. The paper contains quite a few typographical errors which make it somewhat difficult to read. There is an implication that optimum reliability is achieved by one or the other of the systems considered by the author, whereas, in fact, other forms may well give a more reliable result. Hammock networks in particular, which are a combination of series and parallel elements, are always better than just series or parallel as long as neither the short nor open failure probability is zero. Other papers on this same subject have appeared elsewhere and treat the subject more generally.

R67-13180 ASQC 830; 773

DESIGNING FOR INCREASED RELIABILITY THROUGH TEST EQUIPMENT INTEGRATION.

Harvey L. Balderston (Boeing Co., Aero-Space Div., Seattle, Wash.).

IN: National Electronics Conference, Proceedings, Chicago, Ill., Oct. 19–21, 1964. Vol. XX. Sponsored by Illinois Institute of Technology, the Institute of Electrical and Electronics Engineers, Northwestern University, and the University of Illinois, Chicago, Ill., National Electronics Conference, Inc., 1964, p. 921–926. 10 refs.

Integrating test equipment with actual systems is discussed in terms of increasing overall system reliability. Design considerations of integrated test-systems are treated, and the wide range of possibilities for such integration is discussed. Integrated test equipment can determine the operation status of flight vehicles by a series of measurement processes with a degree of reliability that is directly related to the success and failure of the measurements involved. Integration of test equipment has the advantage of eliminating many of the problems associated with transmission lines, test point impedances, and separate test equipment. Use of such equipment is illustrated by a 25 Kw/vlf/lf amplifier and a second generation ICBM system. An integrated concept for a Mach 3 airliner is discussed, as are the Fault Isolation Semiautomatic Techniques (FIST) project. M.W.R.

Review: The idea of integrated test-systems has gained further acceptance since this paper was written and is considered an essential part for many aerospace systems. Integrating the test equipment into the hardware is not always as easy as it might appear from reading the paper. Furthermore, the designer will probably have to evaluate its effectiveness for each different piece of equipment and for various levels of integration; in some cases, of course, the decision will have been made at a higher level. Even with the test-system integration into the equipment there is still a possibility of an erroneous indication; just how much less this would be than with separate equipment would have to be decided in each case. This paper is largely a philosophic one, but it can still be of use to designers. In a private communication the author has indicated that these concepts have since been successfully implemented by Boeing on a test basis.

84 METHODS OF RELIABILITY ANALYSIS

R67-13131 ASQC 840; 522; 814

STATISTICAL APPLICATIONS IN RESEARCH AND DEVELOPMENT TO IMPROVE RELIABILITY AND PRODUCT VALUE.

Keki R. Bhote (Motorola, Inc., Chicago, Ill.).

Value Engineering Symposium on Advancement in the State of the Art, Redstone Arsenal, Ala., Nov. 18–19, 1964, Paper. 11 p. Included in N65-32701 Published by Army Missile Command, Huntsville, Ala. and Available from CFSTI: HC $3.00/MF $0.65

(N65-32701)

Statistical techniques that can be used to monitor the effectiveness of an engineering design and to cut days of delivery time and wasteful expenditures are discussed. These include the use of "random and multiple balance" and "evolutionary optimization" to separate important and interacting variables from those that are unimportant to design. Overstress multiple environment analysis can be undertaken in the prototype and production stages to find weak links in design and to determine consistency of workmanship and materials used during production. Uses of variation charts, factorial design, tolerances, scatter and sequential plots, and design evaluation are mentioned. M.W.R.

Review: The general methods suggested for product improvement and development are worthwhile. The emphasis given to random and multiple balance experiments is out of proportion since these designs are a subject of considerable controversy among statisticians. For one thing they confound the effects and interactions in an unknown way, whereas a fractional factorial experiment confounds them in a known way. It can be argued that if a random balance experiment gives you the answers you are seeking, almost any experiment would have done so. Certainly it is worthwhile to test the effect of several factors at once but the exact method for doing it is something else again. Overstress testing, the other technique discussed in detail, is very worthwhile. The author does not explicitly distinguish between a simple stress-strength type of failure and a damage-endurance type of failure. It is worthwhile noting for each failure mode which one of these simple models, if either, the material is expected to follow because the analyses are different. Near the beginning of the paper Value Engineering is touted too much. In Value Engineering, as in Quality Control and Reliability, it has been found that if one interprets the specialty narrowly, as was done when it was first set up, one cannot properly attack the real problems. Each one of the specialties has broadened its area of interest essentially to that of the entire Engineering cycle in order to do the engineering job that needs to be done. Recent trends are to make the Engineering departments include in engineering what should be there and to limit the specialties such as Quality, Reliability, and Value Engineering to their own narrow realms and to have the specialists in them act more as consultants.

R67-13138 ASQC 840; 770; 850

Union Carbide Corp., Cleveland, Ohio. Linde Div.

PRODUCTION ENGINEERING MEASURE FOR IMPROVED RELIABILITY OF SOLID TANTALUM ELECTROLYTIC CAPACITORS Final Report, 1 Jul. 1963–30 Jun. 1965

H. W. Holland [1965] 106 p

(Contract DA-36-039-AMC-03624(E))

(AD-620599; N65-36320)

A review of progress in process refinement is followed by descriptions of the processes studied and a manual for control of quality from raw material through finished product. The first step in the engineering studies was establishment of life test "acceleration factors". The acceleration factors provide a relationship between the applied voltage and the equivalent time on test, with a higher-than-rated voltage producing the same effect as a longer time at rated voltage. Compared to normal life testing, this work produced a significant reduction in the time required to evaluate the effect of a process change on the failure rate of capacitors affected. Author

Review: This is a comprehensive report. It covers a two-year period during which the reliability of solid tantalum electrolytic capacitors was improved. It is impossible from such a report to be critical of the engineering judgments made and of some of the technical aspects of the program. According to the author the reliability of capacitors was appreciably improved during this period and, by the end of the program, they were able to produce capacitors meeting the reliability goal. It is possible to comment on some of the analyses which are shown and the following criticisms apply thereto. (1) On p. 10, the life vs. voltage characteristics are shown at a given temperature for several voltages. The straight lines on the Weibull paper are asserted to be parallel and in fact are so drawn. However, only one of the lines fits the points at all well; in one of the others, for example, all of the points fall below the line. (2) Later in the report it is said that two slopes were routinely observed for each Weibull line, but these are not shown on Figure 10. On p. 41 where the two slopes for the Weibull line are shown it is certainly easy to see that there might even be three slopes, the third one occurring near the beginning. (3) On p. 42 where the hazard rate is plotted as a function of running time (burn-in time) it is odd how the hazard rate jumps by a factor of over three at around 20 hours. It would be difficult to give a physical explanation for this jump. (4) The curves of breakdown voltage vs. cumulative failure for the powder from different vendors are asserted to be straight lines on Gaussian probability paper. While with large samples this might well be true, it is not at all obvious from the actual data points. (5) To meet the reliability goals for the program, a burn-in time of almost 250 hours was apparently necessary; yet very few of the data shown in the text come from life tests longer than 250 hours. The above comments are not meant to deprecate the engineering improvements which were apparently made in the processing, but to point out the severe difficulties encountered when trying to meet high reliability goals. The use of statistics by engineers is still generally in a very rudimentary state; all too often they are inclined to take statistics and mathematics at appreciably more than their face value.

R67-13139 ASQC 844; 711; 712

Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

ON THERMAL FATIGUE

N. D. Sobolev 25 May 1966 21 p refs Transl. into ENGLISH from Russian

(FTD-TT-65-1697; TT-66-61800; AD-635853; N66-37903)

CFSTI: HC$3.00/MF$0.65

The procedure for testing for thermal fatigue should provide the possibility for variation in the deformations within wide ranges, and the study of the conformity to law in thermal fatigue should be done with the separation of the influence of the thermal and mechanical factors. It was established that the individual features of the process of deformation do not have an influence in the formation of breakdown cracks. The breakdown from thermal fatigue under different stress states is described by the energy criterion. A relative evaluation of the resistance of materials to thermal fatigue can be done with the aid of approximation criteria. TAB

Review: Thermal fatigue is one of the failure mechanisms or failure modes in mechanical structures. About half of this rough draft translation is concerned with a qualitative discussion of the origin of thermal fatigue, namely, heating of a part in the presence of mechanical constraints. Consideration is given to non-uniform cross-sections which produce stress concentration and to plastic deformation wherein elastic theory no longer holds. Some fatigue curves are given but they are difficult to interpret. The author is especially concerned about multi-axial stresses and the means for arriving at a single number indicative of the effective stress on the part. He concludes essentially that breakdown from thermal fatigue is described by the energy criterion. Considerable reference is made to the work of Coffin published in this country (although none of Coffin's work is cited in the author's bibliography). There is no need for anyone to read this paper unless he is doing research in this specific field.

R67-13140 ASQC 841; 773; 842

LIFE TEST RECORDING—WHICH TECHNIQUE?

Abe Siegelman (Beckman Instruments, Inc., Electronic Instruments Div., Schiller Park, Ill.).

Electronic Instrument Digest, vol. 3, Jan. 1967, p. 8–16.

Five classes of life testing are differentiated, and available methods of recording results are discussed in terms of usage and cost considerations. General classes of life testing defined are fixed-time, go/no go testing within predetermined limits, real time recording of device performance, continuous analog recording, and fault recording. Some of the basic types of recorders that are discussed in terms of their advantages, applications, and limitations are the (1) potentiometric strip chart, (2) multipoint potentiometric strip chart, (3) direct writing oscillograph, (4) event, (5) optical, (6) digital, and (7) tape. A table gives the number of channels, chart width, and cost considerations for each of these. Design of a low cost test setup is detailed, as is an economical fault recorder test setup. M.W.R.

Review: This article is quite suitable for the magazine in which it appears. Life-testing is defined and the need for it explained. Kinds of equipment to choose and ways to choose it are each discussed in turn. The article is general and introductory and could be of both interest and use to those who need to learn at that level about life-test recording. One very good point which the author makes is that the life-test equipment should be much more reliable than the items being tested; otherwise "exactly what is testing which?". Life-testing is divided into several classes; they are not mutually exclusive but are just convenient labels. (The term "real time" is confusing and is contrasted in at least two different senses.) The author states that the only meaningful cost for life test equipment is the total cost per data sample. While this may be true, his selection of costs is incomplete. For example, and interestingly enough, repair costs are not included. There may be a cost of training an operator, the cost of money, the cost of delays in acquisition. Finally, the figure of merit most meaningful to your company may not be total cost but something else.

R67-13145 ASQC 844; 782

FAILURE RATES, LONG TERM CHANGES AND FAILURE MECHANISMS OF ELECTRONIC COMPONENTS.

G. W. A. Dummer (Royal Radar Establishment, Malvern, England).

Electronic Components, vol. 5, Oct. 1964, 1. 835–862. 6 refs.

Influence of various environments on failure rates of electronic components is considered, and specific attention is given to the change in component characteristics with time and the failure mechanism under severe environments. Data are tabulated for submerged telephone cable amplifiers, electronic telephone exchange equipment, computers at room temperature, equipment on civil aircraft, general laboratory equipment, and domestic radio and television receivers; and the failure rates are shown for the equipment under each of these six environments. A guide is included for the average failure rate of electronic components in general purpose ground-based equipment at maximum ratings. To show the changes with time on typical electronic components, data are given for evaporated nickel–chromium film resistors, nonlinear resistors, a variety of capacitors, relays and switches, and power transformers. A tabulation is included for the effects of high humidity, high temperature, low temperature, low pressure, nuclear radiation, and vibration and shock on the mechanisms of failure for 32 different types of components. M.W.R.

Review: This is a rather comprehensive article by a well-known British author. It is divided into three parts. The first gives catastrophic failure rates and the influence of environments. A major portion is devoted to the presentation of data in chart form. Similar data are available in this country in the RADC Handbook and MIL HDBK 217 (latest version). One should never be dismayed at any inconsistencies that appear between documents of this sort—these data are just not that well known. There are many variations within a class, due, for example, to time of manufacture, which manufacturer was responsible, lot to lot variations, and the fact that not all items of the same nominal description are built in the same way. The second part deals with the change in characteristics of electronic components with time. It presents quite a bit of material in the form of graphs. Again most of the material is taken from British sources as befits an article in a British magazine. The third part discusses the mechanisms of failure of electronic components under severe environments. The results are given largely in extensive tables, brief though they are by necessity. A very good point that the author makes is, "Whilst it is valuable to collect and summarize failure rates, it is more important to take action to reduce them." The entire three parts of the article can be very helpful, especially to those who have recently entered the field and wish to become oriented in this area. The article is rather long, but not unduly so considering all the charts and graphs presented.

R67-13149 ASQC 844

IDENTIFICATION AND CLASSIFICATION OF MODES OF FAILURE IN AERONAUTICAL EQUIPMENT.

Robert R. Dye (Northrop Corp., Norair Div., Systems Reliability Branch, Hawthorne, Calif.).

(International Conference and Exhibit on Aerospace Electro-Technology, Phoenix, Ariz., Apr. 20–23, 1964.) IEEE Transactions on Aerospace, vol. AS-2, Apr. 1964, p. 535–542. (A64-18145)

Discussion of four different kinds of "failure mode" identifications. These are: by symptom, by primary failed part, by failure mechanism, and by "failure mechanism and its cause." Two years of experience with a failure mode analysis system have led to the classification of approximately 10,000 malfunctions. About 6000 of these were analyzed in sufficient detail to establish at least the identity of the primary failed piece part. About 1500 different modes of failure were thus identified. Another 1000 modes of failure by symptom were also identified. Corrective actions were expedited when the nature of part failure was identified. Identified modes of failure also form a basis for design review checklists for application to future designs. IAA

Review: The first portion of this paper discusses the philosophy of classification of failure modes and failure mechanisms. It is especially valuable because it goes into the subject in greater depth than usual. To quote from the paper, "...Because a symptom from one viewpoint may be considered a cause of failure from another viewpoint...." Similarly, one person's failure mechanism may be another's failure mode. Some examples are given of failure analysis in depth and of the failure-mode analysis program of the company. The latter are interesting as much for what was not done as for what was done. The last part of the paper is similar to many others and is probably of interest only to specialists in this area or to those who have not run across such a discussion before. The early part of the paper, however, discusses points rarely made elsewhere and is very worthwhile reading.

R67-13151 ASQC 840; 775

INFRARED SESSIONS AT THE SPRING CONVENTION OF SOCIETY FOR NONDESTRUCTIVE TESTING, LOS ANGELES, CALIF., FEBRUARY 22–26, 1965, TRANSACTIONS.

Sponsored by the Society for Nondestructive Testing, Inc., Wayland, Mass., Raytheon Co., Oct. 1965. 352 p. 54 refs. Available from the Society for Nondestructive Testing, Inc., Evanston, Ill.: $7.50.

Infrared techniques for use in nondestructive testing of electronic and other equipment, as well as specific applications of these techniques, are discussed in a series of papers. An infrared system for detecting flaws in metals and high speed scanners is described; and attention is given to infrared fiber optics, emissivity equalization by thermosetting coatings, and circuit reliability improvement. Applications of infrared nondestructive testing are considered for the military, for solid propellant missile motors, and for development of thin film resistors. Isothermal mapping and resistance microwelding are evaluated. Tolerance studies are reported for infrared production testing of electronics, and a high speed infrared mapping system for reliability assessment of miniature electronic circuits is described. Contributions of emissivity and thermal conductivity to testing is treated, and two thermal nondestructive testing techniques are presented. M.W.R.

Review: This collection of 21 papers can be valuable to those who are doing research in the applications of Infrared to Reliability and also to design engineers who are interested in ways of ferreting out the weak points in produced material. Two of the papers are available in abstract only; two others later appeared elsewhere. The collection as a whole varies from broad descriptions of programs to specialized applications, the majority of which are to electronics and structures. Some applications show considerable ingenuity; some appear to be reasonably straight-forward applications of basic principles. Infrared is one of the non-destructive testing techniques that deserves to become more popular. Once there are enough manufacturers of equipment and enough engineers who are familiar with its uses, it can take its place on the basis of cost and effectiveness along with many other nondestructive techniques. Of particular interest are those applications in which the infrared approach appears to be the most convenient, and sometimes the only means capable of supplying information difficult or impossible to obtain by conventional techniques. Much engineering judgment is necessary in the use of infrared techniques. Many items will be rejected because it is *supposed* that life will be reduced rather than because such is known from the results of extensive correlation tests. This sort of reasoning will be almost essential as failures become more difficult to find. It can be overdone, however; hypotheses have a way of needing to be tested because it is so easy to lead oneself astray.

R67-13152 ASQC 844

BASIC FAILURE MECHANISMS IN SEMICONDUCTORS AND DIELECTRIC TYPE DEVICES.

R. P. Misra (Newark College of Engineering, N. J.).
In: Basic Failure Mechanism and Reliability in Electronics, Annual Conference, 5th, Newark, N. J., Jun. 15, 1964, Proceedings. Sponsored by the Metropolitan New York Section of IEEE Basic Science and Professional Group on Reliability and the Society for Advancement of Management. 16 p. 8 refs.
Available from Stevens Institute of Technology, Hoboken, N. J.: IEEE Members: $5.00; Nonmembers: $8.00; Student Members: $4.00.

Electric field is computed for the two dielectric materials in a plate condenser and in concentric coaxial cable to shed light on the basic failure mechanisms that might occur when two dielectrics of widely different dielectric constant get in series. Similarity in failure mechanism for reverse bias junction is noted by the calculation of electric field at an abrupt p–n junction. Such data are necessary for the design engineer to have an integrated look at semiconductor reliability. Reliability factors that must be considered for diodes and transistor include electric fields, surface, packaging, ambient temperature and temperature gradient, and considerations such as thermal cycling and g factors. Time required for 50% semiconductors to fail is tabulated, and mechanisms involved in beta-drift variations in transistors are discussed. The internal geometry of the transistor may be optimized to make such factors less surface dependent. M.W.R.

Review: The main portion of the paper is devoted to the fact that very high fields can be generated in thin layers of a dielectric where it is in series with other dielectrics. This, of course, has been well known for years especially in very-high-voltage engineering because it is one of the major causes of localized corona. It is worthwhile emphasizing this point again where low voltages are concerned. The field in the vicinity of an abrupt junction is given—of course on a microscopic basis there is no such thing as an abrupt junction. Therefore one would expect the actual fields, due to the impurity gradients, to be somewhat less. In the several years since this paper was given, more comprehensive discussions of the failure mechanisms in semiconductors have appeared and this paper will rarely need to be consulted.

R67-13153 ASQC 844; 851

TRANSISTOR FAILURE MECHANISMS AT ACCELERATED STRESS LEVELS.

D. S. Peck (Bell Telephone Laboratories, Inc., Allentown, Pa.).
In: Basic Failure Mechanism and Reliability in Electronics, Annual Conference, 5th, Newark, N. J., Jun. 15, 1964, Proceedings. Sponsored by the Metropolitan New York Section of IEEE Basic Science and Professional Group on Reliability, and the Society for Advancement of Management. 25 p. 2 refs.
Available from Stevens Institute of Technology, Hoboken, N. J.: IEEE Members: $5.00; Nonmembers: $8.00; Student Members: $4.00.

Accelerated stress applications are discussed for low to medium frequency silicon npn mesa or planar transistors that do not include contacts which overlay the planar oxide, and a typical failure pattern is shown for such a device. Estimates of failure rates assume a log normal life distribution without the presence of manufacturing freaks, which can increase rates immeasurably; and accelerated temperature or power stress can identify these freaks. The validity of accelerated power stress parameter degradation is considered; along with the generation of catastrophic failure modes, acceleration of mechanical stress, and shortening of life by accelerated stress. Life tests at highly accelerated stresses are considered as efficient and economical means of providing meaningful data on products. M.W.R.

Review: This is a subject on which the author has written extensively and, undoubtedly, this is a compilation of much of the material that has appeared elsewhere. The paper is limited to low-to-medium-frequency, silicon, npn, mesa or planar, transistors. (Other studies, notably those by Partridge at MIT, have shown that usefully accelerating the degradation of most germanium transistors may be very tricky indeed.) The discussions of failure mechanisms and acceleration as given here. certainly seem plausible—not all of the reasoning has to be completely accurate in order for the testing to be effective. Many graphs are shown which contain data points. It is always of interest to see how an author draws the lines through these data points. The question often arises, "Is the author trying to infer the line from the points; or is he trying to see if the points are plausible, given the line?" and there is a difference. The question exists in this paper. Regardless of the violently differing viewpoints on accelerated testing (this one is in favor—others disagree) most manufacturers will continue to use it in one way or another for process control and some sort of life prediction.

R67-13157 ASQC 846

THE USES AND MISUSES OF RELIABILITY DATA.

Ernest R. Jervis (ARINC Research Corp., Washington, D. C.).
In: Electronic Reliability, Annual Conference, 6th, New York, N. Y., May 21, 1965, Proceedings. Sponsored by the Metropolitan New York Chapters of the IEEE Professional Technical Groups on Reliability, Component Parts, Product Engineering and Production, and Basic Science, and the Society for Advancement of Management. 9 p.
Available from S. Houck, Grumman Aircraft Engineering Corp., F-111 Maintainability Group, Plant 15, Bethpage, N. Y.: IEEE Members: $4.00; Nonmembers: $6.00.

An approach to the collection and usage of failure rate data is taken that should result in more precise reliability evaluation. It is emphasized that the proposed use of the data must be known before determination is made of what and how collection should be made. Before using reliability data, the validity of the collection methods should always be confirmed. The various physical processes described by the data should match the processes that are being evaluated or predicted. Following a discussion of the sources of data, examples are given of how these data can be used and misused. Several graphs are included to show different types of reliability data, such as (1) field removal rates for transistors, (2) shelf life of transistors at various temperatures, (3) failure rates of integral electronic devices, and (4) effect of degassing cycle on gas diffusion. M.W.R.

Review: The author has illustrated quite well some of the quandries involved in using experimental data to predict reliability. Whether the data be gathered in the laboratory or in the field, something is always lacking. If they are field data we do not know the conditions very well since people who collect such data have other "more important" things on their minds. If they are laboratory tests we are not sure that the environment duplicates the field well enough. This article is a good one for both design and reliability engineers to read because it is realistic in its appraisal of the usefulness of data. The practicing engineer is faced with the problem, however, that in spite of the inadequacies of the data he must draw some conclusion. While the data do not tell him everything he wishes to know, they can tell him something. This process of finding out just what the data do and do not tell separates the men from the boys. Perhaps the thesis of the paper could be stated as: be skeptical but not so skeptical that you never get anything done. As components become more and more reliable the fond hope that field experiments will be designed better will not often be realized. It is easier to go on hoping and relying on the design engineers' judgment than it is to spend the time, effort, and money for meaningful field tests.

R67-13160 ASQC 844

MECHANISMS CAUSING FAILURE IN HIGH VOLTAGE RECTIFIER CHAINS.

R. P. Misra, Y. D. Kin, and R. Mc Millan (Newark College of Engineering, N. J.).

In: Electronic Reliability Annual Conference, 6th, New York, N. Y., May 21, 1965, Proceedings. Sponsored by the Metropolitan New York Chapters of the IEEE Professional Technical Groups on Reliability, Component Parts, Product Engineering and Production, and Basic Science, and the Society for Advancement of Management. 10 p. 12 refs.

Available from S. Houck, Grumman Aircraft Engineering Corp., F-111 Maintainability Group, Plant 15, Bethpage, N.Y.: IEEE Members: $4.00; Nonmembers: $6.00.

Calculations on potential distribution in series-parallel capacitances are made to determine the potential distribution and failure modes in a series diode chain that must handle high voltages. Design optimization of the chain can be undertaken by setting up a computer program that will effect equal voltage division between each section of the series. Voltage distribution by this means is not very good, even if very large capacitors are used. Therefore, a graded capacitor approach is suggested that assumes a continuous line concept, with variable series and constant leakage per unit length. If a very large number of series capacitors are assumed, it is possible to approximate the discrete case by permitting the unit length of the continuous case to correspond to the integral values in the lumped case. Computed voltage distribution is graphed for 30 high voltage diodes in series. M.W.R.

Review: The title is somewhat misleading since the article deals with a particular conceptual model of a rectifier chain and solves it to show that for a particular case the distribution of voltages across the rectifiers may be poor. By adjusting the parameters of compensating capacitors, the voltage distribution can be made uniform. The relationship to reliability is not through the discussion or elimination of any uncertainty but through a deterministic design to avoid certain circuit operating conditions. The derivations themselves are based on the fact that the capacitances of the diodes and to ground are independent of voltage and that the reverse bias impedance and leakage impedances can adequately be represented by capacitors. The one experiment demonstrated that compensation according to the derived formulas can give a uniform voltage distribution across the diodes insofar as those particular test conditions are concerned.

R67-13161 ASQC 844

FAILURE MECHANISMS IN RAPID DISCHARGE RATE ENERGY STORAGE CAPACITORS.

Timothy C. Gillette (Edgerton, Germeshausen and Grier, Inc., Bedford, Mass.).

In: Electronic Reliability Annual Conference, 6th, New York, N. Y., May 21, 1965, Proceedings. Sponsored by the Metropolitan New York Chapters of the IEEE Professional Technical Groups on Reliability, Component Parts, Product Engineering and Production, and Basic Science, and the Society for Advancement of Management. 4 p. 6 refs.

Available from S. Houck, Grumman Aircraft Engineering Corp., F-111 Maintainability Group, Plant 15, Bethpage, N.Y.: IEEE Members: $4.00; Nonmembers: $6.00.

Standard paper and film capacitors, special paper and foil capacitors, and aluminum electrolyte capacitors are discussed in terms of failure mechanisms encountered during high energy storage use. Applications are discussed, including standard capacitors in exploding bridge wire detonators for missile separation and rocket engine ignition. Rules for obtaining a reliable system with specially optimized capacitors are given; and these include the following precautions: (1) Never use energy storage capacitors beyond their published ratings. (2) Design the system to prevent applying full rated voltage for long periods of time. (3) Perform overvoltage tests specified for short durations on all the capacitors before using them in a system. For both these and electrolytic capacitors, the choice of a reliable vendor is stressed. Electrolytic capacitors should not be used beyond their published maximum working voltages. Maintaining voltage on the capacitor bank improves reliability; and sample testing is recommended where the charge–discharge cycle is simulated and where dc leakage current is measured. M.W.R.

Review: This is a phenomenological discussion of failure mechanisms; there are no failure rate numbers. It would be quite useful to a designer who is using this kind of capacitor since it is short and easily readable. If it were feasible, it would have been helpful to modify statements such as "...safety margins generally need to be increased...to yield a long life unit..." to be more quantitative. Nevertheless, the information which is given is quite in accordance with the title and should be most helpful.

R67-13162 ASQC 844; 711; 714

BASIC MECHANISMS OF FAILURE IN DIFFUSED SILICON AND GERMANIUM TRANSISTORS.

L. E. Miller (Bell Telephone Laboratories, Inc., Laureldale, Pa.).
In: Electronic Reliability, Annual Conference, 6th, New York, N. Y., May 21, 1965, Supplement to Proceedings. Sponsored by the Metropolitan New York Chapters of the IEEE Professional Technical Groups on Reliability, Component Parts, Product Engineering and Production, and Basic Science, and the Society for Advancement of Management. p. 1–37. 52 refs. See R67-13155 for Availability.

Surface, bulk, and structural failure mechanisms are discussed for diffused silicon and germanium transistors. It is shown that although failures may occur in many modes, the mechanisms involved appear to be invariant. The largest proportion of failures in both mesa and planar transistors is due to changes in surface potential from charge accumulation effects. As semiconductor surface technology becomes better understood and devices become more reliable, failures due to bulk effects can be observed. These changes are caused by lattice damage from radiation or by localized changes in impurity profiles from the motion of the fast diffusing impurities. Failure modes that occur because of the physical and metallurgical properties of the transistors include differential thermal expansivities, solid phase chemical reactions, and electrolysis and stress corrosion. Design compromises that will permit minimization of these failure mechanisms are discussed, as are criteria of failure and techniques of aging and analysis. M.W.R.

Review: This is a rather comprehensive tutorial discussion of the basic mechanisms of failure in semiconductors. It is somewhat long, but should be readily understandable by engineers who have an elementary idea of the construction of semiconductor devices. An especially valuable portion is the discussion of differing points of view. The term "inherent reliability" is poor because it concentrates on our conceptual models of the devices rather than on the devices themselves. When high inherent reliability is mentioned, it usually refers implicitly to some very simple-minded conceptual models rather than to accurate ones; such is the case with regard to semiconductor reliability. Generally speaking, the approach taken in the paper is excellent and the paper will be a profitable one to keep for a reference.

R67-13163 ASQC 844; 711; 714

FAILURE MECHANISMS IN THIN FILM RESISTORS.

H. T. Roettgers (Standard Telecommunications Laboratories, Ltd., Harlow, England).
In: Electronic Reliability, Annual Conference, 6th, New York, N. Y., May 21, 1965, Supplement to Proceedings. Sponsored by the Metropolitan New York Chapters of the IEEE Professional Technical Groups on Reliability, Component Parts, Product Engineering and Production, and Basic Science, and the Society for Advancement of Management. p. 39–43. 4 refs. See R67-13155 for Availability.

Concepts of a physics-of-aging program are discussed in relation to failure mechanisms of polycrystalline alloy resistive thin films. These mechanisms are considered under the headings of surface reactions, diffusion processes, and phase changes; and some comments are made on ways of separating the failure mechanisms. Surface reactions include interactions with the outer atmosphere, the resistor substrate, and between gas and metal on the inner surfaces. Diffusion down grain boundaries, through compound layers, and of imperfections and solid materials are described. Oxidation and precipitation are discussed as the most important phase change failure mechanisms, and some remarks are included on the conductivity mechanisms in resistive films. M.W.R.

Review: This paper is of more concern to engineers engaged in research on thin film resistors than to design engineers handling circuitry. The discussion is at a level of the physics and chemistry of the processes and involves surface reactions, diffusion processes, and phase changes. It is generally similar to other such discussions that have appeared in the literature especially in reports of projects sponsored by Rome Air Development Center. The discussion of surface reactions is handled on a conventional simplistic level; the subject can get much more complicated.

R67-13164 ASQC 840; 824; 882

PREDICTING THE RELIABILITY OF A SYSTEM.

J. C. Cluley (Birmingham University, Dept. of Electronic and Electrical Engineering, Birmingham, England).
Electronics and Power, vol. 12, Oct. 1966, p. 361–364. 11 refs.
(A66-42866)

Outline of some elementary concepts of reliability prediction for electronic systems based mainly on a constant failure rate. The MTBF (mean time between failures) measure of reliability is reviewed, and its relation to the MTTR (mean time to repair a fault) measure is considered. The applicability of MTBF to component testing and circuit conditions is discussed. It is not believed to be the most useful criterion of reliability in the case of redundant systems. IAA

Review: This is a short article discussing the elementary concepts of reliability prediction. As such, it will be useful to newcomers to the field, or those who wish to get a quick bird's-eye view of these concepts. However, those with a serious interest in using the concepts should look to more extensive treatments for details. In the expression for n_f on p. 362, the subscripts on N and P should be i; the summation symbol is missing in the denominator in the expression for M on the same page. On p. 366 it is implied that the failure probability for a series system can be obtained by adding the failure probabilities of the components. It happens that in the example given this incorrect procedure gives a correct answer, because the failure probabilities are very small. In general the reliability of a series system, assuming that failures of the components occur independently, is given by the product of the reliabilities of the components.

R67-13166 ASQC 840; 851; 870

FAILURE PREDICTION IN ELECTRONIC SYSTEMS.

Robert A. Kirkman (TRW Systems, Redondo Beach, Calif.).
IEEE Transactions on Aerospace and Electronic Systems, vol. AES-2, Nov. 1966, p. 700–707. 7 refs.

Deterministic failure prediction is contrasted with statistical failure prediction, and a number of classes and techniques of deterministic failure prediction are identified and discussed. By using such techniques selectively and in combinations applicable to a specific system, a sensitive test program can be developed and mission reliability can be improved by permitting repair or replacement before failure takes place. For system effectiveness, the test or checkout program should have as its major objective the detection of incipient failures in addition to the usual objective of verifying current functional performance. A hierarchy of causes and effects leading to mission failures is illustrated, and failure-sensitive parameters and marginal testing are discussed. While the methods discussed are especially adapted for predicting specific failures in electronic systems, they are considered applicable to electromechanical and fluid systems and components. M.W.R.

Review: The theme of this paper is failure prediction as a means of failure prevention. It is concerned with deterministic or quasi-deterministic failure prediction rather than statistical failure prediction. Four methods are discussed, namely tests for the detection of defects, use of failure-sensitive parameters, marginal tests for defect detection, and historical data. In addition, there is a good discussion of the definition of failure (in which the term "random" is used correctly—in contrast to its frequent incorrect use in reliability literature). Naturally in an eight-page paper on the indicated range of topics the author does not get very far into specifics, but he has cited a number of pertinent, references for greater detail. This is a competent, well-written treatment of the topic addressed, and merits the attention of anyone concerned with the reliability testing of electronic (or mechanical) equipment. (This paper is virtually identical to the author's earlier paper covered by R67-12927.)

R67-13168 ASQC 844; 711; 712; 775

ELECTRON FRACTROGRAPHY PINPOINTS CAUSE OF FATIGUE FRACTURE.

Edward A. Lauchner and Robert E. Herfert (Northrop Corp., Northrop Norair Div., Hawthorne, Calif.).

Metal Progress, vol. 91, Feb. 1967, p. 79–80.

A crack analysis of an aluminum component illustrates the completeness of results and details attainable by electron fractography. The crack studied was attributed to stress corrosion rather than to the original suspect, fatigue failure. Five different modes of crack growth were observed during the failure of the machined component. Two of the regions displayed overloading, two stress corrosion, and one fatigue marks. The last assisted crack growth via the stress corrosion mechanisms. M.W.R.

Review: This is a very short case history which shows that analysis with an electron microscope of replicas from the fracture zone is able to assist in more accurate evaluations of failure causes. Even though the part was on a fatigue test, it turns out that the major cause of the failure was stress-corrosion cracking. This kind of paper is easy to read and can be of benefit in failure-mechanism analysis for high reliability.

R67-13169 ASQC 844; 711; 712

AN ANALYSIS OF FAILURES IN SPACECRAFT.

Alfred J. Babecki, John D. Grimsley, and Henry E. Frankel (NASA, Goddard Space Flight Center, Greenbelt, Md.).

Metal Progress, vol. 91, Feb. 1967, p. 100–104.

Corrective measures that have been taken to combat failures of spacecraft components are considered. Leakages that resulted from iron concentrations are mentioned for the Syncom, Early Bird, and Applications Technology satellites. A 16 hr anneal and a 4 hr nitric acid exposure are recommended for the metal bars used in the fittings for the hydrogen peroxide container in the attitude control propellant. Attention is given to fatigue fracture that is caused by poor machining, and examples of fatigue parts are included. Surface brittleness due to nitriding, failures caused by design stress exceeding tensile strength, and dirty steel leaks from the thrust chamber of an Aerobee rocket are noted. Eliminating stress corrosion in Aerobee fuel-oxidizer tanks welds was accomplished by sealing the weep holes prior to pickling and by descaling. Closer control of die shapes improved cutting of diaphragms used with the Aerobee fuel and oxidizer valves. M.W.R.

Review: This paper presents several rather brief case histories which are interesting to read and informative for designers. In some cases, of course, the responsibility for failure lay with production not following the drawings, but many failures were the responsibility of the design group (albeit many would have been very difficult to anticipate). An interesting comment made in the article is: "Fatigue is probably the most common failure mechanism in spacecraft hardware." Designers need to be aware of the various failure mechanisms of metals, plastics, and electronic components. Articles such as this which are short and interesting can help provide that information.

R67-13170 ASQC 844

HOW TO ZAP A ZENER.

David W. Hutchins (Dickson Electronics, Scottsdale, Ariz.).

EEE, Circuit Design Engineering, vol. 15, Feb. 1967, p. 76–80.

A general discussion of zener reliability shows the typical forward and reverse characteristics of standard zeners and temperature compensated zener diodes (TCZD), and the uses and construction of both types are discussed. Two examples are given of how lead-bending can ruin zeners, and mention is made of other failures. An open-circuited zener produced by overloading is illustrated, as is the instability of a TCZD when used with unregulated power supply. It is noted that zener failure detection is not always easy. M.W.R.

Review: This is a paper which makes some very serious points by using a lighthearted technique. The design and construction methods which cause failure are analyzed. In most cases the cures are obvious or stated. The points made are good and the article is both entertaining and well worth reading.

R67-13178 ASQC 844; 824; 837

PREDICTING RELIABILITY OF ELECTRONIC TRANSFORMERS.

H. B. Harms (General Electric Co., Ft. Wayne, Ind.).

In: National Electronics Conference, Proceedings, Chicago, Ill., Oct. 19–21, 1964. Vol. XX. Sponsored by Illinois Institute of Technology, the Institute of Electrical and Electronics Engineers, Northwestern University, and the University of Illinois. Chicago, Ill., National Electronics Conference, Inc., 1964, p. 147–152. 2 refs.

A model for predicting the reliability of electronic transformers considers the four basic transistor subsystems: conductive, dielectric, magnetic, and structural; and further breaks down these subsystems into their components and elements to provide an orderly means for the assignment of failure rates. Deteriorating stresses and their consequences are assigned to each element; and probability density functions are assumed for element strength, applied load, and transformer life. Allocated failure rates for each of the elements are compared with estimates of element reliability obtained from calculations of element strength, applied load, and safety margins. Details are included for these allocations and calculations. M.W.R.

Review: The basic idea in this paper about breaking the design of a transformer into structural, dielectric, conductive and magnetic subsystems is good. The actual statistical procedures used here are only sometimes applicable; the treatment often appears confused between the exponential distribution for life and the Guassian distribution for stress–strength. If the simple stress–strength model of failure holds, then the failure rate is constant only if the probability density of the environmental severity has a particular form. Throughout the discussion there appears to be confusion of the relationships between wear-out and constant failure rate concepts (hazard rate, of course, is meant here). The formula for reliability of several independent sub-systems is correct but the qualification must be emphasized that the sub-systems are *statistically* independent. This is much more restrictive than failures in one sub-system not causing failures in another. For example, an uncertain environmental profile will cause statistical dependence. Furthermore, it is unlikely in a transformer that the four subsystems are even physically independent. There are some misprints, for example, the wording is incorrect on the product of probabilities for Eq. 1 although the equation itself is correct. There is a most important error in sign in equation 5: the variance of the difference is the sum of the variances of the two components. The author's care in analyzing the transformer system and subsystems is very much to the point. Generally speaking, experienced transformer designers use the same care; the engineer who only occasionally designs a transformer probably does not. This may be a good reason to leave design of reliable transformers to specialists unless absolutely necessary to do otherwise. (The author has published a slightly amplified and revised version of this paper as IEEE Conference Paper No. CP 64-450.)

85 DEMONSTRATION/MEASUREMENT

R67-13146 ASQC 851; 815; 844

ELECTROMECHANICAL RELAYS—PART 4: RELIABILITY TESTING.

Norman Hyde (Hellermann Deutsch Ltd., East Grinstead, England).

Electronic Components, vol. 5, Oct. 1964, p. 865–872. 4 refs.

Problems associated with the design, manufacturing, contact phenomena, and testing of electromechanical relays are treated. Reliability acceptance specifications are reviewed, and a set of specifications is recommended for high reliability relays. The minimum current test, overload test, relay operating characteristics time determinations, and vibration testing are considered; as are various aspects of relay testing. Failure modes are also considered, some typical failure patterns for crystal can sealed relays are illustrated, and the dependence of breakdown voltage on pre-breakdown resistance is graphed. M.W.R.

Review: This paper is the fourth in a series on electromechanical relays and deals with reliability testing. The usual problems in reliability testing of electromechanical relays are again set forth. No particular solutions are presented since, at least in the present framework, there are none. The discussion of failure criteria is good. The problem is that the given set of contacts may be used for widely different loads and the contacts behave differently depending on the load. The relationship is not simple. In this connection one must be very careful about applying any derating to relays since the arithmetical reduction of a rating does not necessarily result in operation of the relay under more benign conditions. Some very practical problems associated with the manufacture and test of relays are brought out; the mechanical life of relays is distinguished from electrical life. Telephone-type or smaller relays, which are being considered here, ordinarily have a mechanical life more than adequate for the electrical life; but this is not necessarily true of industrial contactors, which can fall apart or jam long before the contacts are no good. There is a discussion of the NARM document: Recommended Specifications for High Reliability Relays; the author considers it an excellent first try. He also mentions the NARM document: Relay Testing Procedures; and proceeds to analyze it critically. One of the problems the committees which generate these documents are up against is that almost no matter what they write down someone is going to jump down their throats. After reading papers that analyze some of the difficulties in reliability testing, the wonder is not that relays work so poorly but that relays work so well. It should be emphasized that many of the problems are in the newer miniaturized relays; the old standbys when properly applied (this is not too difficult, if care is used) can be extremely reliable long-lived devices. This article is more for the relay specialist than for the general designer, although it certainly would not hurt the latter to read it.

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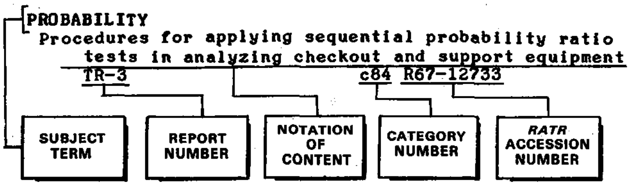
Typical Subject Index Listing



The Notation of Content, rather than the title, is used to provide a more exact description of the subject matter. The category number and *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

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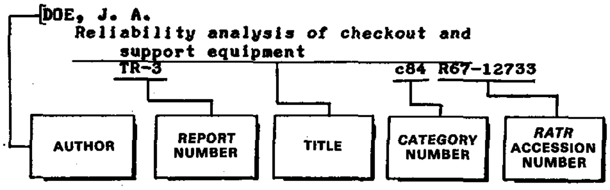

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Reliability Abstracts and Technical Reviews

JUNE 1967

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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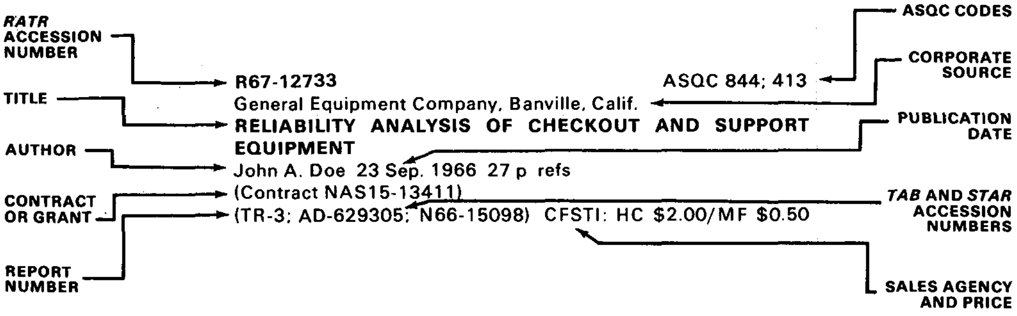

R67-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
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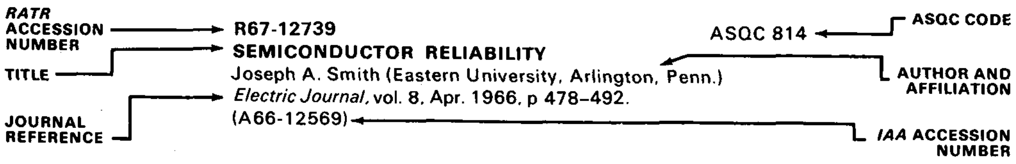
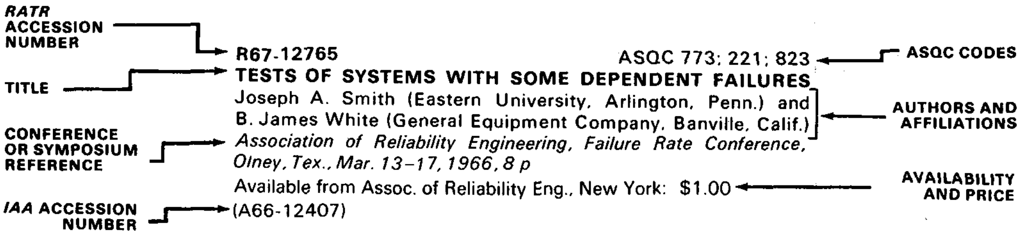
(TR-3; AD-629305; N66-15098) CFSTI: HC $2.00/MF $0.50



R67-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A66-12569)



R67-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A66-12407)

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Reliability Abstracts and Technical Reviews

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June 1967

81 MANAGEMENT OF RELIABILITY FUNCTION

R67-13189 ASQC 810
WINNING RELIABILITY MANAGEMENT TECHNIQUES–VINTAGE 1966.
W. T. Summerlin (McDonnell Co., St. Louis, Mo.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 104–109. 4 refs.
Available from IEEE, New York: $8.00.

Reliability management techniques considered important to the success of the Gemini and Mercury projects and to the F-4 Phantom II aircraft program are compared with methods employed on four earlier successful projects: (1) a 1936 project dealing with radio receivers for policy motorcycles, (2) a 1941 program concerned with the development of an aircraft transmitter–receiver, (3) Lark missile development in 1945, and (4) Sidewinder missile development in 1953. While high reliability was achieved on all of these projects, it is noted that the need for reliability programs increases with the complexity of the equipment and systems under development. A high dependence on reliability organization and/or reliability program is not considered essential to insure major conceptual decisions significant to reliability because of the closeness of spacecraft and aircraft system designers to the aircrews and maintenance personnel. Reliability programs needed by subcontractors require less prime contractor surveillance if reliability demonstration is a requirement. While this is impractical in spacecraft development, it has paid off well in the development of many aircraft subsystems. M.W.R.

Review: As indicated by the title, this paper is philosophic in nature and analyzes the reasons behind success of programs and the need for particular kinds of efforts. The conclusions appear to be quite reasonable; that is, the less complex the equipment and the more closely associated with the hardware is the designer, the less a formal reliability program is needed. The more complex the equipment and the more remote the designer, especially for subcontractors and on down the line, the more important a formal reliability program becomes. There are no specific techniques recounted here, but the over-all evaluation is worthwhile reading. The approach is somewhat different from that usually encountered.

R67-13190 ASQC 813
RELIABILITY IN THE MIDDLE.
M. F. Schmidt and G. A. Raymond (UNIVAC Defense Systems Division, St. Paul, Minn.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 110–113.
Available from IEEE, New York: $8.00.

While the short-term developmental project does not differ from the long-term project in functional or reliability requirements, other areas may differ greatly. In the short-term project, the equipment usually represents a small portion of a complex system and a minimum time may be devoted to equipment design, development, and fabrication. Therefore, experienced reliability people are especially needed to recognize potential problems. Critical items related to the proposal, design, development, fabrication, equipment test, and system integration phases are discussed; along with the capabilities of a project reliability group and coordination of project activities. M.W.R.

Review: This paper will have its greatest impact on the group who have had similar or related experiences. They will recognize the everyday situations that lie behind the written word; whereas those without similar experiences will find that this paper reads like so many others on reliability and project management. In much of the discussion the reliability engineer appears to fill an office similar to that of the executive officer on board ship. In fact, he seems to be almost a co-project-leader or co-designer. In any event he is an integral part of the very small group which in fact actively runs the project.

R67-13191 ASQC 810
THE VIEW FROM THE BOTTOM.
J. R. Isken (IRC, Inc., Philadelphia, Pa.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 114–117.
Available from IEEE, New York: $8.00.

Reliability management problems are reviewed from the point of view of the parts supplier who is concerned with multiple customer requirements, specifications and their enforcement, and general administration. The need for revising specifications at the prime contracting level (government) is mentioned, and three simple rules are stated that can aid in a realistic approach to a problem: (1) Specify only what you need. (2) Specify only that which can be enforced. (3) Specify only what you must have and are prepared to enforce. Such an approach can reduce overall technical support costs and provide a foundation for a solid reliability program by the parts supplier. M.W.R.

Review: An interesting and provocative discussion is given in this short paper about reliability program management problems at the bottom of the contracting tier. The usual contradiction of (a) adequately costing a conscientious implementation of requirements invariably results in lost business, is compounded for the "bottom" by (b) the large number of customers, each with different requirements, who are all actually buying the output of the same production line. Further, and as usual, the creation of an environment which will result in improvement lies primarily in the hands of the ultimate customer—the government. Several succinct foundations for improvement are suggested by the author. These are worth noting; they are: (1) specify only what you must have and *will enforce,* (2) restrict competition to the period of supplier selection, and then work with *one supplier,* or, (3) if there are no parts reliability program funds, then steer the usage into standard military specifications. The reading quality of this paper would have been aided by the use of sub-titles.

R67-13197 ASQC 815

INCENTIVE CONTRACTING FOR RELIABILITY.

Ralph E. Kuehn (International Business Machines Corp., Electronics Systems Center, Owego, N. Y.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 200–203. 6 refs.
Available from IEEE, New York: $8.00.

Various aspects of reliability incentive contracting are considered, as is the impact of incentive provisions on program administration. Reliability performance criteria discussed are mean time between failure, mission success, and qualification testing. It is noted that the design of highly reliable subsystems has forced a consideration of relatively uncontrolled reliability demonstrations from both technical and cost view points. The numerous problems associated with uncontrolled reliability demonstrations are discussed, and some possible solutions are suggested. M.W.R.

Review: A timely discussion on a contractor living with reliability incentive contracting and making it work is presented in this paper. Although couched in general terms, it is apparent that the sources of the material which is presented are actual firsthand experience as well as a study of the noted references. The paper includes some discussion of reliability demonstration by measuring reliability with hardware not intended primarily for reliability testing. This approach has much merit and will probably gain in usage. The author does not deal with the pros and cons of incentive contracting from the points of view of either the contractor or the government. Perhaps this is another indication that incentive contracting for reliability is going to be as much a way of life as reliability programs have become in the government-industry domain.

R67-13198 ASQC 815

SELECTIVE IMPLEMENTATION OF NASA'S NPC 250-1.

C. L. Swindell (Boeing Co., Huntsville, Ala.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 204–208. 3 refs.
Available from IEEE, New York: $8.00.

The "Reliability Program Provisions for Space Systems Contractors," as documented in NPC 250-1, are combined with engineering experience to determine means of establishing reliability confidence for the Apollo/Saturn V launch vehicle ground support equipment program. Criticality of hardware failures, use period of the equipment, and impact of component failure on the program cost or schedule are treated as the three most important factors, in the order listed, for implementing a reliability program. Although these factors may overlap and may not cover the total picture, they provide a basis for initial program action in hardware development. M.W.R.

Review: The various importance factors which are usually implicitly weighted in planning reliability programs are treated explicitly in this procedure. This is good checkoff-type material for use when preparing reliability program plans. It also forces a decision to be made about what is important, which in itself has benefits. The paper is short and well-illustrated, thus allowing the essence to be grasped quickly. Although the author cites only NASA reliability documents, the approach is applicable also with other specifications on reliability, maintainability, etc.

R67-13199 ASQC 810; 814; 815

RELIABILITY OPTIMIZATION IN THE CONCEPTUAL PHASE.

J. T. Hinely, Jr. and B. F. Shelley (Lockheed-Georgia Co., Marietta, Ga.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 209–217.
Available from IEEE, New York: $8.00.

A general approach for optimizing reliability requirements during the earth conceptual phases for new systems places emphasis on technology capability, operational effectiveness, reliability cost effects, and schedule constraints. Specific applications to the development of a transport aircraft are illustrated for the optimization procedure, which can lead to the development of a realistic system reliability requirement for inclusion in contractual documents. Reliability performance of both the C-130 and C-141 aircraft is discussed, along with data for other military aircraft and for commercial aircraft. A computer effectiveness model for use in determining systems effectiveness is discussed, and cost studies and identification of the optimal point value are treated. It is concluded that analytic techniques and background data are sufficient to determine optimal reliability requirements for new systems during their conceptual development. A fresh approach to statistical analysis is recommended to determine criteria for the new complex systems. M.W.R.

Review: A realistic discussion is presented on selection of the optimum reliability level which results in a minimum total lifetime cost. The experience and data from a number of transport aircraft programs provide the material. This paper is primarily discussion, but contains several equations and curves. The orientation of the optimization is at a gross level, namely the reliability level for the whole transport aircraft. Little is given on the many sub-optimization problems concerning the choice of an optimal design approach for a certain reliability or the choice of related maintainability and spares considerations. This is timely material and those interested in cost-reliability tradeoffs analysis will benefit from reading it.

R67-13200 ASQC 815; 814; 871

MULTI-DISCIPLINE APPROACH FOR ACHIEVING OPERATIONAL RELIABILITY.

G. H. Allen and R. M. De Milia (Air Force Systems Command, Electronics Systems Div., Bedford, Mass.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 218–229. 22 refs.

Available from IEEE, New York: $8.00.

Configuration management, personnel subsystem, and maintainability program requirements as well as value engineering incentive clauses are being introduced into contractual documents in order to achieve operational equipment and system reliability. Contractual failure requirements are considered of little interest to personnel involved in the operational program who are concerned with the total program. Requirements and methods for their determination are discussed in terms of quantification and verification of operational reliability, and the need for flexibility is stressed. Specific control and surveillance systems being investigated include: (1) air weapons control system, (2) semiautomatic ground environment (SAGE) system, (3) backup interceptor control system, and (4) ballistics missile early warning system. M.W.R.

Review: The recent experiences at the USAF Electronic Systems Division (ESD) on reliability and related "...abilities" are summarized in this paper. Some of the remarks, such as the following, have a new and interesting flavor. (a) Using data from several different sources, the authors conclude that post-design human-initiated failures comprise from 30% to 40% of all operational failures. This is indeed a significant factor which is often omitted from operational reliability predictions. (b) The old human-factors "...ability" is now termed the Personnel Subsystem, with new types of requirements for contractors. (c) The Contractor Definition Phase is benefiting ESD, as it has the character of a "living" proposal. (d) Experience with reliability incentives has been that industry management is usually stimulated to improve reliability. Current ESD policy is *maximum utilization of incentives for reliability, maintainability,* and performance parameters. Thus this paper would be of particular interest to ESD contractors. Figure 4 in the paper identifies 46 current government documents covering reliability and six related "...abilities."

R67-13201 ASQC 810; 100; 720; 840

PROCESS INTEGRITY THROUGH RAW PRODUCT ANALYSIS.

W. E. Sawyer (Western Electric Co., Inc., Allentown, Pa.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 240–252. 1 ref.

Available from IEEE, New York: $8.00.

Optimal control of processing operations to prevent degradation of inherent reliability levels is stressed in connection with the manufacturing of highly reliable semiconductor devices. Raw Product Analysis (RPA), a systems approach that supports achievement of process stability, consists of sampling the untested manufactured product for electrical characteristics, the generation of statistics from sampling data, and measuring each statistic against a norm. When a deviation from the norm results, a study is undertaken to make the necessary corrective action. The RPA technique uses a computer for speed and efficiency; and several printouts and computer outputs for the program are shown. The program is able to analyze highly skewed distributions, as well as normal distributions. M.W.R.

Review: The rawness of the product referred to in the title means unscreened and untested, but completely manufactured. The program certainly sounds reasonable. It features computerized statistical analysis of distributions of electrical characteristics of raw product, to signal need for corrective action upon the process. The paper will make the most sense to those who are directly involved in similar quality control programs—they will have the background to appreciate some of the details which are given. (The statement, "Manufacturing operations cannot improve inherent device reliability; they will either maintain or degrade it," is more a definition of inherent reliability than a positive assertion.)

R67-13202 ASQC 810; 720; 832

PROCESS CONTROL—KEY TO EQUIPMENT RELIABILITY.

W. A. S. Douglas

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 267–272.

Available from IEEE, New York: $8.00.

Since most reliability problems are considered traceable to inadequate process control during manufacturing, some procedures and documentation techniques are discussed to improve component reliability. Primary attention is given to hardware requirements of aerospace systems having very stringent reliability requirements, although the discussion is considered applicable to other industrial applications where the penalty for hardware failure is severe. The product designer can improve reliability by simplifying his designs and avoiding processes that are difficult to control; and manufacturing personnel can improve reliability by providing closed loop processing controls that automatically record performance for comparison with the required specifications. Solder flux removal, conformal coating contamination, and vacuum bake control are used to show process control loops; electronic assembly surveillance and recording inspection equipment are discussed; and process elimination is considered as an alternative to process control. M.W.R.

Review: This paper carries a worthwhile message for those responsible for managing the production of high-reliability hardware. Ideas for better process control, traceability, and documentation are presented. Some of them—such as recording electronics assembly operations on T.V. tape—may seem rather elaborate, but justification of their use clearly depends on the importance attached to having such records. One effect of the paper should be to encourage some of those responsible for reliability and quality assurance programs to "think bigger" than they have been doing, when the need and resources permit it.

82 MATHEMATICAL THEORY OF RELIABILITY

R67-13208 ASQC 824

Ford Motor Co., Dearborn, Mich.

ASYMPTOTIC EFFICIENCIES OF THE MOMENT ESTIMATORS FOR THE PARAMETERS OF THE WEIBULL LAWS

Satya D. Dubey Repr. from Naval Res. Logistics Quarterly, v. 13, no. 3, Sep. 1966 p 265–288 refs

(AD-640673)

In the paper the asymptotic properties of the moment estimators (MEs) for the location and the scale parameters of the Weibull law, based on its first two sample moments, are investigated. Previously, the author has obtained maximum likelihood estimators (MLEs) for these parameters and has further derived the asymptotic covariance matrix of these estimators which exists when the shape parameter of the Weibull law is greater than two (1962). This result has been used here to compute the joint asymptotic efficiency of the moment estimators (MEs) of the location and the scale parameters. It has been shown that their joint asymptotic efficiency depends upon only the shape parameter of the Weibull distribution. A table has been presented in this paper which provides the joint asymptotic efficiency of the MEs of the location and the scale parameters of the Weibull distribution for various values of its shape parameter. The maximum value of such a joint asymptotic efficiency is found to be 93.18 percent for the shape parameter equal to 4.6. Also presented in this paper are tables for the following asymptotic efficiencies: (a) the asymptotic efficiency of the ME of the location parameter when the scale parameter is unknown; (b) the asymptotic efficiency of the ME of the scale parameter when the location parameter is unknown; (c) the asymptotic efficiency of the ME of the location parameter when the scale parameter is known; and (d) the asymptotic efficiency of the ME of the scale parameter when the location parameter is known. Author (TAB)

Review: See R67-13206.

R67-13182 ASQC 820; 821; 822; 838

AN ENGINEER'S APPROACH TO RELIABILITY MATHEMATICS.

Leonard R. Doyon and Mark L. Hinkle (Northwestern Univ., Graduate School of Engineering, Boston, Mass.; Raytheon Co., Wayland, Mass.). *In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 1–16. 5 refs.

Available from IEEE, New York: $8.00.

Meanings and interrelationships of the failure rate, failure density, and survival functions are discussed from an engineer's point of view, as is mathematical modeling of system reliability block diagrams. The constant failure rate is considered where no repair is possible during the mission and operation of the equipment. A sample space technique used to derive the reliability model is an abstract representation of all possible events, and each event is a point in the sample space. Active and standby redundancy of a parallel diagram and model are discussed, and examples using the sample space approach are included. Mastery of the data presented is considered basic to the modeling of a complex system repairable during a mission that uses Markov chain and flow graph techniques. M.W.R.

Review: As a tutorial paper on the certain topics in reliability mathematics for engineering application, this accomplishes its purpose quite well. While some of the definitions would not pass critical scrutiny by a mathematician, they are adequate within the context in which the paper is written. There are two minor typographical errors on p. 9: a minus sign is missing in the exponent of the first term in the first expression for $(R_s(t))$, and in the next equation, a plus sign appears instead of the equality symbol. The section on mathematical models involves only the application of elementary probability concepts (referred to as "the sample-space approach") to series systems, and simple cases of active and standby redundancy. For the case of standby redundancy involving two units the authors cite the convolution of the two cumulative failure distributions as a means of finding the survival function. They go on to give a simple and quick heuristic method of their own which gives correct results when the failure rates are constant. They say "this mathematical manipulation may make some mathematicians cringe..." There is no reason why it should because the authors' result can be derived by the method of convolutions applied to the case which they have treated, starting with the equation for R(t) cited on p. 8. The authors' method, although having an heuristic basis, is logically developed and yields the same result (for the case treated) as does the more sophisticated approach of convolution of the cumulative failure distributions. All in all, this paper should be quite useful to engineers interested in these topics; it can be read with understanding by those having little or no training in probability theory.

R67-13187 ASQC 823; 433

A BAYESIAN APPROACH FOR DESIGNING COMPONENT LIFE TESTS.

Harold S. Balaban (ARINC Research Corp., Annapolis, Md.). *In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 59–74. 6 refs.

Available from IEEE, New York: $8.00.

Prior quality distributions are incorporated in the Bayesian design of component life tests for serial systems with exponential component-failure-time distributions. System reliability or life testing specifications are converted into equivalent component reliability or component life test specifications by first determining the consumer's risks for a zero-failure acceptance criterion; and these risks are used in conjunction with producer's risks to yield a set of component-life-test plans. Main advantage of the presented approach is that by the use of past quality history in the design of component tests, more realistic and economical life testing can be accomplished. It is noted that cost parameters should be incorporated into the test design; and these costs can be applied within a decision-theory framework. An appendix presents a proof of the theorem that provides the basis for selecting the initial common test time; that is, a sufficient condition for the accepted failure rate distribution of a series system based on independent component-level tests is equal to that based on a system-level test. M.W.R.

Review: This is a well-written paper on the subject of designing component life tests using the Bayesian approach. A large number of papers on Bayesian statistics has appeared in the past few years indicating a real need to make use of all of the prior information that exists in designing tests and analyzing data; see, for example, RATR items bearing *ASQC Code 433. These may be located in the Code Index* of the individual issue or the annual index. The approach used in this paper avoids some of the usual difficulties in trying to design component life tests consistent with system requirements. One of the basic assumptions in this approach *is that the system probabilities can be obtained directly from* the appropriate combination of the component probabilities without the need for considering the interface problems. However, all the approaches to this problem are confronted with the same assumption except when the entire system is *tested. One other approach which uses prior information* concerning the probabilities of defective components is given in the paper by R. J. Christie covered by R66-12607.

R67-13188 ASQC 822; 824

INCREASED ECONOMY IN LIFE TESTING: A NEW APPROACH.

L. A. Washburn (Texas Instruments, Inc., Semiconductor-Components Div., Dallas, Tex.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 75–90. 6 refs.
Available from IEEE, New York: $8.00.

Considerable economy in life testing can usually result if the actual life test law is the generalized gamma distribution (GGD) or any of its subdistributions possessing a shape parameter of less than unity. The exact sampling distribution of the scale parameter of the GGD is derived, and from this a lower confidence limit on the scale parameter is determined as a function of the chi-square distribution. Using additional conditions of life characteristics equivalence, relationships are developed between the minimum sample-size requirements of the exponential distribution and the GGD for the conditions of: (1) equivalent instantaneous-failure rate, (2) equivalent cumulative-force-of-mortality or average hazard rate or mean intensity, and (3) equivalent average reliability. For the simplified Weibull distribution, equal hazard rate, reduced time, and equivalent mean reliability tests are discussed, and examples are presented that demonstrate great savings in sampling time for both the GGD and the Weibull distribution with a monotonic decreasing hazard rate. Usually, the reduced time testing affords additional savings. Mean intensity and mean survivorship are treated mathematically. M.W.R.

Review: This paper gives some mathematical results to illustrate that economy in life testing may be effected when the actual life law is the generalized Gamma distribution (GGD) or any of its specialized distribution forms possessing a shape parameter less than unity. A relatively large number of items must be life tested to demonstrate that the distribution form is GGD rather than exponential. However, once the initial investment has been made and the GGD is the accepted life distribution, many fewer test items are required for some desired confidence statements than would be required for the exponential distribution. The primary problem in most applications would be the amount of *testing required to convince one of the adequacy of or a preference* for the GGD or one of its specialized forms with shape parameter less than unity. The mathematical arguments in the first part of the paper, although correct in that the end results follow, are not expressed clearly. It appears *that the author in an attempt to shorten the paper omitted* some important steps in the analysis. Some points in the paper would be clarified by introducing the variable

$$w = \alpha r/\gamma\beta = \sum_{i=i}^{r} (t_i - \zeta)^r$$

into the discussion on page 76. The random variable w has a Gamma distribution and $2\beta w$ can be shown to have a χ^2 distribution with $2\alpha r/\gamma$ degrees of freedom. Thus

$$P\{\chi^2 = 2\beta w \leq \chi^2(p,2\alpha r/\gamma)\} = p,$$

where $\chi^2(p,2\alpha r/\gamma)$ is the p th percentile of the χ^2 distribution with $2\alpha r/\gamma$ degrees of freedom. Hence

$$P\{\beta \leq \chi^2(p,2\alpha r/\gamma)/2w\} = p$$

yields a confidence interval statement for β.

R67-13206 ASQC 824

Ford Motor Co., Dearborn, Mich.

ON SOME STATISTICAL INFERENCES FOR WEIBULL LAWS

Satya D. Dubey Repr. from Naval Res. Logistics Quarterly, v. 13, no. 3, Sep. 1966 p 227–251 refs
(AD-640690)

The author considers (a) the problem of obtaining the maximum likelihood estimators (MLE), including the BAN (Best Asymptotically Normal) estimators, of all the parameters of the various Weibull laws; (b) their asymptotic properties; (c) some further investigations into the properties of the MLEs for all the one-parameter Weibull laws; (d) some large sample tests of hypotheses and the construction of confidence regions of meaningful parametric functions; and (e) the problem of obtaining a closer approximation to the approximate confidence interval for the location parameter. TAB

Review: These three papers are concerned with the mathematics of estimating Weibull parameters and will be found useful by theoreticians dealing with such problems. It should be noted that most of the results derived in these papers are applicable to large samples only.

R67-13207 ASQC 824

Ford Motor Co., Dearborn, Mich.

HYPER-EFFICIENT ESTIMATOR OF THE LOCATION PARAMETER OF THE WEIBULL LAWS

Satya D. Dubey Repr. from Naval Res. Logistics Quarterly, v. 13, no. 3, Sep. 1966 p 253–264 refs

(AD-640766)

In the paper the author obtained the hyper-efficient estimator of the location parameter of the Weibull laws when it is known *a priori* that their shape parameters fall within the semiclosed unit interval, (0,1). The existence of such a desirable estimator for the location parameter has been further exploited toward obtaining the maximum likelihood estimators for the scale and shape parameters of all possible Weibull laws. Their asymptotic properties are also discussed. Some other estimators have been proposed for the location parameter when the shape parameter is larger than one. A useful property of the Weibull distribution is also stated in the paper. Author (TAB)

Review: See R67-13206

R67-13213 ASQC 824; 512

MULTIPLE FAULTS AND CONFIDENCE LEVELS–RESOLUTION OF A PARADOX.

N. H. Briggs and J. Yarnell (Hawker Siddeley Dynamics, Ltd., Hatfield, Herts., England).

Microelectronics and Reliability, vol. 5, Nov. 1966, p. 265, 266.

(A67-15480)

Indication that a failure-occurrence paradox revealed in a previous article by the authors is capable of resolution by a small change of attitude. The implication is that a self-consistent definition of confidence level will lead to the same mathematical expression as before, except that in computing values, the series terminates one term earlier. IAA

Review: The paradox mentioned in the title arose in the paper covered by R67-13013. It is concerned with setting up confidence limits for failure rate and mean life, and with finding the equivalent Bayesian prior distribution. One of the difficulties, of course, of assuming complete ignorance is that complete ignorance has to be defined. As the authors note, if you are completely ignorant about the failure rate, you are no longer completely ignorant about its reciprocal. They make a compromise, which they call a resolution of a paradox, by effectively asserting that they wish to be ignorant not of λ or $1/\lambda$, but of $\ln \lambda$. Being completely ignorant of $\ln \lambda$ is logically equivalent to being completely ignorant about $\ln (1/\lambda)$, and so their paradox is resolved. It should be pointed out, however, that there are other functions of λ which might possibly be of interest, for example, $\exp(-\lambda)$ which of course appears in reliability expressions. We now note that even though we are completely ignorant about $\ln \lambda$, we have very definite ideas about the pdf of $\exp(-\lambda)$ and of λ itself. In the redefinition of confidence there are two definitions given which are not equivalent, because the random variable is discrete. The reason for the discomfort in the case of zero failures is: a zero failure rate is so extremely likely under the new assumption that, with no evidence to the contrary, it is the only tenable hypothesis.

R67-13215 ASQC 824; 844

A CASUAL REDEFINITION OF FAILURE RATE–THEOREMS, STRESS DEPENDENCE, AND APPLICATION TO DEVICES AND DISTRIBUTIONS.

Robert G. Stewart (Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Research Laboratories, Palo Alto, Calif.).

IEEE, Transactions on Reliability, vol. R-15, Dec. 1966, p. 95–114. 14 refs.

(A67-16852)

Description of a formalism for calculating the reliability of devices starting from causal, physical analysis of the operational and failure modes of the devices. A measured device quantity q_i is expressed in terms of basic material properties p_j, which in turn may depend on time t and stresses s_k. Then, defining a kinetic sensitivity $\phi_j = (\partial q_i/\partial p_j \times (\partial p_j/\partial s_k)$ and failure function $\psi = \Sigma_j \phi_j$, it is possible to prove powerful theorems which show that the kinetics of the failure mechanisms are as important as the stress-dependence of the failure mechanism in determining the stress-dependence of the failure rate. The failure rate of a device F_i is defined as the reciprocal of the time to failure τ_i. The failure rate $\bar{F}$ (cumulant) for a distribution is defined as the arithmetic mean of the failure rates of the individual devices. IAA

Review: The most charitable things to be said about this paper are: (1) It was originally written several years ago. (2) The mathematics is interesting and appears to be essentially correct. (3) It is not a traditional approach. The general difficulties with the presentation are: (1) The author overemphasizes the importance of his "formalism." (2) The assumptions and definitions are not all clearly stated nor are they even assembled in one place where they can be easily scrutinized. (3) The denigration of the statistical approach shows a lack of understanding, especially of the hazard function. However, to be sure, many silly statistical statements are being made. (4) The power attributed to a few equations is reminiscent of the early days of physics-of-failure wherein the world's problems were going to be solved by a Taylor's series expansion in all the relevant variables. Some of the formalism here is neat and clean–the difficulties involved in applying it to a given situation do not show up. As examples, the functional form of the device-quantity dependence on fundamental properties may change with time; there is no such thing as a fundamental set of properties of a device, since it all depends on how far back toward atoms, molecules, and nuclei one wishes to push the discussion. The author's extreme enthusiasm in spots, while perhaps pardonable, gets in the way of appreciating some of the arguments. When some of the definitions are not clearly stated mathematically, it makes it difficult to follow the proofs. Not having the assumptions clearly stated in one place makes it difficult to judge the physical applicability of the mathematical models presented here. The author's rendering of the conventional statistical approach is quite inadequate and repeats early misunderstandings. By the use of statistics to describe a physical situation, one should not imply that there are no physical causes. Certainly one does not imply that just because there is an exponential distribution for life that nothing is happening in the parts during the course of their lifetime which causes them to degrade and ultimately to fail. For example, on a damage-endurance model for failure, it is easy to show that the original endurances of the parts may have a distribution such that the lifetimes will be exponentially distributed. The deprecation of the hazard rate as a description of a probability distribution is uncalled for. As a matter of fact, the knowledge of the hazard rate is sufficient to predict the behavior of a particular population. It is very suitable and useful if the distribution is exponential (contrary to the author's statement) since in that case the hazard rate is constant. A statement, for example, "failure rate is 2% per 1000 hours" gives the actual rate at which failures are expected to occur; it remains constant and it proceeds indefinitely (granted the model). Entirely too much is expected of the physics-of-failure approach. The tremendous uncertainties involved in analyzing a part in a gross sense are merely transformed by this analysis into the severe problems of finding what causes the uncertainties on a new set of parameters. Obviously, if the author's approach is at all adequate, it has to explain the same set of facts such as vastly different lifetimes. If each part has exactly the same kinetics and the same composition to begin with, then there is no problem, they all fail at the same time. But they do not fail at the same time and there is a problem. They do not all have the same kinetics, they do not all have the same composition, they do not all see exactly the same environment; they have not all had exactly the same past history. There are some minor mathematical concerns. For example, the distinction between the partial derivative and total derivative is not always maintained, even sometimes with respect to the same variable in the same equation. In a rigorous derivation such as this it is often wise to be more formal with the partial derivative notation and in any partial differentiation to indicate which are the independent variables for the purpose of this differentiation. The author has not taken the care in his correspondence of mathematical formalism to reality to be concerned with physical units. In some cases one supposes that the parameters have been normalized to be dimensionless (if not, the equations are wrong), but it has not been done explicitly. Several theorems are stated in words, the proof is mathematical in nature, but the words are never translated into a formula to begin with. Some of the words are not defined mathematically. This is a distinct disadvantage in a paper which purports to be rigorous. In one of the equations there is an error when the McLaurin's expansion is differentiated term by term. The author introduces a new definition for failure rate which is certainly his privilege. But to use an old name with a reasonably entrenched connotation to mean something new and different is quite awkward in a paper, because the reader has constantly to make the translation in his own mind. The author's discussion of this concept does consider variability of the parts. It is worth noting that one institution spent considerable time and money trying to use a similar approach and had it come to virtually nought in the initially hoped-for sense. The problems of uncertainty and variability cannot be swept under the rug. They are bound to show up sooner or later no matter what formalism is adopted. Our big problem is that we do not know everything about our components that we need to know. There is a false hope held out in this article to sufferers from the vagaries of the real world. The kinetics portion of this paper, as a practical matter, will be of use only to those involved in theoretical research.

R67-13216 ASQC 824; 411; 412

POINT AND INTERVAL ESTIMATION, FROM ONE-ORDER STATISTIC, OF THE LOCATION PARAMETER OF AN EXTREME-VALUE DISTRIBUTION WITH KNOWN SCALE PARAMETER AND OF THE SCALE PARAMETER OF A WEIBULL DISTRIBUTION WITH KNOWN SHAPE PARAMETER.

Albert H. Moore (USAF, Air University, Institute of Technology, Wright-Patterson AFB, Ohio.), and H. Leon Harter (USAF, Office of Aerospace Research, Aerospace Research Laboratories, Wright-Patterson AFB, Ohio).
IEEE Transactions on Reliability, vol. R-15, Dec. 1966, p. 120–126. 5 refs.
(A67-16853)

Derivation of a one-order statistic estimator $\bar{u}_{mn}$ b for the location parameter of the (first) extreme-value distribution of smallest values with cumulative distribution function $F(x;u,b) = 1 - \exp\{-\exp[(x - u)/b]\}$ using the minimum-variance unbiased one-order statistic estimator for the scale parameter of an exponential distribution as was done earlier for the scale parameter of a Weibull distribution. It is shown that exact confidence bounds, based on one-order statistic, can be easily derived for the location parameter of the extreme-value distribution and for the scale parameter of Weibull distribution, using exact confidence bounds for the scale parameter of the exponential distribution. IAA

Review: These distributions are of importance in Reliability and estimating their parameters is necessary for the analysis of many test results. This paper presents extensions of the results in earlier papers by the authors (see R66-12380 and R64-11580). The results for the present paper for an extreme value distribution and a Weibull distribution are obtained by transforming the variates to the corresponding exponential variates. The paper also provides an extension of the table in the paper covered by R66-12380 for n = 21(1)40.

R67-13218 ASQC 822

AVAILABILITY OF THE STANDARDIZED WEIBULL DISTRIBUTION.

Raymond E. Schafer (Hughes Aircraft Co., Fullerton, Calif.).
IEEE Transactions on Reliability, vol. R-15, Dec. 1966, p. 132–133.

Tables of random standard Weibull numbers are considered usable in exactly the same ways as tables of random deviates if a given conversion formula is used. Weibull distributions possess a nonconstant hazard rate and result in cumbersome expressions, thereby necessitating the use of Monte Carlo simulation methods to determine reliability estimates. The transformation of the random variable simplifies use of this statistical technique. M.W.R.

Review: The standardized Weibull distribution mentioned here is, of course, the standardized exponential distribution, and the variable transformation has been noted before although not necessarily in this connection. The work is accurate except for a misprint in Eq. (1) and an editorial problem in the next to the last paragraph. It is not obvious that this technique is always of value but some people may find it time-saving. It can be shown that if Z is uniformly distributed (0,1) then the variable $x = (-\alpha \log Z)^{1/\beta} + \gamma$ has a Weibull distribution. Comparing this with Eq. (5) of the note, we observe that $y = -\log Z$. The only saving is one operation of taking a logarithm; all other calculations are the same, using exponential or uniform random variates.

R67-13224 ASQC 820; 872; 882

RELIABILITY, MAINTAINABILITY AND AVAILABILITY OF MECHANICAL SYSTEMS.

Igor Bazovsky (Litton Industries, Waltham, Mass.).
1964 Reliability and Industrial Statistics Courses, University of California, Los Angeles, Calif., Aug. 11, 1964, 11 p. 3 refs.

Behavior of the mechanical components that comprise a system are defined and the necessary equations are included to study the reliability, maintainability, and availability aspects of mechanical systems. It is noted that while the reliability of a mechanical part can be described by a definite probability density function with a unique mean time to failure, a system composed of many components will possess a continuously changing function as the parts fail and are replaced. Reliability, maintainability, and availability of multicomponent mechanical systems are considered as very complex functions of time. M.W.R.

Review: This paper is useful for theoretical purposes of a tutorial nature only and mainly for the fact that it shows that some of the simple equations often used in reliability are not always true. The assumption of statistical independence made by the author is implicit rather than explicit as it ought to be. There is a little difficulty with a few of the equations, for example: Eq. 1 purports to define reliability whereas in fact there are two undefined parameters in it; Eq. 2 which purports to define one of those parameters is a logical consequence of Eq. 1 and thus adds no new information. In Eq. 11 where the reliability after two failures is being calculated, the equation presumes that the first item did not fail twice in a row, and thus is not accurate. Some of the statements in the paper, while true, are not at all obvious from the discussion. Probability if one wishes to pursue the subject matter of this paper in detail, it would be wise to consult some of the references given by the author.

R67-13225 ASQC 824; 817; 821; 838

ASYMPTOTIC PROPERTIES OF SYSTEMS SYNTHESIZED FOR MAXIMUM RELIABILITY.

William H. Pierce (Carnegie Institute of Technology, Electrical Engineering Dept., Pittsburgh, Pa.).
Information and Control, vol. 7, Sep. 1964, p. 340–359. 8 refs. NSF Grant No. GP 39.
(A64-26732)

Presentation of a method of establishing those facts about the optimum design of reliable systems which can be obtained with the use of some simplifying assumptions, the most important of which is that component failures in the system are statistically independent events. Two useful ideas for synthesizing systems for maximum reliability are (a) to make improvements in the system in order of highest reliability benefit to cost, and (b) to establish a useful criterion of reliability value per cost. Both these ideas lead to an important v-function, defined when parallel redundant elements of the i-th function of a system have independent failure probability λ_i and are interconnected in such a fashion that a fraction B or more of the R_i (redundant) elements must fail for the function to fail. Its value is $v_i = H(B) + B\ 1n\lambda_i + (1\text{-}B)1n(1\text{-}\lambda_i)$; where H(B) is the entropy function of B and 1-B in nats. The v-function appears in asymptotes for (1) the probability that a redundant function fails, which is asymptotic to e^{-Rv} for a redundancy of R, (2) the optimum assignment of redundancies in an n-function system, which assignment gives all functions equal reliability regardless of cost, (3) the failure probability of an optimum n-function system, which decreases exponent ally with cost, and (4) the cost of an optimum n-function system with fixed reliability, which goes as $\{n\ 1n\ n\}/v$ as $n \rightarrow \infty$. The systematic synthesis procedure established by these ideas and asymptotes shows, for example, that restoring organs in some redundant digital computers should be placed after every N operations obeying $N + 1n\ \lambda(N + 1) = 0$, where λ is the failure probability of logic elements and adaptive vote-takers in the restoring organ. Author (IAA)

Review: This paper provides some useful results and the author appears to define his model quite well. It is largely a mathematical paper, not all of which was checked (but it appears to be accurate). Before using the results, it would be wise for anyone to go through the derivation. One should see what the necessary assumptions are all the way through a proof, and see whether one's own system conforms reasonably closely to those assumptions. By going through the derivation one can understand it well enough to apply it. The use of the word "asymptote" in several places is not clear, expecially in the example. This is typical of the fact that reading the paper for good understanding will require a considerable amount of time and effort for someone not intimately familiar with the methods and derivations. Sasaki (see R62-10496 and R63-10978) and Webster (see R64-11267 and R65-12023) have done some similar work in connection with increasing the reliability of a system for minimum cost.

R67-13226 ASQC 824; 822; 410

ESTIMATION OF A PARAMETER OF A RELIABILITY DISTRIBUTION FROM RESULTS OF TESTS.

L. I. Byalyy and B. R. Levin
Telecommunications and Radio Engineering, Part II–Radio Engineering, vol. 19, Sep. 1964, p. 104–110. 7 refs.

Assuming that the shape parameter of a Weibull distribution is known, the maximum likelihood method is used to obtain point estimates of the location parameter by using the results of a set of time-limited life tests. Procedure for estimating the unknown parameter is given, and statistical variance of the estimate is treated by introducing a new estimate in which the randomness is located in the denominator. Difference between this estimate and the maximum likelihood estimate is expressed quantitatively. M.W.R.

Review: The parameter referred to in the title is the location parameter in the Weibull distribution, when the shape parameter is assumed to be known. The method of maximum likelihood is used and while the tedious details of the mathematics were not checked, the work appears to be accurate. This estimation problem is often and well handled in the American literature. The paper will be of interest largely to those doing theoretical work. Engineers virtually always estimate Weibull distributions graphically anyway. The main advantage of an analytic method is that sometimes the uncertainties in the answers can be calculated. Most of the time the accuracy of graphical methods is more than adequate in view of the scarcity of data and the tenuousness of the original assumption of the Weibull distribution with two parameters.

R67-13227 ASQC 823; 552

WEIBULL PROBABILITY PAPER.

Lloyd S. Nelson (General Electric Co., Lamp Div., Cleveland, Ohio.).
Industrial Quality Control, ASQC, vol. 23, Mar. 1967, p. 452–453. 5 refs.

A probability graph paper is illustrated that is scaled and labeled so that Weibull distribution data can be plotted directly. After the minimum life parameter is estimated, special scales at the top of the graph paper permit the estimation of the shape parameter and the percentile of the mean. Means of constructing the paper are noted, and an example from fatigue life testing illustrates the use of this Weibull probability chart. M.W.R.

Review: This paper introduces a new form of probability paper for the analysis of Weibull data. Its unique feature is the presence of two monograms so placed and so scaled as to permit the graphical estimation of the shape parameter and the percentile of the mean. This estimation is accomplished by means of a line through an estimation point marked on the paper, and perpendicular to the fitted line. It is a neat approach to the graphical estimation of the parameters of the Weibull distribution. The author (who is also editor of the journal) has granted permission for the reproduction of his probability paper which is printed full size with the article. The reviewer worked an additional example using a xerox copy and obtained satisfactory results. The explanation in the paper is concise but adequate for those with some prior acquaintance with Weibull probability paper. For those desiring more details, Reference 2 cited in the paper is one of the better papers on this topic. Reference 3 provides tables and some discussion.

R66-13231 ASQC 822; 821

PARAMETER DISTRIBUTIONS AND THE PROBABILITY OF FAILURE-FREE OPERATION OF ELEMENTS SUBJECT TO WEAR.

V. B. Gogolevskii

Translated into ENGLISH from *Avtomatika I Telemekhanika*, vol. 25, Mar. 1964, p. 408–415. 3 refs. Published by Instrument Society of America.

Parameter distributions in devices subjected to constant and accelerated wear were studied, and formulas were derived for determining the probability of failure-free operation of such devices. The value of the wear or aging parameter at a fixed time is considered random and varies with the device. In practice the probability values for the devices are usually close to the critical rather than the exact critical values. Two typical cases are considered in the mathematical derivations are when the rate of change of the parameter is constant or when it increases with time. M.W.R.

Review: This paper treats a rather special case and the mathematics is rather tedious. For this reason it was not checked in detail, but appears to be accurate. The Gaussian distribution is assumed for some of the parameters. The paper is written in such a manner that it is actually difficult to tell what is going on without more tedious analysis of every sentence. The paper will be of use only to theorists because of the way in which it is written.

83 DESIGN

R67-13183 ASQC 831; 844

RELIABILITY PREDICTION TECHNIQUES.

John J. Gaudet (Sanders Associates, Inc., Systems Reliability Section, Nashua, N. H.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 17–29.

Available from IEEE, New York: $8.00.

Advantages, limitations, and design data requirements are discussed for various reliability prediction techniques that can be used to evaluate performance of new electronic designs and to indicate what can be done to increase successful performance. Consideration is given to prediction based on (1) equipment similarity, (2) active element group count, (3) part complexity and assumed stresses, and (4) actual part count and circuit stress analyses. Other reliability analyses affecting reliability predictions are mentioned, along with other bases for making predictions and the accuracy aspects of reliability determination. M.W.R.

Review: The scope of this paper is essentially a description of the four popularly-used methods for prediction of electronic equipment reliability: (1) equipment similarity, (2) active element group count, (3) part count with assumed stresses, and (4) part count with known stresses. The question of the relative accuracy of the four methods is raised but not answered to any degree. Thus, this paper is tutorial in nature, covering widely-known approaches mainly concerned with data bases. The absence of references is a short-coming in a paper of this type. Although the subject of reliability prediction for electronic equipment is old hat in a sense, it nevertheless contains many unanswered questions such as the one raised by the author concerning the accuracy of the four popular prediction methods. Some others are: Does the Poisson distribution of failures really apply to most electronic equipment? If so, is there any prevailing tendency in the length of the operational time (burn-in) needed to reach the Poisson distribution? What about failures induced by "post-factory" handling? What are the implications of part characteristics drifting so as either to cause an equipment performance characteristic to drift to an unacceptable value or to cause catastrophic failure? How about the piece part that fails, has no visible effect on equipment performance, but increases a stress somewhere? The reason for spelling out these questions is not to criticize this paper, because it does indeed cover the routine methods. Rather, the reason is to emphasize that the widespread application of the routine methods cited in this paper does not necessarily mean that they have a solid foundation nor that they all represent effective use of engineering time.

R67-13184 ASQC 831; 844

PREDICTION OF MECHANICAL RELIABILITY–A REVIEW.

David W. Weiss (Booz, Allen Applied Research Inc., Bethesda, Md.)

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 30–39. 26 refs.

Available from IEEE, New York: $8.00.

Requirements for reliability prediction in mechanical systems are discussed, and some significant prediction tools are reviewed. Progress in compilation and analyses of empirical data are noted; and probabilistic design analyses, especially for structures, are described. Fatigue, wear, and design of machine parts, and prediction of drift probability as a failure mode are considered. It is noted that knowledge on the prediction of mechanical systems reliability from physics of failure data is limited. In the past, therefore, reliance has been placed on empirical data about similar parts for survival predictions at every system hardware level. M.W.R.

Review: The reader will need to have a good grasp of probabilistic analysis and of mechanical failure terminology in order to follow this tutorial paper. This is a result of the situation that the prediction of mechanical reliability does not lean toward routine, handbook approaches such as in electronics and of the level at which this paper is presented. For instance, where the author discusses the stress–strength notion he essentially by-passes the simple stress–strength case which is often seen and goes directly into cumulative damage and extreme-value approaches. In the opening remarks concerning the variety of purposes for conducting reliability analyses, nothing is cited about what is probably the key use, such as where the relative values of prediction numbers may have a use even though the absolute values are suspect. (However, such a remark is made in the body of the paper.) Overall, this is a timely paper and should be of value to those who are first learning of mechanical reliability prediction as well as to those who are working in the area. The discussion is a probing one. Some of the points are basic and thereby have pertinence to non-mechanical reliability prediction. Many references are given, but two of them are not shown in the reference list although they are cited in the paper. In a private communication the author has indicated the following. (a) The two missing references were unclassified references to classified Air Force Reports prepared in 1961 and 1962 which were deleted by request. However, they can be obtained by contacting the author on an individual basis. (b) There is an error on page three (3) of the paper. The sentence beginning "The design allowables given represent...", should read as follows: "The design allowables given represent the strength value above which a given percentage (99 or 90) of the population of values is expected to fall with 95% confidence."

R67-13185 ASQC 831; 431; 821; 882

SYSTEM EFFECTIVENESS ANALYSIS–A CASE STUDY.

I. Bosinoff and S. A. Greenberg (MITRE Corp., Bedford, Mass.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 40–53. 8 refs.

Available from IEEE, New York: $8.00.

A telemetry system composed of several sites forming a test range is used as a case history to illustrate a flow graph method for determining system reliability. Potential capability of the range is evaluated with respect to its systems effectiveness, with failure rates at each site assumed identical. A probability fill, telemetry coverage, and transition rate diagram are illustrated; and mean time between failure and reliability are determined by an analog computer program. Techniques are developed that permit the allocation of limited resources in an optimum fashion. System effectiveness measures are computed for a group of computing configurations, and the configurations providing the most system effectiveness per available funds are arranged in sequence. The cost of the system is balanced against the cost of aborting a mission. For the parameters studied, mission success does not vary appreciably if some sites are down initially. M.W.R.

Review: A case history illustrating the use of flowgraph techniques in solving system reliability problems is given in this paper. While the specific reference is to a telemetry system consisting of several sites forming a test range, the type of analysis is applicable to almost any complex system. The objective here was design optimization based on the criterion of cost–to give the most effective system for the money. However, in other cases optimization with respect to reliability, availability, safety, or some other index may be desired. The same techniques can be used; they are applicable generally to problems in the optimum allocation of limited resources. The material is clearly presented and well illustrated; it could serve as an example of implementation for those who have access to other sources for the fundamentals of the technique. A number of useful references are cited.

R67-13186 ASQC 838; 821

RELIABILITY OF LOADED PARALLEL-REDUNDANT SYSTEMS.

Peter Beckmann (Colorado Univ., Department of Electrical Engineering, Boulder, Colo.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 54–58. 4 refs.

Available from IEEE, New York: $8.00.

An explicit solution is presented for the surviving spares of a loaded parallel redundant system that are exposed to increasing stress with successive failure. Hazard rate for an element of the system is allowed to change at each failure. Dependence of the failure rate on the loading stress does not have to be given analytically; although reliability for such a system is derived for a general, not necessarily linear, dependence of the component failure rate on the loading stress. Details are given for a numerical analysis. M.W.R.

Review: This is a mathematical paper treating the subject of the reliability of loaded parallel-redundant systems. These techniques should find many applications in the design of such systems. Very little work has been done in this area, and the appropriate references are given. This paper is a new, but limited, contribution since the hazard rate for an element of the structure is allowed to change at each failure. Between failures, however, two implicit assumptions are important: (1) hazard rates of the operating elements are constant and the same for each element, (2) failure-time intervals are statistically independent. Two problem areas in which further work might be useful are (1) consideration of the effect of the mode of failure, and (2) the treatment of the general case in which the hazard rate has an arbitrary dependence on both age and stress (although this will be difficult at best). Some of the statements in the paper need very careful interpretation by the reader. (When writing for engineers it is wise to modify "independence" by "statistical" when that is what is meant. Otherwise they may construe it to mean physical independence which is different and less restrictive.) An example of four transistors working in parallel into a common load is given to illustrate the techniques.

R67-13192 ASQC 836

IMPLEMENTING FORMAL DESIGN REVIEW.

Richard M. Jacobs (Westinghouse Electric Corp., Elevator Div., Jersey City, N. J.).

In: *1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 118–127. 8 refs.
Available from IEEE, New York: $8.00.

A design review procedure is outlined that results in considerable cost savings. Since a formal design review changes the attitudes of engineers and instills in them a greater willingness to consider improvements on succeeding designs, a better product usually results at a lower cost earlier in the design cycle. Customer satisfication, too, appears to increase with a formal design review. In addition to money savings and customer design approval, other benefits attributed to the review program are: (1) accelerating maturity of the design, (2) speeding delivery dates, (3) generating new product lines, (4) reducing design changes, and (5) improving staff capabilities. M.W.R.

Review: Many papers in the reliability literature have dealt with design reviews, either as prime topics on their own, or as parts of reliability programs. (See RATR items with ASQC Code 836). This is a tutorial paper addressed to the subject of how to implement a design review. It is an effective presentation which will be of most value to those without previous experience in this phase of management for reliability. However, those who have conducted/participated in this activity might wish to scan the paper for ideas. A number of pertinent references are cited, and should serve as useful supplementary reading.

R67-13194 ASQC 832

HUMAN FACTORS ENGINEERING IN REENTRY SYSTEM DESIGN.

W. P. Woodcock, H. L. Gilmore and G. R. Hatterick (AVCO Corp., Missile Systems Div., Wilmington, Mass.).
In: *1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 137–147.
Available from IEEE, New York: $8.00.

Approaches, problems, and solutions are discussed for the application of human factors engineering to the Minuteman reentry vehicle airborne and ground support equipment. Consideration of human factors can reduce subsequent human errors, and increase reliability and safety from conceptual design through the operational environment in the field. Magnitude and types of human errors are noted, and some corrective actions are recommended. Human factors in design and in post-design applications are mentioned. M.W.R.

Review: Human factors aspects of design, manufacture, and testing have an important role in the achievement of reliability of systems. The concern in this paper is with this consideration as it pertains to missile systems, but the principles clearly have wider applicability. Some examples of human error and associated corrective action are cited. The integration of human factor considerations in design and development, as well as in the post-design phase are discussed, and some illustrative material is given. The overall effect is a rather general picture of the role and potential accomplishments of human factors engineering.

R67-13195 ASQC 831; 817

RELIABILITY AND PROGRAM DECISION MAKING.

C. S. Bartholomew (Boeing Co., Space Div., Kent, Wash.).
In: *1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 148–161. 5 refs.
Available from IEEE, New York: $8.00.

Reliability is considered for a planetary exploration program, such as Voyager, that requires complex maneuvers and operation of television cameras over wide areas for long periods of time. Although computers provide the fast and economical means of making repetitive simulations for tradeoff and sensitivity, obtaining good cost and reliability data still presents a problem in performing system effectiveness analyses. The effect of reliability considerations is shown for a few of the decisions made in connection with the Voyager program. Relative frequency of decision peaks during the preliminary design and early detail design phases are noted, and the relative magnitude of decisions tends to decrease as the program progresses. Overall mission success probability is discussed, as well as reliability allocation to mission phases, subsystems, and components. Reliability versus weight and power tradeoffs, reliability demonstration, and allocation of test time are considered. M.W.R.

Review: A collection of observations about reliability and (a) tradeoffs, (b) parts, and (c) testing, are presented in this paper. The material is sensible and timely, apparently resulting from Voyager (Mars) proposal efforts. No equations are used, but there are numerous illustrations. An interesting note in this paper is about Boeing research, under contract to the Jet Propulsion Laboratory, on methods for improving the effectiveness of test planning.

R67-13196 ASQC 837

VARIABILITY PREDICTION–A NEW METHOD.

Richard O'Bryant (Texas Instruments Inc., Dallas, Tex.).
In: *1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 181–188. 9 refs.
Available from IEEE, New York: $8.00.

A convolution method is described that calculates a partial distribution of each circuit variable with respect to all circuit parameters, and then derives the total distribution for each of the circuit variables by convolving all of its partial derivatives. Convolution prediction is considered as good as either moment or Monte Carlo predictions for determining the extremes of the circuit variable variation. It does not have the accuracy that Monte Carlo does for predicting any point of the circuit variable distribution, but it provides more accurate results than the moment method. For circuits with from 10 to 120 parameters, the convolution method is faster than either Monte Carlo or moment methods. Solution of the propagation of variance equation of the convolution method gives all of the information that a moment analysis does and also predicts the actual shape of the circuit variable distribution. A worst-case method, MANDEX, is also discussed. M.W.R.

Review: Four methods for the prediction of performance variability are compared with respect to their general utility on the basis of an example using a constant-current generator equivalent circuit. The first three methods–MANDEX, Monte Carlo, and moment methods have been discussed frequently in the literature. The fourth method, that of convolution, is a new application to the computer analysis of electronic circuits; however, the approach is described in many probability textbooks and is the basic technique for deriving the distribution of a sum of independent variables. The methods are described only briefly and one would have to resort to the references or appropriate textbooks on the subject areas in order to apply them. The histograms for performance of the equivalent circuit are compared for the moment, Monte Carlo, and convolution methods. The input data for this computation involved one variable with a bimodal trapezoidal distribution. Because this variable has the greatest effect on the performance of the circuit among the eight variables considered, the resulting performance distribution is highly dependent on the form of the distribution of this particular variable. Consequently, in comparing the moment method in which a Gaussian distribution was assumed with the convolution and Monte Carlo methods, it is obvious that a real difference would exist. This paper is of value to the reader in that it points out that the usefulness of the method is dependent on the nature of the distributions of the input variables and the relative effects of the variables on performance. It should be pointed out, however, that in the moment method one need not assume that the resulting performance distribution is Gaussian and in examples like this one such an assumption is unrealistic.

R67-13203 ASQC 831; 612; 782
American Power Jet Co., Ridgefield, N. J.
PREDICTION OF THE EFFECTS OF COMBINED AND SEQUENTIAL ENVIRONMENTS Final Report
George Chernowitz, S. J. Bailey, S. Gurman, and S. M. Levin
Jul. 1965 151 p refs
(Contract DA-36-038-AMC-1784(A))
(APJ-415-1; R-1793; AD-626422; N67-82435)

The project applies advanced techniques to determine the environmental competence of materials and equipments under combined and sequential environments experienced by Army systems and components in field operation. The critical aspect of environmental interaction is thoroughly treated and integrated into the overall approach. A plan is presented for receiving, organizing, and operating on the problem elements to yield the desired output of environmental effects prediction. The plan is specifically designed for computerization. The rationale is set forth in a logical and comprehensive framework that may be readily understood and implemented by the potential user. A pilot exercise of the computerized prediction system gives specific examples of the system operation in specific instances. Conclusions and recommendations are offered regarding system practicality, usefulness, potentialities and limitations, and the guideposts presented for future action in the field of environmental effects prediction. Author (TAB)

Review: The effects of environments–combined and sequential–are an important factor affecting the reliability of equipment. The interaction of environments has been a serious problem. This very comprehensive report makes a substantial contribution in the area of environmental effects prediction, including the aspect of environmental interaction. The system described serves in effect as a computerized environmental test facility. While the specific concern was with Army systems and components, aerospace equipment could be treated by the same approach. The report leaves little to be desired in terms of clarity and detail. Potentialities and limitations of the system are described, and a rather extensive bibliography is given.

R67-13205 ASQC 831; 431; 821
SYSTEM STATES ANALYSIS AND FLOW GRAPH DIAGRAMS IN RELIABILITY.
Enrico Dolazza (Olivetti General Electric, Milan, Italy).
IEEE Transactions on Reliability, vol. R-15, Dec. 1966, p. 85–94. 13 refs.

A described method permits rapid evaluation of reliability functions and some probabilistic parameters related to the operation of systems. The method is based on the concept of system states and on the observation that, in terms of such states, the probabilistic behavior of systems is well described by the Markov process in infinitesimal *dt*, whenever subsystems behave independently of each other and randomly in time. Out of many methods useful to determine the probability that a system is in state *Sj* at time *t*, i.e., to solve the set of system state differential equations, the algorithm of the signal flow diagram has been emphasized here. Actually, such an algorithm gives us a Laplace transform of the reliability function which permits evaluation of some probabilistic parameters related to the reliability of systems (as mean time between failures) without passing through time–domain. Several applications are examined. Author

Review: There are enough confusing and unclear points in the paper to lower its quality (some are probably due to a language difficulty). For example, (1) In a paper written for engineers the word "independence" should always be stated as statistical independence, if in fact that is what is meant. An engineer may have in mind only physical independence. (2) The phrase "randomly in time" has little meaning. (3) It is unlikely that the events of "change from state j to state k" are statistically independent, since a knowledge that one has or has not occurred will give some information as to whether another can *possibly* occur or not. (4) The idea of maximum entropy does not give a unique answer, since it depends on the form of the variable. (5) There are quite a few misprints or omissions in the algebra. (6) In Section IV on System Reliability Parameters three typical cases are discussed with regard to their coefficient of variation and the worthwhileness of preventive maintenance. There is too much generalization too soon. The author does not distinguish between the behavior of the replaceable elements in a system or subsystem and the behavior of the system itself. The very concept of preventive maintenance is not too well defined here. It is not immediately obvious that the difference: "1–variation coefficient" gives a quantitative idea of how preventive maintenance can improve the reliability of the system. (7) In the discussion of degree of redundancy the term "functional states" is not defined. Obviously it has a very specific meaning and may well not be the same one that a systems analyst would use. (8) The term "first cut" evaluation of system reliability is implicitly defined as knowing the mean time to failure and the coefficient of variation of time to failure. In many redundant systems, knowing the mean time to failure is of relatively small importance compared to the failure rate at times small compared to mean failure times of the elements (the author brings this out later). (9) In the examples there is again the confusion between the behavior of the system and the behavior of the subsystems or replaceable elements. Further, apparently the only kind of preventive maintenance considered is element replacement as opposed to say correcting the drift in an element, or greasing it. (10) It is implicitly assumed in all examples that the nonoperating failure rate is zero. (11) In Example 1 it is implicitly assumed that the debugging system failure time is exponentially distributed. The discussion of flow graph techniques is reasonable. The reader is referred to other papers for methods of reducing flow graphs or solving them. Flow graphs, of course, are most convenient when the system is simple. When the system gets very complex the flow graphs themselves get very complex (as of course do other techniques) and it is certainly an open question whether the flow graph or some other technique is more suiable in that situation. Obviously the method of reducing flow graphs corresponds to some particular method of inverting a matrix. In a complex situation, which would be the most convenient would have to be determined. It is important to note that some of the assumptions are physically restrictive. This does not mean that the model is not analyzed correctly, but it does mean that the usefulness of the model may be limited. This paper is similar to others which have appeared in this journal and elsewhere showing how flow graphs may be used and also deriving a simple first-order Markov process as a description of a particular kind of system.

R67-13210 ASQC 832

HUMAN ERROR?–FACTORS AND FALLIBILITY.

H. R. Willis (Lockheed Aircraft Corp., Lockheed-Georgia Co., Marietta, Ga.).

Lockheed Georgia Quarterly, vol. 4, Feb. 1967, p. 3–6.

(A67-20229)

Discussion of some of the causes of human error. The extent of human error is considered, and the effects of mental and physical fatigue, microsleep, and flicker fusion frequency are investigated. IAA

Review: This is a very readable paper. It discusses the kinds of mistakes people make and how they make them rather than than how to correct them. A very worthwhile point of view expressed is that not only do equipment operators make mistakes, but some of these mistakes are virtually caused by poor design. The human factors field has tended to concentrate on the operator as a cause for error or on some of the more obvious design deficiencies. The designer needs to have *his* human factors considered also and his environment adjusted so that the equipment he produces will be part of a more reliable man–machine complex. Another factor which comes into the situation involves the installation or service personnel who may not know or may not care about doing the job properly. Some consumer industries have managed to design equipment which is very tolerant of just about everyone in the system. This has been forced upon them because a consumer product virtually must be designed that way in order to hold up. The article is well worth reading by those concerned with any portion of the product cycle. Even though they are familiar with some of the information, the shock value of case histories is always helpful in refocusing one's attention.

R67-13211 ASQC 833

SEMICONDUCTOR RELIABILITY–FOCUS ON THE CONTACTS.

J. A. Cunningham and J. G. Harper (Texas Instruments, Inc., Dallas, Tex.).

Electronic Engineer, vol. 26, 1967, p. 74–79. 12 refs.

(A67-18246)

Discussion of the temperature stability of the metals used for the contacts and interconnections on semiconductor devices. Contacts in the form of gold ball-bonds to aluminum make up a suitable system for normal temperature operation. For higher temperatures, a more stable metal system is gold wire ball-bonded to a molybdenum–gold laminated contact. While the performance and reliability of aluminum contacts with gold ball bonds are excellent, there are several reasons why aluminum is not the best choice for high-temperature (greater than 125°C) testing or use. The main reasons are: chemical reaction of aluminum with SiO_2, the electromigration of aluminum, and the formation of the gold–aluminum compound $AuAl_2$ (purple plague). In addition to increased metallurgical stability, the molybdenum–gold contact system offers: (1) greater resistance to abrasion and scratching due to the hard layer of molybdenum; (2) a high degree of freedom from problems related to current-induced mass transport; and (3) freedom from chemical reaction with the protective thermal oxide, since the reaction between SiO_2 and molybdenum is not thermodynamically favorable. It is noted that corrosion resistance is not a feature for either the aluminum or the molbydenum–gold contact systems. IAA

Review: The high temperature (>125°C) limitations of aluminum-metalization and gold-wire bonding for silicon semiconductor devices are well recognized. This paper presents a metalization system, developed at TI, consisting of a molybdenum–gold bimetal layer which allows gold-to-gold bonding. The reliability problem of the aluminum to gold interface is eliminated and presumably no worse ones are introduced. The paper is well written, not highly technical, and includes photographs of wire bonds made with three different material combinations: aluminum to gold-wire, aluminum to aluminum-wire, and gold to gold-wire. The all-aluminum system with wedge bonding has been used by many semiconductor manufacturers for their high-reliability lines. The physical strength of a wedge bond is less than for the ball bond used in the all-gold system. The all-aluminum system successfully passes military device acceleration and shock qualification tests and is probably more than strong enough. The reliability advantage of ball bonds over wedge bonds is hence not clear-cut. The molybdenum–gold metalization system has considerable potential. Since it is rather new, a comparison of its reliability with that of the all-aluminum system is not now possible. It is reported to be more expensive to implement, but it does offer relative freedom from metal migration, which is a problem in the all-aluminum system when high current densities are encountered at high temperatures. Other manufacturers will probably retain their own systems until the advantages in changing to new ones become clear-cut.

R67-13217 ASQC 838; 824; 844

THE ANALYSIS OF A CLASS OF NON-SERIES PARALLEL REDUNDANT SYSTEMS.

Carl J. Benning (Tracor, Inc., Austin, Tex.).

IEEE Transactions on Reliability, vol. R-15, Dec. 1966, p. 127–132.

Two analysis techniques are presented for studying a class of non-series parallel, dual channel systems. The first technique is a method for obtaining an approximate solution for the system. It is based on a systematic analysis of first- and second-order failure modes and involves the use of matrix algebra. The second technique is a method for generating the exact solution from the approximate solution. This method involves a transformation that converts the system into a logically equivalent system. An exact solution for the transformed system is derived and is shown to be the exact solution for the original system. Author

Review: This is essentially a mathematical paper and it appears generally to be in good order. The author confuses events with their probabilities which makes for some difficulty in reading parts of the paper. When writing for engineers it is wise to use the term "*statistical* independence" if that, in fact, is what is meant (as in this case). Otherwise an engineer may think of physical independence. The restriction that the logic diagram must possess an axis of symmetry may be severe. The rules for generating some of the matrices are not clear. For example, in the system matrix on second-order failure modes it is not at all obvious why the diagonal should be 1 in view of the definition of each element. In a private communication the author has indicated that this is a further restriction on the system. The differences between lines which terminate in an arrow and those which do not are not clearly explained, especially in connection with analyzing the logic diagram, and must be inferred from the figures. The discussion on transforming the matrix would require a fair amount of thought to understand in order to be able to reproduce on one's own. On a complex system it might actually be difficult to carry out the instructions. The function of the symmetry axis is not clear; the only important place in which it is used appears to be in a definition of a second-order failure mode. The so-called factoring theorem, while credited to a particular author in 1963, is, of course, a special case of a well-known probability formula. The author gives no references wherein his method might be more fully explained. In a private communication he has stated that he believes this work to be original. The idea appears to have merit as one of the possible techniques of analysis assuming that the aforementioned problems are cleared up. Since apparently the author was able to write down the expression for success before doing this analysis, it is not clear why the probability of the complex event was not expanded by the usual rules. The difficulty with many methods such as the author's is that on simple systems they all work relatively well; on complex systems they are virtually all difficult to apply. In this particular situation, for example, some authors would undoubtedly wish to recommend flow graphs (why, I do not know, but they would). In a private communication the author has pointed out the following typographical errors: on p. 129, third line, Fig. 2 should read Fig. 3; the vertical bar in Eq. 6, p. 131 should not be there; Figs. 6 and 7 are interchanged.

R67-13220 ASQC 838; 821
Royal Aircraft Establishment, Farnborough (England).
REDUNDANCY IN DIGITAL SYSTEMS
F. A. Inskip Sep. 1965 42 p refs
(RAE-TR-65201; N66-14610) CFSTI: HC \$3.00/MF \$0.65

A number of methods of using redundancy in digital systems is described. Numerical values of reliability are given for a small system of the order of size typical of a satellite data handling system. Two values of reliability are given; one using the best values of component reliability available at the present time and the other using an order lower. Author

Review: The theoretical and practical aspects of four types of redundancy (component, gate, majority voting, and quadded logic) for use in digital systems are discussed. The mathematical analysis is straight-forward and clearly presented. It should be remembered that the analysis applies only to the particular conceptual models which are analyzed. Often these are more restrictive than it would appear; in particular the dichotomy of failed vs. not-failed is not always adequate. The report should be of value to designers of electronic systems employing redundancy.

R67-13229 ASQC 833
RELIABILITY AND STANDARDIZATION *ARE* COMPATIBLE.
James A. E. Hyams (Servonic Instruments, Costa Mesa, Calif.).
EDN, vol. 12, Mar. 1967, p. 74–77.

Emphasis is placed on the problems involved with producing new components as opposed to first considering off-the-shelf well-proven designs. Specific examples are cited in which the component is considered last in a system design, and as a result the component is subjected to cascading safety factors. The problem of obtaining reliability without quantity is discussed, and a graph is included of the relation between the production quantity and the product reliability and cost. Methods are suggested for alleviating the problem, and includes early involvement of the vendor, making specifications available, putting reliability in the correct perspective, making use of past experience, and building a manufacturing capability. C.T.C.

Review: This is a short readable paper directed toward design engineers and manufacturers. While the contents are certainly old, they are even more certainly worth repeating. As a matter of fact, reliability and standardization are very compatible, it is just that neither is often compatible with some of the other restrictions imposed on the designer (and at times his own inclinations). One of the suggested cures for specials is to contact the manufacturer early in the design. Unfortunately there are those instances where this accomplishes virtually nothing, since the manufacturer's reply is "Tell us what you want and we'll give it to you." This, however, should not stop a designer from trying to cooperate early in the design.

R67-13230 ASQC 838; 821
THE RELIABILITY OF IDEALLY REDUNDANT SYSTEMS.
V. V. Naumchenko
Translated into ENGLISH from *Avtomatika I Telemekhanika*, vol. 25, Mar. 1964, p. 314–415. 2 refs. Published by Instrument Society of America.
(A64-19651)

Discussion of the problem of increasing the reliability of a system when the reliability of the system elements is known and is smaller than the reliability required of the system. A solution is obtained by introducing the concept of ideal redundancy, in which the redundant system carries out all the functions of the initial system as long as the number of the serviceable elements of the redundant system is greater than (or equal to) the number of the nonredundant system. Derived are relations between the minimum redundancy required and the ratio of the mean time of efficient operation of the system to the mean time of the efficient operation of the system's elements. IAA

Review: The ideal redundancy referred to in the title is merely the situation wherein spares have zero failure rate during nonuse. While not all the mathematics was checked, it appears to be correct. The assumptions of statistical independence for failures of the identical elements and their constant hazard rate are made implicitly. The ratio of total elements to necessary elements is shown to lie between e^m and $1 + m$ where m is the ratio of system mean failure time to element failure time. The author uses mean failure time as the parameter descriptive of reliability and arrives at the well-known conclusion: with active redundancy, trying to improve the mean failure time is a lost cause. Generally speaking, this paper would be of interest only to a few theorists.

R67-13232 ASQC 838; 821

RELIABLE LOGIC ELEMENTS AND OUTPUT AMPLIFIERS WITH REDUNDANT STRUCTURE.

S. M. Domanitskii and I. V. Prangishvili

Translated into ENGLISH from *Avtomtika i Telemekanida,* vol. 25, Apr. 1964, p. 555–561. 2 refs. Published by Instrument Society of America.

Various redundancy methods are considered for increasing the reliability of semiconductor logic control systems, with specific attention given to transistorized NOR elements. A comparison of reliabilities of redundant and nonredundant NOR elements results in a reliability coefficient of 0.9 for the nonredundant system, 0.972 for a system with unit redundancy and voting, and 0.99886 for a system with elementary redundancy. It is, therefore, concluded that logical elements and amplifiers using elementary redundancy can increase the reliabilities of logical control systems. An analysis is included of possible faults and their consequences in the redundant logical element. M.W.R.

Review: This is a type of comparison that has appeared in the American literature from time to time. It compares quad redundancy with majority voting. One should pay special attention to the assumptions involved in the majority voting failure scheme, especially those which define failure, since the results are quite sensitive to their exact nature. For example, (1) the voters are not redundant; (2) no account is taken of degradation and in quad circuitry this can be especially difficult. The whole procedure is based strictly on catastrophic failures in a go no–go situation. The quad system turns out to have by far the largest failure reduction potential in this example, but the results cannot necessarily be extrapolated to other situations. Not all the mathematics was checked, but it appears to be good.

R67-13233 ASQC 838; 824

ADDITIONAL ESTIMATES FOR A FRACTIONAL REDUNDANCY SCHEME.

A. L. Raikin

Translated into ENGLISH from *Avtomatika i Telemekhanika,* vol. 25, Apr. 1964, p. 582–584. 3 refs. Published by Instrument Society of America.

(A64-19346)

Determination of additional characteristics for a previously developed redundancy scheme. Specifically, the number of available redundant elements and the dispersion of behavior are defined as a function of time. IAA

Review: This is a short note. It assumes statistical independence and a constant hazard rate of elements. Not all the mathematics was checked but it appears to be accurate. The paper will be of most use to theorists doing work in the field. While the calculations are not very deep, they are tedious. This is typical of the special cases analyzed in some detail in the Russian literature.

84 METHODS OF RELIABILITY ANALYSIS

R67-13204 ASQC 844; 775

LOW-FREQUENCY NOISE PREDICTS WHEN A TRANSISTOR WILL FAIL.

Albert van der Ziel and Hu Tong (Minnesota University, Minneapolis, Minn.).

Electronics, vol. 39, Nov. 28, 1966, p. 95–97.

(A67-14277)

Discussion of the possibility of improving the simplicity and accuracy of transistor reliability studies by using noise measurements instead of statistical values to forecast the lifetime of the device. Preliminary results of an investigation showed that transistor noise serves as an indicator of when the device will fail because this parameter changes drastically toward the end of the transistor's life. It is shown that, by measuring the low-frequency noise of new transistors, it is possible to make a reasonable prediction about the life expectancy of the device. IAA

Review: Noise at 1 kHz is proposed as a basis for simple and accurate reliability studies on transistors. The methods used by the authors and the results obtained are concisely described. This appears to be a promising nondestructive test method, but large-scale testing will need to be done in order to see just how well the low-frequency noise measurements are correlated with transistor lifetimes. In a Letter to the Editor appearing in *Electronics,* vol. 40, no. 1, 9 Jan 67, p. 4, 7 Mr. John M. van Beuren, President, Quan-Tech Laboratories, Inc., Whippany, N. J. points out that this concept was developed by his company over five years ago. He goes on to say: *"We are not overly disturbed by the fact that credit for* the origination of an important reliability tool was given some five years late to the wrong source. After all, mistakes can be made with the best intentions. But we continue to be disturbed by the fact that this concept has never been fully accepted by the engineering public, especially those who should be most interested in the ultimate in reliability, such as the military and aerospace agencies." Reliability engineers concerned with transistorized equipment will do well to read the rest of Mr. van Beuren's letter.

R67-13212 ASQC 840; 844; 851

MODERN BASIC CONCEPTS IN COMPONENT PART RELIABILITY.

C. M. Ryerson (Hughes Aircraft Co., Culver City, Calif.).

Microelectronics and Reliability, vol. 5, Nov. 1966, p. 239–250.

(A67-15477)

General review of modern basic concepts in component part reliability. These concepts are basic to an understanding of part reliability and the procurement of parts with the highest reliability. The paper relates the engineering significance of types and modes of failure with techniques for lot-screening. Some results of application of these techniques are described. Typical questions concerning quality and reliability control are answered. Author (IAA)

Review: The paper deals largely with screening techniques for electronic component parts to achieve high reliability. As the author indicates, much of the material has appeared elsewhere. In general, the article is competent and worth reading. An important point is that many observed failures are actually secondary failures whether they are in another component or not. The manifestation of the secondary failure depends considerably on circuit conditions; for example, an original short somewhere may produce a secondary open-circuit if enough current is available. The discussion of screening is good, and the success of the author's company in regard to its satellites is not to be taken lightly. But screening is a subject of considerable controversy. In essence, and originally, all part specifications are considered a screen. It turns out that some of them are not very well correlated with good performance over a long life and that further specifications must be developed. The trick is to find those things which can be specified and measured rather easily which do correlate with good performance over a long life. This is certainly not to quarrel with any of the examples given in the text, but to point out that one should be aware of just how much he is guessing with regard to the actual effectiveness of a screen. The story of the man who waved a broom on top of his house to keep away the polka-dot colored elephants is not to be forgotten. When the man was questioned about the need for his action he merely pointed to its effectiveness in completely keeping away all polka-dot elephants. There are a few places in the introductory material where one could disagree with the author. For example: (1) Parts are said to fail because the stress exceeds the strength. The simple stress–strength model of failure is not sufficient; for example, there are degradation-type failures such as pipe-lines which get clogged. (2) It is suggested that the parts which fail are nontypical. It may be that they are reasonably typical, but that the environment was atypical. (3) The failure rates for digital circuits are asserted to be lower than those for analog circuits when comparable safety factors in design are used. This is really a definition of the word "comparable." (4) It is stated that reasonably accurate reliability prediction can be achieved when degradation failures are minimized by considering catastrophic failure rates such as listed in MIL-HDBK-217. There are certainly those who would say that anyone who comes within a factor of two is very lucky and to be within a factor of five requires some luck (except on equipment very like that from which the data were gathered). (5) The basic catastrophic failure modes are assumed to be open and short. Obviously this is only for two-terminal electric devices. The previous comments are not intended to detract from the quality of the paper, but to show that it should be taken for its overall value, rather than for all of the details.

R67-13214 ASQC 844; 851

FAILURE MECHANISMS IN SILICON TRANSISTORS DEDUCED FROM STEP STRESS TESTS.

M. R. P. Young and O. M. Elkins (Texas Instruments, Ltd., Bedford, England).

Microelectronics and Reliability, vol. 5, Nov. 1966, p. 271–290. 7 refs. Research sponsored by the Ministry of Defence (Navy) and Texas Instruments.

(A67-15482)

Intensive study of the mechanisms of mechanical failure in silicon transistors deduced from step stress tests. Several examples from p–n–p and n–p–n designs are presented and analyzed. The experiments use both temperature and power as stresses, the latter taking two forms–step stress in current at constant collector voltage and step stress in voltage at constant collector current. IAA

Review: This paper largely describes experimental results. The authors appear to handle the data well. They do not try to read into it more than is there, e.g., the drawing of straight lines on graphs is used to indicate trends more than to support theoretical behavior. The idea of using step–stress tests to find failure mechanisms which then might be important in actual transistor operation is a good one and needs to be emphasized more. In terms of making a contribution to the reliability discipline, the discussions of why and how are more important than the actual results. A reading of this paper would be worthwhile for those who are interested in the use to which step–stress testing might be put in their own organizations. The material is well handled.

R67-13221 ASQC 844

APPLYING INTEGRATED CIRCUITS–NEW FAILURE MODES.

Gled R. Madland (Integrated Circuit Engineering Corp., Phoenix, Ariz.).

Electronic Products, vol. 9, Mar. 1967, p. 148–155.

Causes and corrective measures for new failure modes of integrated circuits are treated by citing actual experiences. Carelessness about electrical design limits is implicated as a failure cause; and the lack of uniformity and all-inclusiveness of specifications covering electrical, mechanical, environmental, and other parameters is noted. Inspection of components is stressed, and failures caused by reversing the labeling of integrated circuits 180 degrees are noted. Consideration is given to so-called vanishing metallization lead bonding, and radiation resistance; and emphasis is placed on stringent fabrication and quality control procedures. The savings to both the military and industry is stressed in connection with the production of more reliable electronic equipment. M.W.R.

Review: This is a qualitative but good article on failure modes in integrated circuits. Unfortunately the state-of-the-art is such that about all the author can do is state the problems; very few solutions can be given. Anyone who has not yet received his first disillusionment about integrated circuits should very definitely read this short paper. It is not difficult to read and can help achieve a reasonable perspective on the disadvantages involved with integrated circuits. The advantages are covered in earlier articles in this series by the same author, and also in all of the advertising literature by manufacturers of integrated circuits.

R67-13222 ASQC 844

SOLDER BALL FORMATION IN SILICON ALLOY TRANSISTORS.

E. B. Hakim, L. K. McSherry, and B. Reich (U.S. Army Electronics Command, Electronics Labs., Fort Monmouth, N. J.).

IEEE Transactions on Electron Devices, vol. ED-12, Jun. 1965, p. 369–372. 2 refs.

Investigation and solution of the so-called "solder ball" problem, which has plagued the transistor industry for years, are discussed. Upon investigating silicon alloy transistors that use tin for electrodes, it was discovered that solder balls (which can cause internal short circuiting of the device) are not necessarily associated with manufacturing procedures as previously believed, but are produced by the devices themselves because of the material used in construction. Electrical stresses or low temperatures produce balls in units which were initially free of any foreign matter. This is due to the low-melting temperature tin alloy used in the construction of the transistor (or other semiconductor). Thus, devices may have balls when put in use that cause equipment failure later. The devices appear good under all measurement; however, the devices are in use, a mechanical short circuit may shake a ball loose to short circuit the transistor and make the circuit inoperable. Author

Review: This is an expanded version of the note (with the same title and by the same authors) covered by R65-12050.

R67-13223 ASQC 844; 782

RELIABILITY AND STERILIZATION.

C. S. Bartholomew and D. C. Porter (Boeing Co., Aerospace Group, Seattle, Wash.).

Journal of Spacecraft and Rockets, vol. 3, Dec. 1966, p. 1762–1766.

(A67-15239)

Relationships between the electronic reliability requirements and spacecraft sterilization requirements have been studied. An optimistic view on the compatibility of the reliability and sterilization requirements for present electronic systems is projected. The demands for reliability and long life have created parts immune to temperature damage well above the time temperature dose requirements for sterilization. Exceptions exist such as certain classes of capacitors where the sterilization time temperature dose is clearly damaging. Step stress data identifying the damage threshold over a broad range of time temperature dosage is used to illustrate the wide margin above the sterilization requirement for certain part types. The possibility is examined of more effectively utilizing the resources available for heat sterilization compatibility verification by broadening the objective to better identify the damage thresholds and the relationships of environments and failure mechanisms. Decontamination with ethylene oxide gas is examined. The few problems that exist appear to be primarily caused by the water vapor used with ethylene oxide rather than the ethylene oxide itself. Author (IAA)

Review: The relationship between reliability and sterilizable electronics is an important consideration for planetary vehicles. This paper shows that reliability and sterilization are not really competing characteristics. Both thermal and chemical sterilization are considered. Results are presented compactly, mainly in the form of tables and graphs, making the paper valuable to those who wish to get a quick picture of the essentials in this topic area. A worthwhile suggestion made in the paper is that of using the design, analysis and test effort involved in developing sterilizable electronics to extend our understanding of the relationships between the sterilization environments and reliability in terms of failures mechanisms, damage functions, and improved parts. Specifically, step-stress testing is recommended in preference to fixed-temperature testing in exploring part compatibility with the sterilization environment. This kind of accelerated testing is often very helpful in making engineering decisions.

R67-13228 ASQC 844; 814

IC RELIABILITY–WHAT DOES IT COST?

H. T. Go (Fairchild Hiller Corp., Electronic and Information Systems Div., Germantown, Md.).

EDN, vol. 12, Mar. 1967, p. 40–45. 4 refs.

A discussion is presented of the major causes of integrated circuit failure, and of the guidelines for economical system design. Processing flaws are given brief consideration, with emphasis placed on the economics involved in choosing circuits constructed with off-the-shelf items, modified standard circuits, and custom-made circuits. A review is presented of the objectives for economic design, and several formulas to determine the relative cost of different circuit configurations based on area requirements are suggested. C.T.C.

Review: This is another good short paper on the reliability problems associated with integrated circuits. It contains some numbers and specific failure modes; the pictures are certainly informative. There are some quick and dirty formulas for calculating single circuit chip versus multi circuit integrated approaches and for the economic advantages of sampling. All in all the article is a good one: it will not take long to read and can provide a designer who is inexperienced in integrated circuits with a much better idea of what he can expect. As the author points out at the end "These formulas should be considered as 'rules of thumb'. They are empirical estimations and not based on strict laws of science." This of course is virtually all that is possible at this stage of the integrated circuit development. The paper is remarkably candid considering that the author is associated with a manufacturer of these circuits; traditionally, manufacturers dissemble excessivly.

R67-13234 ASQC 840; 775

CURRENT INFRARED PAPERS.

Papers presented at SNT 25th, National Convention, Detroit, Mich., Oct. 18–22, 1965, 1966 Spring Convention of SNT, Los Angeles, Calif., Mar. 7–10, 1966, and SNT 26th, National Conference, Chicago, Ill., Oct. 31–Nov. 3, 1966. Wayland, Mass., Raytheon Co., and Stamford, Conn., Barnes Engineering Co., Oct. 1966, 338 p. refs.

Available from the Society for Nondestructive Testing, Inc., Evanston, Ill.

Infrared techniques used in testing and inspection are reviewed in 20 conference papers. Thermal surface impedance and other infrared techniques for nondestructive testing of electronics equipment and aircraft are examined. Use of a fast response infrared scanner, measurements in real time, thermal imaging for material integrity, thermomicrography, and a state of the art review on infrared nondestructive testing are considered. Papers dealing with specific infrared applications include detection of microcircuit metalization failure mechanisms, thermography for diagnostic evaluation of electronic modules, component derating of printed circuit modules, and guidance electronics. A study of reliability screening of operational transistors using infrared is reported, and mention is made of vendor selection through infrared evaluation techniques. Flaw detection, realistic stress analysis, weld quality, measurements on semiconductor microcircuits and of plastic flow in metals, use of cholesteric liquid crystals, and a fast scanning infrared microscope are also discussed. M.W.R.

Review: This is the latest collection of more than 20 papers on the subject of infrared techniques for evaluation and testing. The volume, distributed by the Society for Nondestructive Testing, Inc., includes most of the papers presented at recent (1966 and late 1965) SNT conventions and conferences. The infrared approach is rapidly developing as a useful tool in evaluating the reliability and life expectancy of electronics and hardware. This volume reports much of the latest progress in the field. The topics covered range from general information on infrared technology through general and specific applications and special studies. One paper describes a new piece of equipment: a fast-scanning infrared microscope. Topics likely to be of interest to reliability specialists include detection of failure mechanisms, diagnostic evaluation of micromodules, component derating and reliability screening applications. Thus the papers will be of value to those who are doing research in the applications of Infrared to Reliability and also to design engineers interested in ways of ferreting out the weak points in produced material. Infrared techniques will undoubtedly become more popular. The electronic equipment for turning the infrared messages into intelligible signals will become more widely available. Thus engineers concerned with reliability testing should become familiar with the capabilities of Infrared, particularly those of supplying information difficult or impossible to obtain by conventional techniques.

85 DEMONSTRATION/MEASUREMENT

R67-13193 ASQC 853; 844
FAILURE REPORTING ON SATELLITE PROGRAMS.
George S. Gordon (Radio Corp. of America, Astro Electronics Div., Princeton, N. J.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 128–136.
Available from IEEE, New York: $8.00.

Failure reporting, analyses, and correction methods are reviewed by citing experiences with: (1) high voltage degradation in multipin connectors, (2) open failure mode in tantalum capacitors, (3) decrease in resistance of film resistors, (4) shunt paths due to board conformal coating, and (5) integrated circuit chip analyses. A well organized and skilled reliability department permits a high level of attention to be given to all malfunctions so that both patterns and singular failures can be recognized and corrected immediately. The described industrial system is aimed at inhibiting failure recurrence and promoting the cross breeding of corrections to benefit all satellite-related programs. M.W.R.

Review: After reading many of the papers which describe reliability programs, it is difficult to envision how any failures might ever occur. A description of a failure-reporting system obviously does not have this disadvantage, since it is predicted on the existence of failures. While it is not obvious from the title, this paper deals with failures occurring in-plant rather than out in the field. It has been commented elsewhere that if each failure were reported and analyzed in the depth implied by some papers, there would not be enough time, money, or people in the world to accomplish the task. In the introduction to this paper it is asserted that there is "...prompt reporting of each failure, thorough analysis to define the failure cause... and corrective action..." In the conclusion, however, it is pointed out that "the depth of analysis may vary from a sophisticated and detail level...to being somewhat trivial." What it amounts to, of course, is that engineers do exercise judgment in the matter. The case histories are interesting, informative, and examples of some of the intensive efforts rather than the trivial analyses. The problem mentioned in the first sentence of the review is now transferred back to the suppliers. If their product is as good as their advertisements and reliability-program papers usually assert it to be, how does it happen that they have these kinds of failures?

R67-13209 ASQC 851; 838
International Business Machines Corp., Owego, N. Y. Federal Systems Div.
RELIABILITY DEMONSTRATION OF A SPACE DIGITAL COMPUTER
J. E. Anderson and L. E. Peters Jul. 1965 14 p
(IBM-65-825-1499)

Techniques are described that give reasonable assurance to the user that a Space Digital Computer (SDC) and an Input–Output Unit (IOU) can achieve mission success probability. The equipment, designed to meet a 98% reliability for 250 hours, was in prototype configuration. Based on clearly defined failure criteria, failure data were collected while the prototype equipments were performing their assigned tasks in the user's laboratories. The number of component part failures was used to obtain reasonable assurance that the system reliability requirements could be met by the triple modular redundancy design used. A reliability growth curve based on experience with other programs was used to correlate between the demonstration on a prototype model and requirements for a production model.

Review: A clear and concise description of a reliability demonstration plan for a space digital computer is presented. Features of the plan are that it was implemented on prototype equipment, required no additional equipment for test purposes, and was based on component part failures (rather than failures of the redundant system). The component part failures were allowable only when the equipment continued to meet its design and performance specifications; that is, the design redundancy proved satisfactory. A reliability growth curve based on experience in other programs was used. These ideas should be applicable to reliability demonstration for similar systems.

R67-13219 ASQC 851; 844
Motorola, Inc., Phoenix, Ariz. Semiconductor Products Div.
ELECTRONIC PARTS-ACCELERATED LIFE TESTS Final Report, 31 Jan. 1963–30 Jan. 1964
P. H. Greer Griffiss AFB, N. Y., RADC, Oct. 1964 170 p
(Contract AF 30(602)-2970)
(RADC-TDR-64-142; AD-609808; N65-15778)

The purpose of this effort was to investigate and develop test measurement techniques to controllably accelerate aging of silicon epitaxial planar transistors and to empirically determine a linear equation relating stress factors, environmental tests, and operating life tests, thereby making it possible to predict the reliability of these transistors. A total of 4265 PNP type 2N1132 transistors were used. Summaries of the results of step–stress tests, operating life tests, environmental tests, and matrix test are presented. Analysis of these test results with estimated acceleration factors, failure rates, and parameter distribution and stability plots is also presented. Important conclusions resulting from the tests completed, along with recommendations of areas in which additional studies might be pursued to obtain a better method of transistor reliability prediction and measure are given. Author

Review: The purpose of the effort was essentially to find accelerated tests for silicon epitaxial planar transistors and to find a linear equation relating stress factors, environmental tests, and operating life tests; the latter equation would then presumably be used to predict the reliability of the transistors. While much useful information was gained, it is doubtful that the purposes of the project were achieved. Why the equation was required to be linear by the sponsor is hard to say. There would seem to be little a priori reason for it. Section 2 dealing with accelerated testing theory is very mixed up. In it the acceleration factor is defined in at least two mutually contradictory ways (see pp. 4, 6, and 8), neither of which is the one most commonly found in the literature, viz., the ratio of the time required to achieve the same state in the elements for two different "stress" conditions. That whole section would have been better left out of the report. In Sections 3 and 4 there is some difficulty with the assumption of a Gaussian distribution for the probability density function of reciprocal-temperature (τ) for failure: (1) When the parameters of the distribution are estimated from the data by calculating straight lines on Normal probability paper the data are apparently presumed to be uncorrelated. They are, however, quite correlated and an analysis such as the Probit method must be used to calculate the line. (2) In four out of the six curves the actual trend appears to be not a straight line but a curve which is concave downward. (3) There is an upper limit to the temperature for which the Gaussian distribution is presumed to hold; therefore there is a lower limit on the reciprocal-temperature for which this distribution holds. The normalizing factor used in the distribution, however, apparently presumes that the distribution holds from minus infinity to plus infinity; this is obviously incorrect. (4) The probability density of failures at temperature (T) and time (t) as given by the author uses at best poor notation. It is rather the probability density of failure-temperature given test time, i.e., $f[(1/T) \mid t] = f(\tau \mid t)$ is definitely not the probability density function of failure time. (In Eq. 1–4, Sec. 4.4 there are several misprints.) (5) It is most helpful when calculations of the straight lines are made to also estimate the uncertainties involved or an average deviation of points from the line. Some of the figures show a very poor fit of the lines to the data, for examples Figs. 17–19. In Section 4.5 under acceleration factors it is interesting that the text suggests that the calculation of acceleration factor is not necessary since the probability density function for τ given T is known. If the usual definition of acceleration factor is used, there is a very simple expression for it, viz., $\exp[(\tau_2 - \tau_1)/\eta]$ where the subscripts 2 and 1 refer to the two different temperatures and η is an empirically determined constant. Contrary to the acceleration factors derived elsewhere in the text, this one is independent of test time. The formula for estimating failure rate from step–stress testing is not at all clear. The actual data which were gathered and the graphical representations of them are probably quite good and a contribution to knowledge in the field; however, the detailed analysis leaves much to be desired as exemplified by the comments above.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 6

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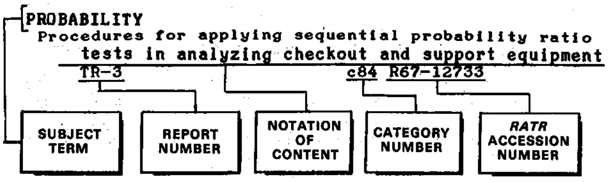

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 6

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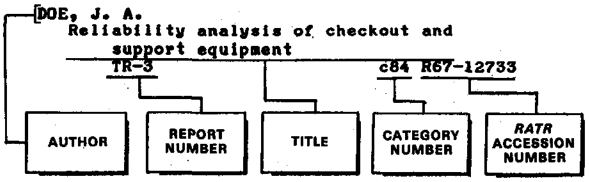

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 6

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NASA-Langley, 1967

Reliability Abstracts and Technical Reviews

JULY 1967

Volume 7
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R67-13235—R67-13285

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VOLUME 7 NUMBER 7

Reliability Abstracts and Technical Reviews

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July 1967

81 MANAGEMENT OF RELIABILITY FUNCTION

R67-13257 ASQC 813; 815
PROGRESS REPORT—DoD ESTABLISHED RELIABILITY SPECIFICATION PROGRAM ON ELECTRONIC PARTS.
Stanley Grubman (Army Electronics Command, Fort Monmouth, N. J.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 376–387.
Available from IEEE, New York: $8.00.

History and background are traced for the DoD reliability specifications program on passive electronic parts, including the revisions and changes that have resulted from actual experience. Problems and solutions are presented that result from the introduction of single service specifications; and the military established reliability specifications and associated specification sheets are tabulated for resistors, capacitors, filters, connectors, relays, coils, transformers, and crystal units. A summary of 100% screening tests in established reliability specifications gives the type, temperature, duration, and stress condition for the test for each specification, as well as the requirement and lot reject rate.
M.W.R.

Review: The high-reliability DoD specifications program which is nicely described in this paper is of high potential benefit to government and industry. It seems a pity that such a long time has been required to evolve this DoD standard program. Of particular reference value are a number of tables identifying the current specifications, superseded specifications, and the testing features of the reliability specifications. Those procuring to these established reliability specifications must guard against the practice sometimes found in the conventional MIL specifications of a supplier taking the attitude that all the tests and documentation in the specification are only performed when specifically negotiated, and that otherwise the supplier is only saying that his product is designed and produced to meet the specification. This point looms particularly large with high-reliability specifications in that the additional features contribute so much to achieving the desired reliability.

R67-13258 ASQC 815; 851
PROCUREMENT SPECIFICATION TECHNIQUES FOR HIGH-RELIABILITY TRANSISTORS.
C. H. Zierdt, Jr. (Bell Telephone Laboratories, Allentown, Pa.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronic Engineers, Inc., 1967, p. 388–407. 6 refs.
Available from IEEE, New York: $8.00.

Procurement specifications govern the purchase of a wide range of transistors and applications; and most current ones are deficient in several reliability-essential areas. Novel features of the specifications described herein, such as very high stress, short-time 100%-screening and sampling tests, contribute to their demonstrated effectiveness in controlling very high degrees of transistor reliability at minimum cost in time and money. The methods used to select capable device sources, the evaluation testing and data analyses which are performed to provide background data, and the form and procedure used for construction of these procurement specifications are illustrated. Some examples of the degree of reliability control achieved are given. It is concluded that the methodology set forth is capable of assuring very low failure rates (>0.001%/1000 hours) for small procurement lots and for the product of new, unrefined production lines, as well as for high rate, stable lines, with an unprecedented degree of confidence.
Author

Review: A detailed discussion of the subject as specifically cited in the title is presented in this paper; it reflects a meaningful amount of thought and experience. The techniques and benefits of accelerated testing are emphasized. The author has in mind a sizable effort entailing such tasks additional to actually writing the specification as testing to help write the specification, source site evaluation, and the specification requiring 100% screening under stressed conditions. Undoubtedly these or similar tasks are essential to achieving high-reliability parts, and when someone is considering them he must keep in mind that implementation will involve specialized talent and a noticeable cost. This paper would be of interest mainly to semiconductor reliability engineers, with the generalities of some interest to parts engineers. Note that Figures 11 and 12 (conclusions) are not missing as might at first be suspected, but are to be found at the end of the paper inserted between Figures 7 and 8.

R67-13260 ASQC 815; 844

ESTABLISHED RELIABILITY FOR ELECTRICAL CONNECTORS.

James E. Atkinson (Amphenol Corp., Amphenol Connector Div., Chicago, Ill.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 420–427.
Available from IEEE, New York: $8.00.

Following a historical review of established reliability in the electrical connector industry, methods are presented for systematic and responsible inclusion of reliability requirements in connector specifications. Both manufacturers and users are asked to be more concerned with reliability, and cost of such programs is discussed. The reliability program espoused costs $0.22 for each $20.00 connector manufactured. M.W.R.

Review: This paper discusses the philosophy of reliability developed by the connector industry. There has been considerable and vociferous disagreement among the large manufacturers of connectors. From time to time this disagreement has been aired in the trade magazines, usually in a discrete way. It is difficult to know, without being on the inside, how much this report represents the opinion of the industry and how much it represents the opinion of just one company. (The vast majority of the industry apparently endorses the Guidelines as a whole.) The paper is short and easy to read. There are two editorial problems which make it difficult to understand one of the approaches toward reliability. On page 421 in approach no. 1, the comma after "limits" should appear after "reduction" in order to have the sentence make sense. In the discussion following it, the author says, "The first mentioned area is a corruption..." and it is not obvious from the text in what sense the word is meant, whether it is merely a deviation or whether it is a very bad deviation. The paper is largely for management-oriented people; it will be of little direct value in design (but design engineers may well be interested in the philosophy expressed here).

R67-13261 ASQC 810

A CHASE-AROUND CHART FOR DETERMINING SENSITIVITY OF EQUIPMENT VALUES TO PARAMETER CHANGES.

Fred A. Brooks, Jr. (Thomson–Brooks, Inc., Washington, D. C.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 482–488. 8 refs.
Available from IEEE, New York: $8.00.

A technique is described for determining the sensitivity of the value of an individual piece of equipment to parameter variations. Value is a number representing the worth of the piece of an equipment in a task performed by a major system; and the technique employs a chase-around chart that systematically indicates the points where decisions must be made. The chart improves somewhat with capability for using available data to make overhaul decisions, and also indicates where the dollars available for data collection will be most productive in increasing confidence in these decisions. The parameters used, which can be feasibly changed during the overhaul of a major system, include those resulting from changes or removal in other pieces of equipment. The technique can be extended to make alternative decisions, in terms of cost savings, such as to whether to replace or modify equipment. A cost effectiveness index indicates the priority for each overhaul action for each equipment. M.W.R.

Review: Although some good points are made in this paper, the author hides them among the details of his example. The philosophy of decision-making is well expressed, especially the good emphasis on the fact that subjective opinions come into all analyses, regardless of how many objective measures are employed. The "controlled judgments" of qualified raters seems a good way to improve the accuracy of engineering decisions. There is no example which shows how to use the graphs (it probably is supposed to be obvious), nor are the sources of some of the equations explained in enough detail to enable the reader to have confidence in them. It is doubtful that anyone would pick this article up and use the graphs without knowing more about it than is available in the paper. (In a private communication the author has stated that the equations and graphs are not general, but pertain only to the specific example.) There appears to be some minor jargoneering: the words "homoscedasticity" and "multicolinearity" seem out of place in a discussion not intended strictly for statisticians. All in all, the philosophy concerning decisions and judgments is well worth reading.

R67-13262 ASQC 814; 831

OPTIMUM SYSTEM RELIABILITY AND COST EFFECTIVENESS.

Lee R. Webster (Radiation Inc., Palm Bay, Fla.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 489–500.
Available from IEEE, New York: $8.00.

A general procedure that can be used with any type of reliability distribution is presented for configuring a system with optimum reliability, system effectiveness, and/or cost effectiveness. The relationships between system effectiveness, cost effectiveness, availability, reliability, and capability are discussed; and a nonmathematical review of the procedure is included to show its relationship to the cost effectiveness maximization problem and to justify the claim that the optimum system configuration is obtained. Formalized analytical techniques are used so that extremely complex engineering problems can be treated. Examples of the optimization process are included, along with theorem proofs, and sensitivity analyses. M.W.R.

Review: A sensible discussion of the objectives of cost-effectiveness analyses is given in this paper, in which there is no attempt to oversell cost-effectiveness. The general problem and the specific examples are structured in a manner which is reasonable and in accord with approaches being used by others who are working on these problems. For instance, one of the examples poses a timely question, that of simultaneous optimization of non-redundant and redundant approaches to reliability improvement. Unfortunately, the paper is difficult to follow with respect to the "hard core" material pertaining to the specific optimization approach which is presented. The assumptions are not clearly stated nor is the description of the procedure self-contained. A key feature of the approach is to include the item with the lowest effectiveness in those items which are initially improved. (Effectiveness is used in this review to mean any probabilistic measure of effectiveness, such as reliability alone or reliability considered with other "...abilities.") It seems that this feature requires for each item which is a candidate for effectiveness improvement some assumptions about the relation between the amount of effectiveness improvement and the constraint increase which is required to obtain this improvement. This would in turn lead to certain restrictions on the forms of the effectiveness functions. These assumptions are not clearly stated, but some brief general remarks are made in this area at the very end of the paper. Some theorems and proofs are given, but they are completely concerned with effectiveness, and contain nothing about constraints. The procedural steps which are given in the body of the paper should be more explicit, as the examples which are given in the appendix contain aspects which amount to expansions and modifications of them. It is suspected that the author has an approach here which could turn out to have a place in a "tool kit" of cost-effectiveness optimization techniques. Those readers who are not already familiar with the approach will have to pursue in depth the material presented in this paper in order to understand it. Perhaps some earlier papers by the author which are referenced will be of assistance.

R67-13271 ASQC 813; 836; 844; 864

DEVELOPMENT OF A FAILURE ANALYSIS PROGRAM FOR A HIGH RELIABILITY MISSILE HYDRAULIC POWER SUPPLY.

H. P. Schmidt and C. J. Reed (Borg-Warner Corp., Pesco Products Div., Bedford, Ohio).

In: Society of Automotive Engineers, Aerospace Fluid Power Systems and Equipment Conference, Los Angeles, Calif., May 18–20, 1965, Proceedings. Conference sponsored by the Society of Automotive Engineers. New York, Society of Automotive Engineers, 1965, p 301–309.

(A65-28050)

Description of a successful failure-analysis program for high reliability missile-borne hydraulic power supplies. Functional discrepancy is defined as that condition occurring prior to and including production acceptance testing wherein a part has become inoperative or has drifted outside tolerance limits. Failure is defined as a functional discrepancy that occurs on a product that has successfully completed production acceptance testing, and dimensional discrepancy as being any variation of a part, subassembly, or assembly from in-process measurement limits or drawing requirements. The program as developed is concerned only with failures and functional discrepancies. The first requirement for initiating a failure analysis system is that the prime responsibility must be assigned by management to one man; the latter must have the authority to require that corrective action be taken when the cause of failure has been identified. IAA

Review: This paper emphasizes the failure analysis aspects of a reliability program, and the subject is worth emphasizing. A special failure-reporting form was developed as happens on most programs (with each one feeling that at least for his own needs he has come close to the ideal form). In some other situations a copy of the final disposition is sent to the originator of the report so that at a minimum he feels his actions are worthwhile and worth continuing. The classifications of failure and the procedure set up for evaluating and processing the failures appear quite adequate insofar as one can tell from the printed word. Others who are involved in the failure analysis program may well wish to see the point of view expressed here and find from it ways in which their own procedures can be improved. In cases where there is a tremendous number of failures it may not be feasible to analyze them all. Then engineering judgment is used to classify them as to their seriousness and the potential benefit to the company if an analysis is performed.

R67-13272 ASQC 813; 836; 837; 844

DESIGN MARGIN: KEY TO LUNARCRAFT SHOCK ABSORBER RELIABILITY.

Daniel A. Hodgkins (Pneumo Dynamics Corp., National Water Lift Co., Kalamazoo, Mich.) and Jack D. Eggerman (Hughes Aircraft Co., Culver City, Calif.).

In: Society of Automotive Engineers, Aerospace Fluid Power Systems and Equipment Conference, Los Angeles, Calif., May 18–20, 1965, Proceedings. Conference sponsored by the Society of Automotive Engineers. New York, Society of Automotive Engineers, 1965, p. 310–318.

(A65-28051)

Discussion of the design margin of performance capability over mission requirement and a detailed description of the shock absorber for a lunar landing vehicle in relation to functional and environmental requirements. Progressive stages of the reliability program for this complex mechanism are reviewed. Development of design margin is traced from configuration definition through qualitative and quantitative appraisal, by means of failure mode analysis and reliability prediction. Design margin is then further validated by rigorous assurance testing and finally carefully protected during fabrication and assembly. Author (IAA)

Review: After a brief description of the shock absorber, the reliability program is given—including design reviews, safety margins, failure mode analysis, and development testing. Two examples are given of the development testing. The design margin uses the safety margin concept involving two Normal distributions. The authors proceed then to convert the safety margin to a reliability which turns out to be virtually one, since the safety margins are all well above 3σ. When converting safety margins over 3σ to probabilities, the conversion can be misleading since the actual reliability will depend heavily on the deviations from Normality. The use of the term "inherent reliability" is poor, since it implies something that is not there; a term such as reference reliability is better and more descriptive. All in all this is an adequate paper for giving a general description of a particular program, but it will not be useful as a permanent reference.

R67-13273 ASQC 814

RELIABILITY IMPROVEMENT POTENTIAL.

Douglas A. Lyle (Western Electric Co., Inc., Winston-Salem, N. C.).

The Engineer, vol. 11, Jan. 1967, p. 36–41.

To reduce the total cost of purchasing and maintaining large electronic systems, a method was devised for determining the potential for reliability improvement inherent in the subassemblies of such systems. This potential, which in each case is calculated by comparing the reliability predicted for the subassembly with the reliability experienced, constitutes an index in terms of which the subassemblies can be rank ordered and a basis upon which excess, or potentially unnecessary, future maintenance cost and down time can be predicted. For those subassemblies high on the rank ordering, development cost studies are justified. On the basis of both the improvement potential and the estimated cost of engineering development, developmental effort can then be channeled into those areas offering an expectation of the greatest net savings. Author

Review: Up to a point, reliability improvement does not cost—it pays. This paper is concerned with the determination of the point for which this statement is true. Naturally that point varies with the type of equipment, the model postulated for its calculation, the inaccuracies in the input data on failure rates, and the adequacy of the experience of those who supply the engineering judgment. The paper is a straightforward discussion of a reasonable approach to the problem, and the ideas presented should be useful to those concerned with reliability in relation to total operating cost of a system. Refinement/modification of the approach to suit the requirements of the particular situation at hand will always be required. At one extreme, for example, are those cases in which cost is negligible. Such would be the case for a minor component the failure of which could cost the life of a highly-skilled astronaut.

R67-13275 ASQC 810; 330

RESPONSIBILITY OF QUALITY CONTROL FOR ACHIEVING PRODUCT RELIABILITY.

Richard M. Miller (American Motors Corp., Detroit, Mich.).
Society of Automotive Engineers, Mid-Year Meeting, Chicago, Ill., May 17–21, 1965, Paper 650467. 14 p.
(SAE Paper-650467)

Product quality and reliability are described in terms of assuring customer satisfaction, and eight steps for attaining product reliability are outlined. These include the establishment of design levels, preparation of comprehensive engineering drawings, development of manufacturing processes to eliminate human error, control of the manufacturing process, and establishment of follow-up procedures in the field. Coordinated efforts are stressed as essential to reliable product development; and attention is given to failure analyses, inspection procedures, supplier surveillance, and maintenance of specifications. M.W.R.

Review: This is a reasonably comprehensive outline of the tasks that must be carried through in order to achieve a reliable product. While the paper refers explicitly to an automotive manufacturer, the provisions apply as well to the aerospace industry. In this paper the responsibility for achieving product reliability is assigned to the quality control department. (The days of pointless arguing about the differences in responsibility between quality control and reliability are probably happily gone.) While the paper will have little value as a permanent reference, it can be valuable for an introduction in some depth to the problems of reliability.

R67-13277 ASQC 810; 814; 844

RATIONAL RADIO RELIABILITY RENDITION.

R. E. Metzler (General Electric Co., Lynchburg, Va.).
IEEE Transactions on Vehicular Communications, vol. VC-14, Mar. 1965, p. 149–152.

Reliability engineering has generally concerned itself with system failures caused by catastrophic failures of components. Given a stable system and known environment, existing techniques may give accurate predictions of the reliability of electronic systems. When mobile communication systems are analyzed, however, the available propagation conditions presented to equipment operated under extremely variable environmental conditions may cause reliability predictions to be quite inaccurate. The factors affecting actual reliability are discussed, and means are examined for designing mobile communication equipment to achieve optimum results in each of these areas. A specific equipment design built around these techniques is discussed, and life testing under simulated environmental conditions is examined. Author

Review: This paper emphasizes the value of net annual cost in determining whether an improvement in reliability is worthwhile. A rather simple cost formula is used (time value of money is generally neglected) and an example is shown. The reliability improvements used as examples are gained by substituting parts with low failure rates and reducing the operating stresses on the components. Many other papers have also appeared which used the figure of merit of net annual cost. Other than these points, the paper will have little value for design engineers.

R67-13281 ASQC 811

IMPLEMENTING AN EFFECTIVE PRODUCT ASSURANCE PROGRAM FOR HIGH-RELIABILITY EQUIPMENT.

Stanley A. Rosenthal (Kollsman Instrument Corp., Syoset, N. Y.).
IEEE Transactions on Engineering Management, vol. EM-13, Sep. 1963, p. 143–154.

Effective control of the reliability and quality of complex, space-age systems necessitates an organized, formal product assurance program covering all aspects in the conception, design, development, and production of this equipment. Using the aerospace industry as an example, the following basic requirements are discussed for a complete product assurance program: (1) product assurance organization and program planning, (2) reliability design control, (3) parts reliability specification and procurement, (4) production surveillance and control, and (5) reliability evaluation. Specific examples of the type and extent of product assurance program activity required to implement each of these phases are given, with particular emphasis on the need for an organizational structure providing for continuous close coordination among the engineering, manufacturing, and product assurance operations. Such a complete reliability and quality control program, managed and directed by a responsible organization can assure the high reliability necessary in modern aerospace equipment. Author

Review: This paper is essentially the same as the one covered by R65-12061.

82 MATHEMATICAL THEORY OF RELIABILITY

R67-13247 ASQC 824; 831

RELIABILITY APPROXIMATIONS FOR COMPLEX STRUCTURES.

Martin Messinger and Martin L. Shooman (Polytechnic Institute of Brooklyn, Dept. of Electrical Engineering, Brooklyn, N. Y.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 292–301. 4 refs.
(Contract AF(648)-1402)
Available from IEEE, New York: $8.00.

Reliability graphs are used in a general topological approach for analyzing reliability of a complex structure, and several bounds and approximations are developed that reduce computational time. The reliability graph for the system is directed from its constituent tie sets, its directed paths from input to output, and its cut sets of interrupting branches; and the reliability of the system is the probability that at least one tie set is good, or that all cut sets are good. A cut set is considered good if at least one of its components is operative. Two upper and two lower reliability bounds are then found, and the assumptions required to apply these bounds are discussed. Several examples are included. M.W.R.

Review: This is a basic mathematical paper which describes and compares several bounds and approximations for the reliability of complex structures. It is well written and should be of value to design and/or reliability engineers concerned with the problem of estimating system reliability. Several examples are given which aid in the understanding of the approximation techniques. The approximations are obtained on the assumption that each component may assume one of two states, one failed and the other non-failed. Some of the bounds apply only to systems containing components which are statistically independent; however, others apply even if the components are dependent. As indicated by the authors, further work needs to be done in evaluating the bounds in the case of dependent components. There have been several papers on this subject in the last three to four years. The results in this paper are an extension of those found in the literature in that new and useful approximations are obtained for the system reliability based on component reliabilities. Although the paper does not treat automatic computerized solutions, the methods presented in this paper would lend themselves to convenient computational procedures. One such procedure is described in a recent paper (see R66-12515).

R67-13251 ASQC 824; 844

SILVER ZINC SECONDARY BATTERY RELIABILITY.

James J. Crawford (Yardney Electric Corp., New York, N. Y.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 323–328.
Available from IEEE, New York: $8.00.

Models, presented for the silver–zinc secondary cell and battery, permit the evaluation of reliability of these power sources for a given application. A study of the reliability physics of the silver–zinc battery resulted in a cell model in the form of a series of six basic components, namely the separator system, positive electrode, negative electrode, model cell case with cover and cell hardware, electrolyte KOH, and the electrical connections. The mathematical model for the battery is given by a series consisting of the total number of cells, case and hardware seals, relief valve, heater, electrical connectors, and the electrical connections. Mathematical model considerations are detailed for both the cell and battery, and parametric cell data requirements are given. The reliability models are illustrated, and a histogram depicts large silver–zinc secondary battery failure versus operating life. M.W.R.

Review: This is a paper wherein the engineering content is important and the statistical concepts fairly simple, yet most of the space is devoted to statistics. The assumption of statistical independence is unfortunately implicit and the words "chance failure rate" are used to denote constant hazard rate. A Gaussian distribution is assumed for all components or parts of components. The battery reliability is then asserted to be the product of the reliabilities of each of the components. The problem of repair is not discussed explicitly and probably should have been, especially since one of the batteries cost five million dollars—obviously this battery was not replaced after each failure. The failure modes and mechanisms analysis, and feedback to design, is a tremendous engineering aid to reliability, regardless of the exact statistics used.

R67-13252 ASQC 824; 713; 844

STRUCTURAL RELIABILITY WITH NORMALLY DISTRIBUTED STATIC AND DYNAMIC LOADS AND STRENGTH.

C. W. Cable and E. P. Virene (Boeing Co., Seattle, Wash.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 329–336. 5 refs.
Available from IEEE, New York: $8.00.

A statistically valid method is presented for calculating the reliability and associated confidence of a statistically loaded structural component, when adequate material strength and static loads data are available and when both the stress and strength distributions of the component are described by the normal statistical distribution. The method is developed, the necessary parameters are defined, and illustrative examples are provided. The mathematical tables required for the discussed problems are included. Author

Review: This is strictly a tutorial paper and most of the material can be found in [1], which is Reference 2 in the paper. It is strongly recommended that the reference be consulted in addition to the paper. The second part of the paper, dealing with a lower confidence bound on the reliability fails to mention that one of the distributions is presumed known exactly and the other one has its parameters estimated from a sample; the formula in the text is correct only for this case. Unfortunately this paper was not placed in the tutorial section of the Proceedings and might lead one to believe that the mathematics is appearing for the first time. The reference for the second part is [1], p. 237. If the above points are kept in mind, this paper can usefully supplement the textbooks.

Reference: [1] Lloyd, D. K. and Lipow, M., *Reliability: Management Methods, and Mathematics,* Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1962.

R67-13276 ASQC 824

INFLUENCE OF NEGATIVE FEEDBACK ON AMPLIFIER RELIABILITY.

Yu. S. Rasshcheplyayev
Telecommunications and Radio Engineering, Part I: Telecommunications, vol. 19, Jan. 1965, p. 33–37. 3 refs.
(A65-19483)

Description of a method for the analysis of the effect of negative feedback on the reliability of an amplifying system, taking into account the spread of amplification factors of the individual stages. It is shown that negative feedback greatly increases amplifier reliability, regardless of the number of stages. IAA

Review: This is a translation from a Russian journal. The problem is a rather simple one. Failures are presumed to be either catastrophic or drift. The catastrophic failures of the amplifier stages are assumed to be statistically independent as are the drift failures of the various stages. The expression for gain with or without feedback is expanded in a Taylor series so that the mean and variance of the gain can be calculated easily. An example shows that adding negative feedback greatly improves the drift reliability without appreciably increasing catastrophic failure probability. One can probably derive the formula more quickly than one could find the article.

R67-13278 ASQC 824; 431

TIME TO FAILURE IN ELECTRONIC TELEPHONE SWITCHING SYSTEMS.

J. D. Beierle and V. B. Gylys (Automatic Electric Laboratories, Inc., Northlake, Ill.).
IEEE International Convention Record, Part I, 1965, p. 96–102. 3 refs.

The designer of electronic telephone switching systems is severely challenged by the reliability standards for electromechanical systems. The design problem centers about the electronic common control which must be duplicated to provide service continuity over forty or more years. One control is available while the other is being repaired. To facilitate the evaluation of competing common control designs, expressions were derived for mean time and standard deviation of time to failure in an ensemble of n common controls, from each of n states in which J $(1 \leq j \leq n)$ controls are working, assuming identical constant failure and repair rates. An absorbing Markov chain model of the transition process is used. As expected, the standard deviation is of the same order of magnitude as the mean time to failure. Numerical results for some typical systems are presented. Author

Review: This is a rather common analysis of a system wherein all of a set of identical subsystems must be down at once for the system to fail and wherein the subsystems are repairable, usually at a rate much faster than they are failing. Not all of the mathematics was checked, but one of the conclusions in the analysis makes one suspect difficulties somewhere, i.e., the standard deviation of times to failure is always very close to the mean failure time. This means that very short failure times are likely, regardless of the amount of replication. No mention is made of this peculiar situation, so the results should be checked before using them. It is presumed implicitly that the failure rates of the subsystems are the same whether they are usefully operating or not. In a private communication the author has indicated numerous typographical corrections for equations 1a through 1e.

R67-13282 ASQC 824; 411; 822; 838

POINT ESTIMATION OF RELIABILITY OF A SYSTEM COMPRISED OF K ELEMENTS FROM THE SAME EXPONENTIAL DISTRIBUTION.

Hurbert C. Rutemiller (California State College, Fullerton, Calif.).
Journal of the American Statistical Association, vol. 61, Dec. 1966, p. 1029–1032. 5 refs.

Minimum variance unbiased estimators of reliability are developed for a series, parallel, and standby redundant system where the components are from a single exponentially distributed population. It is assumed that sampling information has been censored with respect to number of failures or test time. A problem in point estimation is considered. Author

Review: This paper presents formulas for estimating the reliability of a system when the sampling information is available on components only. These minimum variance unbiased estimators will be found useful in estimating reliability of systems constructed from identical components. Although the author gives no practical example, the estimators will be found quite simple to use.

R67-13283 ASQC 824; 411; 822

THE EFFICIENCIES IN SMALL SAMPLES OF THE MAXIMUM LIKELIHOOD AND BEST UNBIASED ESTIMATORS OF RELIABILITY FUNCTIONS.

S. Zacks (Kansas State University, Manhattan, Kansas) and M. Even (Israel Institute of Technology, Haifa, Israel).
Journal of the American Statistical Association, vol. 61, Dec. 1966, p. 1033–1051. 19 refs.

The paper presents the results of an inquiry concerning the small sample relative efficiency of maximum likelihood and best unbiased estimators of reliability functions of one-unit systems. Three cases are considered: The Poisson, exponential, and normal (standard deviation known). Two kinds of relative efficiency functions are studied. The first kind consists of the common ratio of the Cramer–Rao lower bound of the variances of unbiased estimators, to the mean-square-error of the considered estimator. The second kind is a new type of a relative efficiency function, which is called 'the closeness relative efficiency function.' This function is defined as the ratio of the probabilities that the maximum likelihood and the best unbiased estimators yield estimates in a prescribed neighborhood of the unknown reliability value. A substantial part of the study is devoted to the derivation of the required moments of the estimators. Author

Review: These papers represent an excellent study of the relative efficiencies of maximum likelihood and minimum variance unbiased estimators of reliability functions. The first paper deals with one-unit systems and the second with two-unit systems. The numerical values of efficiencies and the corresponding graphs are also given for the sample sizes n=4 and n=8. The summary of results will be found useful in deciding on the use of an estimator in a particular problem at hand.

R67-13285 ASQC 824; 411; 822

MINIMUM VARIANCE UNBIASED AND MAXIMUM LIKELIHOOD ESTIMATORS OF RELIABILITY FUNCTIONS FOR SYSTEMS IN SERIES AND IN PARALLEL.

S. Zacks (Kansas State University, Manhattan, Kansas) and M. Even (Israel Institute of Technology, Haifa, Israel).
Journal of the American Statistical Association, vol. 61, Dec. 1966, p. 1052–1062. 4 refs.

The bias and mean-square-error functions of the maximum likelihood and best unbiased estimator of reliability functions are derived. Information is available on the operation of subsystems connected in series or in parallel. The Poisson and the exponential cases are considered. Author

Review: See R67-13283.

83 DESIGN

R67-13237 ASQC 831; 612
Arinc Research Corp., Washington, D. C.
DESCRIPTION OF THE COMPUTERIZED RELIABILITY ANALYSIS METHOD (CRAM) Arinc Research Monograph No. 11
David E. Van Tijn 13 Nov. 1964 104 p refs
(Contract NAS8-11087)
(NASA-CR-77414; Publ.-294-02-14-444; N66-34791) CFSTI: HC $3.00/MF $0.65

Applications, procedures, and analyses are made for the Computerized Reliability Analysis Method (CRAM), which is a method for analyzing reliability by using computer programs that are strictly utility routines. In concept, CRAM can be used for all systems in which a failure of one part can be defined without reference to any other part. On the basis of a system description, operating modes are identified and the system is partitioned into subsystems. Reliability diagrams are prepared for these individual subsystems, and data on subsystem elements and failure probabilities of the element classes are tabulated. The first computer program converts the coded reliability diagrams into a formula representing the condition for system success; a second program converts this formula into a reliability model; and a third program computes a reliability value for the subsystem from the model and data tables. The subsystem values are then converted into a single value representing the system. Preparation of computer inputs is detailed, computation of reliability expressions and functions is discussed, and a list of applicable definitions is included. M.W.R.

Review: This is the full description of the Computerized Reliability Analysis Method (CRAM) which has been summarized in other articles such as the one by Rivera and Ryland (see R67-13159). While the report itself is fairly old, it was just recently released in the NASA STAR system. The comments applying to the Rivera and Ryland paper apply as well as to this report except for one or two which are restricted obviously to that paper. Even with the full description one will not be able to use the program without additional instruction. Programs such as CRAM which analyze the logic diagram of a system can be of tremendous value to design engineers. As the author points out, there is quite a bit of clerical work involved and for simpler systems it will be easier to do the calculations by hand. The warnings in the review R67-13159 of course apply as well to this one.

R67-13240 ASQC 830; 815; 870
THE ATTAINMENT OF HIGH RELIABILITY OF MARINE RADAR.
G. J. Mc Donald (Maroni International Marine Co., Ltd., Chelmsford, England).
(Radar and Navigational Aids Group Symposium, London, England, Dec. 15, 1965). The Radio and Electronic Engineer, vol. 33, Jan. 1967, p. 31–34.

General requirements that should be met by designers of marine radar equipments are reviewed, and it is suggested that in planning a new design the minimum standard of reliability should be set at 500 hours mean time between failures. Some basic design precautions are described covering various aspects from initial design and selection of components to installation, environmental, and operational conditions. Short notes on maintenance and training aspects are included, as is an example of the extremely high reliability achieveable by using a twin inter-switchable radar system. The probability of trouble-free operation for this radar over a specified period can be raised from 95.3% to 99.8%. Author

Review: This paper contains rather broad generalizations which would be applicable to the design of almost any electronic equipment. The major source of documentation appears to be the (British) Radio Advisory Service (RAS) study (see the paper by Wylie in the same issue of the *Radio and Electronic Engineer,* pp. 17–23), which is still in the process of being analyzed by RAS. Other factors that might be used as design guidelines are mentioned without source reference. Finally, the suggested requirement of 500 hours mean-time-between-failures seems to be rather arbitrary; percentages cited appear to be computed assuming a uniform failure distribution over time. These shortcomings greatly reduce the usefulness of the paper.

R67-13241 ASQC 838
PARTIAL VERSUS TOTAL REDUNDANCY.
Narsingh Deo (California Institute of Technology, Jet Propulsion Laboratory, Pasadena, Calif.).
Electronics Letters, vol. 3, Jan. 1967, p. 2, 3.
(A67-19604)

Observation that, contrary to common belief, better reliability can be achieved by triplicating only part of a computing machine rather than by triplicating the whole machine. The reliability figures for varying degrees of partial redundancy are obtained. From such figures conditions are derived which are best suited to the totally redundant, partially redundant, or nonredundant system. IAA

Review: The qualitative results of this article are in line with other conclusions about redundancy. Pointing out that it pays to make part of a machine non-redundant is certainly interesting and worthwhile. The equations are only approximate and, as a matter of fact, are incorrect to the order stated because of the neglect of some terms. The author's equation 4 for the difference between two probabilities and his equation 5 for the critical probability are thus incorrect. When the probabilities of failure are very small these corrections are unimportant; however, the graph and table go up to probabilities of over 1/2 and then the approximations made are no good. Therefore, it would probably be wise, unless dealing with very small probabilities (in which case the point of the article is lost), to work out the exact equations. Statistical independence of the failure events is necessary for the analysis, but is only implicitly assumed. The probability p is defined as a probability of failure of the machine; the reader is supposed to understand that it is the nonredundant machine, contrary to the reference to the figure.

R67-13242 ASQC 831; 614
ASSURING QUALITY AND RELIABILITY AND MATHEMATICAL PROGRAMMING.
N. L. Enrick (Kent State University, Kent, Ohio).
Quality Assurance, vol. 6, Mar. 1967, p. 30–33. 2 refs.

A typical example of assuring system reliability by providing an adequate number of spare components is presented to demonstrate the technique of mathematical programming (or linear programming). The spare parts evaluation is limited to a case with only two components, and the probabilities of component failures during any one mission are tabulated. This programming technique can also be used to minimize quality control costs, to insure optimum process yields, and for the apportionment of reliability and failure rates. M.W.R.

Review: This paper extols the virtues of Mathematical Programming (a more accurately descriptive name in Linear Programming since linearity of the model is essential) and states "the quality-reliability engineer . . . should know enough about the nature of MP to be able to phrase his problem variables in identifiable terms." The only difficulty is that the paper discusses nothing about Linear Programming except that it is good to use. The example in the text appears to be worked by trial and error, but Linear Programming cannot be handled in that way except in trivial examples. Nowhere in the example are specific applications of general principles pointed out. It is easy to infer that the solution must be a point on the boundary—which certainly is not generally true. Mathematical Programming might include Nonlinear and Dynamic Programming, but there is no reference to them in the paper; in fact, it is implied that Linear Programming and Mathematical Programming are the same. There have been papers in the reliability literature which do give an introduction to Linear Programming. The first reference cited by the author is one of these (see R66-12618), and serves as a better introduction to the topic than does the present paper. For other examples see R64-11255 and R64-11284.

R67-13243 ASQC 833; 782

RESISTOR RELIABILITY, CHOICE OF TYPE AND INFLUENCE OF ENVIRONMENT.

B. H. Nichols (Welwyn Electric, Ltd., Bedlington, England).
(Component Reliability Conference, Bristol College, England, Mar. 8–9, 1966.)
Microelectronics and Reliability, vol. 6, Feb. 1967, p. 1–8. 10 refs.

The design of reliable electronic equipment is dependent upon knowledge of the components as well as the actual electronic design, and designing for a known safety factor will enhance resistor reliability. Failure rates are tabulated for wirewound resistors used in airborne military applications and in computers; for the former these range from 0.00034 to 0.70% for 100 hr, for the latter between 0.022 and 0.94. Manufacturing quality is considered, and the selection of resistors for environmental conditions is discussed. Attention is given to circuit design and safety margins as related to reliability. M.W.R.

Review: Some general guidance on the choice of resistor types for use in such environments as high ambient temperature, high humidity, and extreme mechanical stress constitutes the main content of this paper. There is also some discussion of quality of manufacture, economics of reliable components, circuit design, and safety margins. This paper will be of value mainly to those who need (and do not already have) a simple appreciation of the nature of resistors and their appropriate application relative to environments.

R67-13245 ASQC 833; 815; 844

CAPACITORS—RELIABILITY, LIFE AND THE RELEVANCE ON CIRCUIT DESIGN.

D. S. Girling (Standard Telephones and Cables Ltd., Paignton, England).
(Component Reliability Conference, Bristol College, England, Mar. 8–9, 1966.)
Microelectronics and Reliability, vol. 6, Feb. 1967, p. 36–50. 6 refs.

About one-seventh of all equipment failures are due to capacitors, and half of these are due to improper selection or application. In choosing a capacitor for a given operation, it is important to recognize that the limits given in specifications are statistical quantities and to select correct operating conditions of voltage and temperature. With proper care in selection, rating, and application a reliability of about 0.01% per 1000 hr is achievable; in extreme conditions this may rise to 1%/1000 hr or more. The conditions for open or short-circuit failure are given for various types of capacitors. The main need of the circuit designer is for regular and systematic testing and the feedback of fault data to improve the control of the manufacturing processes. Reliable components can only be produced by fully optimized manufacturing techniques. Economic considerations show that it is unreasonable to expect a component to be significantly better than its specification. The reliability of a component is thought to be optimum for a given application when first cost plus replacement cost plus the cost of the loss of equipment time is minimum. Author

Review: This paper was covered by R67-13005. Reference to the previous publication is cited by the author.

R67-13248 ASQC 831; 612; 838

AUTOMATED SYSTEM RELIABILITY PREDICTION.

R. B. Coffelt (International Business Machines Corp., Owego, N. Y.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 302–304.
Available from IEEE, New York: $8.00.

A program is described that provides a practical means of assessing the reliability of large, complex triple modular redundant systems such as in the Saturn V Guidance Computer. It uses a Monte Carlo technique for failure generation and a method of logic simulation for tracing the effects of the failure. If a large number of failure sets are employed, a good estimation of system reliability may be obtained. Author

Review: Solution of a reliability prediction equation for a rather specialized type of design approach, triple redundancy with majority voters, is the topic of this paper. It is short and without references, but well illustrated. The mechanics of how to proceed with a Monte Carlo approach on a digital computer in order to obtain numerical solutions is sufficiently discussed to be helpful to someone interested in this.

R67-13250 ASQC 833; 710; 770; 782

CURRENT RESULTS OF THE ELECTRONIC PART STERILIZATION PROGRAM AT THE JET PROPULSION LABORATORY.

J. Visser (Jet Propulsion Laboratory, Pasadena, Calif.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 312–322.
(Contract NAS7-100)
Available from IEEE, New York: $8.00.

Preliminary results of an electronic parts sterilization program that is geared to reflect current NASA sterilization policy are presented. Involved in the program to establish an approved list of sterilizable electronic parts are 72,846 parts in 577 categories. Wear-out data are given for several types of capacitors, and a summary is tabulated of parametric and catastrophic failures during the capacitor testing. Sterilization cycling does not affect various part types catastrophically, and usually the parametric instability is increased. Major deleterious effects were experienced with capacitors and transformers. In spite of stringent controls in obtaining test specimens, a large number of the parts exhibited poor workmanship and overall quality. The number of fixed resistor catastrophic failures is tabulated, resistor drift is graphed over a 10,000-hour life test, and a flow chart is presented for the test design program. M.W.R.

Review: The reliability of electronic parts as affected by sterilization environments is an important problem in relation to planetary vehicles. A program aimed at establishing an approved list of sterilizable electronic parts is described in this paper. The main concern in the phase covered was with heat sterilization, although brief reference is made to ethylene oxide decontamination. In addition to sterilization effects, this program has produced useful information on the true abilities of parts in relation to their specified ratings, wear-out phenomena, and reliability over long periods of time. The paper is a compact description of results and conclusions to date in an area in which work is continuing.

R67-13255 ASQC 833; 815; 844

SELECTING AND SPECIFYING HI-REL INTEGRATED CIRCUITS.

Dennis L. Mulcahy (General Electric Co., Apollo Support Dept., Houston, Tex.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronic Engineers, Inc., 1967, p. 359–364. 5 refs.
Available from IEEE, New York: $8.00.

Reliability can be increased and cost procedures decreased by a coordinated effort for selecting integrated circuits and developing procurement specifications. With these considerations in mind, an analytical method for evaluating integrated circuits is presented that includes the study of failure mechanisms. A technical review of the manufacturer's facilities begins with consideration of part history, construction, processes, and failure mechanisms; and is climaxed by the process line survey which permits evaluation of inherent reliability of the IC. Development of screening requirements is detailed, and specification of lot acceptance testing is discussed. M.W.R.

Review: This paper says most of the things that need to be said on the subject and have been said in the past in other good papers. The author is, if anything, over-generous toward the attitudes and performance of manufacturers. Although it was undoubtedly not the author's intention, the messiness of the whole situation does not come through in reading the paper. Positive statements are made and one tends to get the feeling that things will go all right if the rules are followed. Unfortunately in moments of desperation, one might say merely that all of these precautions give a base to start from when things do not go all right. The pleas for standardization are most worthwhile; however, it certainly will not happen by itself. Someone is going to have to make standardization happen.

R67-13264 ASQC 831; 612

A NEW RELIABILITY DESIGN APPROACH FOR ELECTROMECHANICAL SYSTEMS.

Lucas Nenoff (Collins Radio Co., Reliability Div., Dallas, Tex.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 542–552. 8 refs.
Available from IEEE, New York: $8.00.

A new approach for the incorporation of the reliability in the selection and design of mechanical subsystems and components is demonstrated by including reliability as a fixed parameter at the early design stage. The major mechanical components are treated individually. For bearing selection the procedure is based on the Weibull failure density function. For gear subsystem, the procedure utilizes the AGMA published literature. For cables and pulleys, the selection procedure is based on fatigue and wear failure assuming a normal failure density function. Component selection curves are developed which give the component reliability as a function of the system operational life. The mathematical developments of these selection curves are shown where applicable, and the literature data for the empirical design formulas are cross referenced. A case study of mechanical components selection on an airborne antenna system is presented as an example. Author

Review: This paper is a practical demonstration of the incorporation of reliability considerations into the selection of mechanical subsystems and components. The paper would be of particular interest to the design engineer concerned with bearings, wire ropes and cables, and gears. Although the techniques will have more general application the discussion and results are rather specific to these hardware types. Some minor typographical errors appear in the paper, but they are easily spotted by the reader who follows the mathematics. They do not detract from the overall understanding and value of the paper to the interested reader. It is good to see papers treating the reliability of electromechanical systems.

R67-13265 ASQC 838; 821

MULTIPLE REDUNDANCY APPLICATIONS IN A COMPUTER.

J. E. Anderson and F. J. Macri (International Business Machines, Inc., Owego, N. Y.).

In: *1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 553–562.
Available from IEEE, New York: $8.00.

A computer design is presented whose redundancy results from various tradeoff studies that yield optimum overall design for the digital computer and the data adapter for the uprated Saturn I and Saturn V launch vehicles. These equipments are used mainly for the launch guidance, orbital checkout and data processing, and translunar injection guidance for Apollo missions. Several redundant approaches are considered, and it is concluded that no one form of redundancy is optimum for a complex guidance system when tradeoffs among weight, power, volume, and design complexity are considered. Derivation of the reliability equation for the dual redundant memory is detailed, and operations and equations are considered for a duplex redundant power supply reliability model. M.W.R.

Review: Too often, the rationale behind design decisions which affect reliability gets left unstated and eventually forgotten. This paper describes narratively the reasons for selecting various forms of redundancy in portions of a computer design in which reliability is at a premium. Even though some analyses are presented in an appendix, there is not sufficient detail given to substantiate all of the statements in the text. However, the discussion is fairly clear and will interest and benefit persons concerned with employing practical redundancy schemes. No one form of redundancy is adequate for all parts of a complex system and selection of the most appropriate form for each situation demands close liaison between reliability analysts and design engineers, as the authors note. Relying on extensive redundancy, however, to achieve notable increases in reliability as required in this application is an alternative to standardization and development of highly reliable components in a non-redundancy configuration. The intensive effort on component reliability required in the latter approach (described in reports covered by R66-12467) can be very costly, but in some situations it can offset penalties of weight, size, power, and complexity associated with redundancy techniques.

R67-13267 ASQC 830; 813

DESIGNING FOR RELIABILITY.

Frank A. Barta (Hughes Aircraft Co., Space Systems Div., El Segundo, Calif.).

In: *1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 586–597.
Available from IEEE, New York: $8.00.

Operational and reliability data are presented for approximately five years of operation of both the Surveyor and SYNCOM programs. Evolution of parts during the early phases of the programs is described, along with savings effected by the elimination of parts failures during system tests, the derating policy that resulted in high reliability, and various levels of parts acceptance. Management controls involving trouble and failure reports, necessary steps for corrective action, and methods for transmitting information to management personnel are discussed. Operation of the consent-to-ship and consent-to-launch procedures are described; and the status of operational hardware, data on hardware approaching operational readiness, and data affecting failure rates are summarized for both the lunar soft lander and the communications satellites. The need for strong reliability management controls is emphasized. M.W.R.

Review: These case reports on specific spacecraft reliability programs are worthwhile. The high operational reliabilities which have been achieved show the effectiveness of the programs. Sufficient details are given in both the discussion and the illustrations to provide some ideas on planning high-reliability programs. Parts screening seems to play a strong role here, and it is interesting to note that the experiences reported indicate that heavy parts screening reduces subsequent testing costs. The operational reliability data are shown to contribute to improved reliability predictions, and the resulting set of failure rate-stress curves which were developed will be of general interest. The full reliability program has apparently proven itself for spacecraft, and this makes one wonder what its implementation would show on run-of-the-mill DoD equipment.

R67-13274 ASQC 830; 612; 740

COMPUTER-AIDED DESIGN.

Joseph J. Casazza, ed.

Electronic Design, vol. 14, Oct. 11, 1966, p. 54–57, 70–74, 76–80. 30 refs.

Four articles on computer-aided electronic design deal primarily with circuits and feedback systems. A design program is offered that permits the designer to use Laplace transform techniques to check circuit performance; and the use of a Fortran program called LISA (Linear System Analysis Program) is described for an emitter-follower circuit. The simplification of feedback system design is discussed in terms of using a digital computer to save time. A circuit design program called AMPLI (Program for Analysis of Amplifier Circuits) was developed to permit custom tailoring of circuit designs; and this program is considered to be easily modified. The fourth article lists computer programs developed for the design and analysis of electronic circuits. M.W.R.

Review: Tools which allow the designer to pay more attention to detail are always useful for increasing the reliability of a product. The computer is a rather raw tool which is coming to have more, better, and easier applications for paying attention to detail. Before the computer can do a designer any good there must be a program. And, in a sense, it is this program which actually helps the designer. Engineers have traditionally had difficulty in that they tend to use special-purpose formulas and forget the special-purpose assumptions that went along with them. These computer programs are just large special-purpose formulas and the engineer should be at least reasonably familiar with what they presume about his electronic circuit. This set of articles is not a comprehensive series on computer-aided design, but rather a collection of vignettes. The articles are all reasonably well done and show the designer what he can do. What they do not do is give any sense of the trials, frustrations, and costs that are associated with such techniques, especially in learning. These early tribulations are worth going through by the designer and his company because the benefits to be gained generally far outweigh the disadvantages. Design engineers who are interested in using computers to assist them can get some insight in readily assimilable form from this papers. For some *of the papers a knowledge of computer programming, at* least in principle, will be most helpful. The complete novice will probably be stumped by most of the material.

R67-13279 ASQC 838
Atomic Energy Commission Research Establishment, Riso (Denmark).
IMPROVEMENT OF REACTOR SAFETY-SYSTEM RELIABILITY BY MEANS OF REDUNDANCY
P. Timmermann *In* IAEA Nucl. Electron. 1966 p 527–543 refs (See N66-38869 24-22) CFSTI: HC $3.00/MF $0.65 (N66-38907)

In reactor safety it is generally accepted that the essential reliability factors are the concept of safe and unsafe failures, the fail-to-safety principle, redundancy and testing of safety equipment. The main contributions, especially concerning the two-out-of-three system, are reviewed in the light of these factors, and the possible causes of the existing discrepancies between the theoretical models and operating experience are discussed. It is indicated that certain extensions of the present models may facilitate the proper design and maintenance procedure. The redundancy problem in general digital circuits has many counterparts in safety systems. The safety channels, used as on–off devices, as well as the logical decision elements, which are usually disregarded in models, may be analyzed from this point of view. Some methods of applying redundancy on the logical level are discussed in *connection with a replacement of relays by solid-state* circuits. Progress here has been rather slow, and several designs have been suggested which overcome the problems of logical element reliability by extensive use of fail-to-safety philosophy and self-checking in non-redundant systems.
Author

Review: For those interested in redundancy as a means of improving the reliability of digital circuits, this paper will serve a useful purpose. While the specific concern is with reactor safety systems, many of the principles discussed have much wider applicability. The related literature, especially that pertaining to the two-out-of-three system, is reviewed and 20 references are cited. The paper represents a blending of theory with practical engineering considerations, serving to cast light on the possible causes of discrepancies between operating experience and predictions based on theoretical models.

84 METHODS OF RELIABILITY ANALYSIS

R67-13235 ASQC 844; 775
Air Force Systems Command, Wright-Patterson AFB, Ohio, Aeropropulsion Lab.
ASPECTS OF USING INFRARED FOR ELECTRONIC EQUIPMENT DIAGNOSIS
Ruth A. Herman 31 Oct. 1966 28 p refs Presented at the 26th Natl. Conv. of the Soc. for Nondestructive Testing, Chicago, 31 Oct.–4 Nov. 1966
(AFAPL-CONF-67-7; AD-642428; N67-17159) CFSTI: HC $3.00/MF $0.65

The validity of infrared radiation as a checkout parameter for the diagnosis of electronic equipment is verified by laboratory *research. Other advanced checkout techniques are re*viewed and compared with that of infrared; the limitations *of all the techniques are described. A discussion* follows on the implementation of the infrared-radiation technique.
Author (TAB)

Review: Infrared radiation patterns have been receiving attention recently as a means of identifying faulty components in electronic circuits. In this role they have considerable potential as the basis of an important reliability tool. This paper describes some fault-diagnosis experiments using both infrared techniques and computer diagnosis methods. The methods are also compared on the basis of ease of implementation. Limitations of the techniques are pointed out. This paper will be of value to design and test engineers interested in ways of diagnosing faults in electronic circuitry, as well as to those who wish to further the development of the infrared technology.

R67-13236 ASQC 840; 775
Sylvania Electric Products, Inc., Woburn, Mass.
RELIABILITY SCREENING USING INFRARED RADIATION Final Report, Jun. 1964–May 1966
Bernard Selikson and Joseph Di Mauro Griffiss AFB, N. Y., RADC, Oct. 1966 132 p refs
(Contract AF 30(602)-3452)
(RADC-TR-66-360; AD-642112; N67-16597) CFSTI: HC $3.00/MF $0.65

A program was conducted to determine the feasibility of developing a process whereby transistors which have a high probability of failing during their lifetime can be screened from a lot of similar but reliable transistors on the basis of their infrared output while operating under normal electrical conditions. The report includes discussions of the mode of operation of the infrared instrumentation used in the program and details of the life tests which were conducted.
Author (TAB)

Review: This is a comprehensive report based on a study to see if a relationship between infrared emission and early failure could be found in transistors. As such it will be of value to those concerned with the development of infrared technology as a nondestructive screening method. It leaves little to be desired from the standpoints of clarity and detail. However, the conclusions drawn from the study do not point to a superiority of the infrared technique over other methods for the reliability screening of transistors on the basis of either effectiveness or cost. Nor was there evidence of failure mechanisms detectable only or most effectively by infrared. There is a need for faster and cheaper infrared measurement techniques before this can become a practical basis for screening. These results are, of course, no reflection on the work done in this program, which itself contributed to improvement in measurement techniques.

R67-13238 ASQC 844; 871
AN INVESTIGATION INTO MARINE RADAR RELIABILITY.
F. J. Wylie
(Radar and Navigational Aids Group Symposium, London, England, Dec. 15, 1965.)
The Radio and Electronic Engineer, vol. 33, Jan. 1967, p. 17–23.

Failures encountered during a 6-month period in 100 sea-going marine radars of 65 different types are summarized. The sets, made by British, German, Norwegian, and United States manufacturers, were fitted on 550 British-registered *ships and 450 from other nations; and most of the ships were* engaged in regular trading. The average unserviceable time per set at sea was 7.22 days for the 801 sets that failed, whereas the average total unserviceable time at sea and in port was 11.56 days. Vibration is mentioned as a possible failure cause. Incidence of breakdowns as they affected operational availability is discussed, as is the effect of switching on failure incidence, fault incidence and maintenance, and relation between age of radar and fault incidence. Of the 4134 failures tabulated, 1081 are attributed to thermionic valves, 643 to display defects, 618 to power supply defects, 545 to receiver defects, 491 to fuse failures, 356 to scanner defects, 146 to transmitter defects, 83 to display ancillaries, and 171 are unspecified. M.W.R.

Review: The results of 1000 complete replies of a survey of marine radar usage experiences are reported. The report is therefore based on a considerable volume of data on type, age, and occasions of use of the radar; regularity of maintenance and qualifications of the maintainer; and failure history over a six-month period. No general attempt is made to obtain estimates of population statistics since the sample was spread over 65 different types of radar installations manufactured by ten companies. Many unexpected results are noted, such as: (1) twice as many failures occurred during periods of continuous operation than at switch-on times; (2) results of maintenance were essentially the same whether performed by (British) Board of Trade Radar Maintenance Certificate holders or by non-certificated maintainers; (3) little correspondence existed between age of radar and average failures. The number of unexpected results and the failure to obtain firm conclusions indicates that somewhat further work will be required before the study's main value can be attained. The report is clearly written and fulfills its purpose of providing interim information. It does not contain sufficient detail, however, to become the basis for independent study.

R67-13239 ASQC 844; 871

RADAR RELIABILITY ON TRAWLERS.

A. J. Harrison (Kelvin Hughes, Radar Development Dept., Dagenham, England).

(Radar and Navigational Aids Group Symposium, London, England, Dec. 15, 1965.)

The Radio and Electronic Engineer, vol. 33, Jan. 1967, p. 27–30.

Records of reliability and maintenance of radar equipment on a specified group of ships (deep-sea trawlers) operating from a specified port under controlled conditions are presented. The reasons for the very long 'mean-time-between-failures' under these conditions are considered to be: (1) the equipment is not switched on and off, but allowed to run for a long time, (2) the operators have been given training on the maintenance of this particular set, (3) the spares provisioning is at a high level, and (4) a rigid system of preventive maintenance is applied. These factors are considered to be significant in achieving high reliability. Author

Review: The maintenance and failure records for essentially one type of marine radar operating a total of 188,000 hours are summarized in this report. Its main contribution is the documentation of the reliability obtainable (1385 hours mean-time-between-failures) with a strong preventive maintenance program. However, although this paper in itself offers no comparative data with non-maintenance cases or different radars, taken in conjunction with Captain Wylie's paper (pp. 17–23 in the same issue of the *Radio and Electronic Engineer*), it documents the improvements in MTBF which can be obtained by practical maintenance and good spares backing.

R67-13244 ASQC 844; 775

FAILURE ANALYSIS OF MICROCIRCUITRY BY SCANNING ELECTRON MICROSCOPY.

P. R. Thornton, K. A. Hughes, Htin Kyaw, C. Millward, and D. V. Sulway (Wales University, University College of North Wales, School of Engineering Science, Bangor, Caern, Wales).

Microelectronics and Reliability, vol. 6, p. 9–16. 8 refs. Research supported by the Science Research Council; Ministry of Defence Contract No. CP 14000/65.

(A67-22017)

The paper describes the use of the scanning electron microscope (SEM) as a means of detecting unwanted leakage paths in complex microcircuitry due to the presence of extraneous inversion layers. This method involves the use of the SEM to obtain charge collection "maps" of the devices. By comparing acceptable and rejected devices it is possible to detect regions of unwanted depletion layer which are present in the absence of an applied voltage or which are created by the application of a small voltage. By observing the VI characteristic during the SEM observations it is possible to determine whether the observed depletion layers have inversion layers associated with them. An additional effect is described in which bombardment of the specimen by the primary beam of the SEM removes unwanted leakage paths. It is shown that this is a very powerful method of analyzing faults due to unwanted inversion layers, in particular it is possible to detect such layers which give leakage currents as small as 1 na. The full implications and usefulness of the approach are not fully assessed because the exact nature of the physical processes involved is not completely understood. The various factors which tend to increase the sensitivity of the method and which avoid unwanted effects are described and some relevant orders of magnitude are included. Author (IAA)

Review: For those interested in the scanning electron microscope (SEM) as a tool in the failure analysis of microcircuits, this paper will serve a useful purpose. In addition to a qualitative description of the manner in which leakage paths can be detected by the SEM, it presents the results of some experimental studies on faulty devices, and an assessment of the present ability of the approach. The paper is well illustrated with figures and micrographs. Eight references on the subject are cited and their connection with the present work is indicated. A question was raised previously (see R65-11980) as to how nondestructive the scanning electron beam is. Because of the possibility of getting a wrong answer, it is important that the beam not change the characteristics of the device while scanning. This consideration more severely limits its use as a nondestructive test. Some light on this is given in the reported results concerning the removal of unwanted inversion layers by relatively long exposures to the primary beam. However, it is indicated that the physical basis of the process is not fully understood and is subject to further investigation. This absence of physical understanding need not impede the application of the method to failure analysis, as the authors have explained.

R67-13246 ASQC 846

COMPARISON OF MIL-HDBK-217A AND MIL-HDBK-217.

Allan S. Golant (Electronic-Specialty Co., Los Angeles, Calif.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 273–282. 4 refs.
Available from IEEE, New York: $8.00.

Prospective users of the new handbook entitled "Reliability Stress and Failure Rate Data for Electronic Equipment" (MIL-HDBK-217A) are asked to compare its contents with the older 217 handbook in order to make suggestions for possible changes. Accuracy and validity of reliability prediction data in the new handbook are questioned, and examples are offered that indicate most of the basic failure rates and K-factors are higher in 217A than in 217. It is, therefore, concluded that predictions based on 217A data and methods will produce lower MTBF estimates. A comparison on a national scale is urged before definite conclusions are drawn. M.W.R.

Review: The challenging of reliability prediction techniques such as is done in this paper is worthwhile, particularly when the techniques which are challenged are among those consuming the larger amounts of engineering manpower. Reliability prediction techniques have sometimes been lacking in rigor and in common sense, where rigor does not necessarily mean more detail. The author points out that MIL-HDBK 217A data are from parts laboratory testing and not from equipment reliability measurements. If this is so, then what about the differences in the failure criteria for parts testing as opposed to the situation in which the part actually causes an equipment failure, and what about the human-initiated failure from equipment manufacture and use? This paper notes that predictions based on the original 217 have proven to be accurate; here actual equipment reliability measurements are implied without giving any data or references. Nevertheless, using real-world equipment reliability measurements would seem to be the preferred starting place, and proceeding from there to identify the significant variables which determine equipment reliability. Manufacturers should proceed in this manner to develop their own data, and possibly even their own techniques.

R67-13249 ASQC 844; 782; 833

THE EFFECTS OF SPACE ENVIRONMENT ON SPACECRAFT RELIABILITY.

John B. Singletary and John B. Rittenhouse (Lockheed Missile and Space Co., Materials Science Lab., Palo Alto, Calif.). *In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967. p 305–311. 7 refs.
Available from IEEE, New York: $8.00.

Various factors in space environment are discussed, and spacecraft reliability strategy is considered along with the reliability of mechanical components and subsystems. While the demonstration of reliability in complex long-lived systems is considered to present a serious problem, it is necessary to assure that imperfections will be detected through effective acceptance testing. Experiences have indicated the reliable application of materials and components in spacecraft, and the emphasis is placed on more stringent requirements to enable the accomplishment of long-term missions. Tables outline capabilities of reinforced plastics used for spacecraft, as well as the meteoroidal shielding efficiencies of various materials. Operating times of instrument size ball bearings are given, and reliability is tabulated for electromechanical components for a 1-year lifetime. M.W.R.

Review: The material in this paper which deals with the title, namely the effects of space environment on spacecraft reliability, is good. It is review material, but nevertheless of value. The failure modes and mechanisms discussed such as fatigue in vacuum, the evaporation of bearing lubricants in vacuum are good. The other sections should be interpreted qualitatively rather than taking each sentence as the last word on the subject. This is perhaps due to covering a great deal in a short article. For example: (1) Virtually all of the failure rate and statistical calculations presume a constant hazard rate and no possibility of using prior information in a reliability estimate. (2) The phrase "... failure in random mode is extremely rare" uses the word random in a most ambiguous way. (3) It is easy to infer in one place that the distributions of stress and strength are useful virtually only in calculating probabilities of failing for electronic components whereas they are used for mechanical ones also. (4) One of the big problems with generic component failure rate data is that the failure rates vary between manufacturers and between lots. (5) The cliché "you can't inspect quality into a product" is true of course in the sense that if the product is indivisible into smaller elements you cannot put good ones into the lot by inspecting it; they must be there to begin with. If the product is divisible into smaller items, one can, of course, inspect the poor quality sub-items out of the system and replace them with good ones (if they exist). So in this sense quality can be inspected into a product. (6) The statement that "... it becomes evident that reliability demonstration must be accomplished by analysis..." is misleading even though the figures for even simple demonstration are appalling. Reliability *demonstration* is never accomplished by a theoretical analysis. It may be that reliability estimation accomplished by an analysis will be accepted in lieu of a demonstration, but the two should not be confused.

R67-13253 ASQC 844; 775; 851

SCREENING SILICON INTEGRATED CIRCUITS.

Ben C. Peralta (Battelle Memorial Institute, Columbus, Ohio). *In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 337–348. 6 refs.
(Contract N62269-3111)
Available from IEEE, New York: $8.00.

The improvement of reliability screening procedures for silicon integrated circuits was studied by (1) reviewing screening practices used for selecting transistors and integrated circuits for high reliability projects, (2) reviewing the literature on failure modes and incidence for integrated circuits, and (3) setting up experiments dealing with the simulation and external detection of surface defects. Six types of failure sensitive parameters are tabulated according to the source of failure and type of parameter. By using dual, two-input integrated circuits, it was shown that low frequency noise and certain other electrical parameters that measure abnormally nonlinear static characteristics may be correlated with scratches and other surface defects. Preliminary investigations were also made of charge control parameters, switching waveforms, and radio frequency noise as possible screening parameters. An appendix deals with decision theory and "screen/no screen" "accept/reject" decisions. M.W.R.

Review: A large portion of this paper is quite general. It deals with the topic of screening on a fairly abstract level. There is some confusion between stresses which cause aging and stresses which do not. The author distinguishes in reliability screening between those items which are killed in failing the screen and those which are not; although the purpose of the distinction is not clear. The discussion of failure causes is good, but one must be careful about relying solely on manufacturers' data. Failures that customers observe especially in unscreened units, may have quite a different distribution from that listed in the paper although many of them might be regarded as initially defective. The paper is introductory, suitable for the edification of the novice who wishes to spend the time to become more informed. Managers, for example, could get all they wanted to know from a shorter paper.

R67-13254 ASQC 844
MICROELECTRONICS RELIABILITY.
Charles C. Eliot (Raytheon Co., Bedford, Mass.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 349–358.
Available from IEEE, New York: $8.00.

Microelectronics failure modes, mechanisms, and rates are studied in terms of applications to the mechanization techniques of thin films, thick films, and integrated circuits. Although integrated circuits are found to exhibit greater reliability than the film devices, each of groups is found to have its own advantages and limitations. Thick films are highly producible, inexpensive, pattern flexible, and more radiation resistant than integrated circuits. Thin films do not exhibit spurious interactions and are radiation resistant. The add-ons of both film techniques, however, severely limit their reliability. The use of integrated circuits is limited primarily to digital applications because of limited power. Operating and nonoperating storage failure rates for integrated circuits are tabulated as a function of temperature, a qualitative comparison is made of various connecting techniques, and various failure data are given. M.W.R.

Review: The discussion of failure modes and mechanisms is detailed enough so that an engineer can get a good idea of what is going on and the language is understandable. One of the reasons for failure due to thermal mismatch between dies and headers may be that the values for the thermal expansion coefficient of silicon in some of the handbooks are incorrect. (The correct values are: in $10^{-6}/°C$—3.0 at 400°K and 4.0 at 650°K.) The new user of integrated circuits should not be lulled into a sense of security by the dispassionate discussion of failure modes and mechanisms The vast reductions in failure rate are not achievable without many trials and tribulations on the part of the user as indicated in other papers at the Symposium. The quality shipped by manufacturers from time to time is terrible or worse. Not infrequently the manufacturer is loathe to do anything about it, especially for small quantity users; and in the sellers' market which now exists for integrated circuits, life is sometimes just tough. All problems do not disappear by (1) choosing a good-looking standard circuit from the manufacturer's literature, (2) designing a circuit using reasonable principles, and (3) staying within ratings. The prospective user of integrated circuits should read carefully the failure modes and mechanisms sections of this paper and look at the pictures; then remember that these can happen to him through no fault of his own. The discussion on thick and thin films is reasonable, although there are various definitions of thick and thin films; one of the more useful ones has to do with the way in which the film is deposited. For example, in the author's definitions there is a gap between 0.005 mils and 0.5 mils where the film is neither thick nor thin. There is an editorial error at the bottom of page 353 where the author probably meant to say, "It is not *un*common to encounter resistivity changes in the order of 2x." All in all the article is a good one and the tables are helpful (the ones giving numbers of course should be used only as rough guides).

R67-13256 ASQC 844; 775; 851
RELIABILITY OF INTEGRATED CIRCUITS BY SCREENING.
T. J. Nowak (Autonetics, Anaheim, Calif.).
In: 1967 Symposium of Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 365–375 14 refs.
Available from IEEE, New York: $8.00.

Concepts on product variability and on failure modes and mechanisms are used to develop screening procedures to improve reliability of silicon integrated circuits. Typical integrated circuit parameter variables are tabulated to show manufacturing levels of interrelationships, and types of failure modes and their relative occurrence are given. Significant cause of integrated circuit failures in system use is attributed to defects which are not noticed during precap visual inspection, and the biggest single failure cause is attributed to defective passivation layer or oxide pinholes under metalized network patterns. Power burn-in screen is the most effective screen in eliminating a wide variety of defects in integrated circuits. Various screening costs and levels are described, and a screening program for integrated circuits is formulated. M.W.R.

Review: This paper contains much good information and will be useful as a reference. As with many other papers on this subject, it is so well organized and presents the material so smoothly that the trials and tribulations of living with the problems do not come through clearly. The author's general remark, "By proper screening operations we can figuratively question the product at any stage of its manufacture..." is akin to the situation the mice had in Belling the Cat. The concept of a lot containing very good and very bad parts is emphasized but needs much more fundamental work done on it in order that the conclusions people usually draw will have a better foundation, in both theory and practice. For example, no distinction is made between parts wherein the stress causes damage and those wherein stress less than the strength does not cause damage. Screening is certainly an essential part of any high-reliability program for integrated circuits. One of the biggest problems generally encountered is the trade-off of cost versus hoped-for reliability improvement. The reliability is generally demonstrable only by accelerated tests, and these have their own problems with interpretation.

R67-13263 ASQC 844; 612; 831; 843; 874

COMPUTER GENERATED FAULT ISOLATION PROCEDURES.

E. Rivera, E. R. Garcia, and R. Ranalli (Autonetics, Anaheim, Calif.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 534–541. 1 ref.
Available from IEEE, New York: $8.00.

A computerized procedure for predicting the unique circuit indicators of component part failure modes is presented. A nonlinear, full range, dc computer model of circuit operation is used to simulate circuit responses to component failures. These responses are systematically examined by computer search to disclose which ones, singly or in combination, uniquely identify a failed component and its mode of failure. By using this information and arranging tests in logical sequence, fault isolation test plans can be established which yield repairs in less time, with less rework stress, and with a minimum replacement of good components. Pertinent features are summarized for two programs, and an application to a regulator circuit is illustrated for one of the programs. Author

Review: Even though there are several unclarified points in this paper, it is an extremely interesting and well-written description of a sound and practical approach to automatic fault isolation in analog circuits. It represents an extension of the automated failure mode and effects analysis effort described in the paper covered by R66-12514. Considerable computing time can be required for this approach, but the cost could possibly be offset by savings in time for design, testing, and repair as well as higher reliability, lower maintenance skills and better knowledge of logistics requirements. The practicality of this study is evidenced, for example, by the inclusion of effects of test probe impedance on measurements, treatment of obvious failure effects by inspection, and resolution of the test equipment. The effect of parameter variations of non-failed components was not included but was identified as a needed refinement. Several unclarified points noted were: (1) Most of the attention was on single component failures. For the specific failure combinations included, it is not clear what they represented. Did they, for example, represent those situations where the failure of one component causes subsequent failures of others by created overstress conditions? Such failures are not independent since the subsequent failures are highly probable given that the failure creating the overstress condition has occurred. Any practical approach to failure isolation must include this type of situation. On the other hand, a less probable event of multiple failures where individual failures can be reasonably assumed independent can receive lower priority for consideration. (2) It was stated that isolation of 10% of the failure modes in a particular circuit required transient analysis. Yet, there was the conflicting implication that the AMAP program, designed to perform only d–c analyses was the sole computer aid employed for computing circuit response. (3) On the basis of the information given solely in Figure 3, a statement that both node 1 and node 2 information are necessary to prevent failure 1 from being masked is incorrect. Failure 1 can be uniquely identified by either node 1 and node 3 information or node 2 and node 3 information. A similar incorrect statement is made in the discussion of a later example presented in Figure 5 about resistor R_{23} requiring three node measurements when clearly two, say, node 11 and node 17, will suffice. Since these examples represent extracts of information from a larger example, it is possible that the statements could be correct when other data are included. (4) More information on comparison of computer results with laboratory results would have been welcomed. For example, what proportion of measurements with failure modes simulated in the laboratory resulted in the same conclusions on failure isolation as those provided by the computer?

R67-13266 ASQC 844; 833; 851

SEMICONDUCTOR RELIABILITY DESIGN GUIDES FOR CHARACTERIZATION AND APPLICATION OF SIGNAL DIODES, TRANSISTORS AND DUAL TRANSISTORS.

Erwin A. Herr and Albert Fox (General Electric Co., Semiconductor Products Dept., Syracuse, N. Y.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 563–585. 4 refs.
(Contract AF 04(694)-247)
Available from IEEE, New York: $8.00.

Techniques for the determination and improvement of reliability of semiconductor silicon diodes and transistors were obtained by three intensive physics of failure reliability programs on large quantities of equipment used by the military, industry and the public. Quantitative information provides a choice of circuit design operating conditions that permits optimization of device performance and reliability. Stress factors affecting reliability are described, and reliability is shown to increase with a decrease in such critical device stresses as junction temperature, voltage, and environment. Accelerated step-stress testing to determine failure threshold and accelerated stress region for the device is shown, and test results based on three or more level for periods of 1200 to 4000 hr or longer are made to determine constant-stress-in time tests. Failure rates at these multilevels followed the Arrhenius failure rate on the Weibull failure-in-time models. Data are given so that expected failure rates can be determined for a range of operating conditions. M.W.R.

Review: This is another of the papers which show progress made under the CQAP of Autonetics. They have all involved accelerated testing to discover failure modes/mechanisms, and subsequent action to correct them if they were deemed detrimental. No data are given from which to judge the adequacy of the curves; this is unfortunate since it is well known that many such curves in the literature are poorly drawn through an insufficient number of points and display none of the uncertainties involved. The improvements do appear impressive. The Weibull shape parameter's being almost 1 is interesting in view of the fact that many people in the last several years have been advocating a shape parameter appreciably less than 1 for semiconductors. Care should be used in the extrapolations, since at best the curves are good only for the failure modes/mechanisms accounted for in their derivations. At room temperatures other failure modes/mechanisms may be important. Regardless of the preceding questions, the value of this kind of program in producing high-reliability parts cannot be over-emphasized. This is one of the more useful and less controversial aspects of accelerated testing.

R67-13268 ASQC 844; 782

TOWARD STORAGE RELIABILITY FOR ELECTRONIC SYSTEMS.

D. C. Schiavone and W. L. Hadley (Martin Co., Baltimore, Md.).

Space Aeronautics, vol. 47, Feb. 1967, p. 98–104.

Factors affecting failure rates after dormant storage of missiles are tabulated according to worst, intermediate, and optimum condition; and the failure rate reducing effect of optimum condition over worst condition is shown in each case. Most of the failures during storage are attributed to built-in manufacturing defects, which are not apparent although they will cause electronic parts failure under the stress of a storage environment. Although no single checkout concept appears to insure good storage reliability in all cases; an optimum procedure is considered to depend on the number and types of parts in the stored system, the failure detection capability of the checkout equipment, the rate at which failures are induced during checkout and subsequent repair. Parts screening to obtain defect-free parts is discussed, and reductions of 100:1 seem to be possible. Analog circuits are reported to be more failure prone than the discrete parts in digital circuits, and minimizing the time between checkouts during dormant storage can reduce failure by as much as 50:1. M.W.R.

Review: The effects of nonoperating storage on the reliability of electronic systems is an important topic on which relatively little has appeared in the reliability literature. This might lead to the conclusion that very little has been done about it, which is negated to some extent by the program described in this paper. The presentation is compact, containing a listing of factors affecting failure rates after dormant storage, some discussion of checkout practices, and a summary of the more significant conclusions thus far drawn. It is noted that no conclusive information is yet available on which to formulate design practices that would ensure survival in storage.

R67-13270 ASQC 844; 775

Honeywell, Inc., Minneapolis, Minn.

A MANUAL DEVICE FOR LOCATING ELECTRIC ARC-PRODUCING FAULTS Final Technical Report

Richard T. Stevens Wright-Patterson AFB, Ohio, AF Aero Propulsion Lab., Mar. 1965 141 p refs *Its* Rept.-20070-FR1 (Contract AF 33(615)-2031)

(AFAPL-TR-65-25; AD-613263; N65-25963)

It is known that certain types of electronic circuit and component defects can generate RF fields when energized. This program's purpose is to develop a noncontacting portable instrument for locating defective components and circuits which generate these RF fields. To implement this program, initial effort was concerned with a study of the RF spectrum generated by various defective components and circuits. The spectrum was found to be rich in RF noise in the vicinity of 26 megacycles. Accordingly, a portable broad band 26-megacycle radio receiver and associated RF pickups were designed to provide a moderately directional means of coupling to both RF voltage fields and RF current fields. The effectiveness of this equipment was evaluated using specially constructed sources of localized RF fields. The equipment was also used for locating simulated defective circuits and components as well as actually defective circuits and components. These experiments show that circuit and component defects resulting in an electric spark discharge can usually be detected by the receiving equipment developed under this program. The results show that extremely low level RF disturbances, such as those generated by noise diodes, usually cannot be detected by the receiving equipment developed under this program. When used with this limitation in mind the equipment should provide a highly effective portable device for locating a large number of electronic circuit and component defects. Author

Review: This is a final report which summarizes some of the work done in trying to locate faults in components and circuits by means of the RF energy in the neighborhood. This kind of nondestructive technique appears to have great potential, and there have been a few indications in the nonclassified literature that it is being applied. This report contains more detail on the experiments than someone just interested in trying the method would need, and it does show how the RF probe is constructed. Such nondestructive test methods will be vital when considerable redundancy is used because redundant components are especially difficult to check out by means of measurements at the terminals. Those who are interested in pursuing the matter further with their own products should contact the author of this report or his company.

R67-13280 ASQC 844; 351; 770; 816

INTEGRATED CIRCUIT RELIABILITY.

Electronic Procurement, vol. 7, p. 43–47.

Integrated circuit reliability is discussed from the points of view of the military user as well as of the supplier. Techniques and complaints are presented as they were considered at a recent symposium on reliability; and tables are included that compare various connecting techniques for microcircuits and that give the stress conditions and failure modes controlled for various screening techniques. A copy of an integrated circuit product review summary is shown, and specifications evaluation is considered. Quality control is described as risk control by one supplier who summarizes the program carried out by his company. M.W.R.

Review: This is a report largely concerned with a session on integrated circuit reliability at the 1967 Annual Symposium on Reliability. Not all the material appearing here, however, appears in the Proceedings of that Symposium. (This article includes a summary of a paper not received in time to be included in the Proceedings, a summary of remarks from the floor, and an additional summary of remarks from a supplier afterwards—since so much of the commentary at the Symposium was anti-supplier.) The article is well worth reading, although it is not the kind where one can say anyone is right or wrong. The problems arise from the differences between buying and selling that are probably hundreds of years old. Users tend to forget that the companies from whom they buy have sales, marketing, and production departments that behave in exactly the same way as the sales, marketing, and production departments of the user's company: they make promises to get contracts, some of which are expressions of hope; they say ship it, don't scrap it, the customer is waiting; and they behave in general as everyone does when confronted with conflicting pressures and no satisfactory solution in sight. This reasoning is not to provide an excuse for poor behavior, merely to explain it and to point out that pious moralizing gets no one anywhere. What customers have to do, as they have always had to do, is find a way of exerting pressure on the supplier.

R67-13284 ASQC 844; 782

Lockheed Missiles and Space Co., Palo Alto, Calif. Research Lab.

CATASTROPHIC FAILURES IN SEMICONDUCTOR DEVICES EXPOSED TO PULSED RADIATION

De Witt Landis Repr. from IEEE Trans., 1966, p. 590–598 (AD-637907; N67-83383)

Semiconductor devices were exposed to high intensity 1.6 MeV electron pulses. Glass diode packages and integrated circuit chips were broken. However, the failure occurring at the lowest radiation doses is lead-chip separation at the point where the lead is bonded to the chip. Statistical experiments show that the damage is caused by energy absorption in the device. The 90% confidence level failure rates and survival probabilities for many lead systems are also given. Author (TAB)

Review: The results of a series of experiments to study the effect of high intensity 1.6 MeV electron pulses on semiconductor devices are reported in a concise form. It is assumed that probability of failure and dose are related by a Weibull distribution. The statistical analysis is straightforward, clearly presented, and adequately referenced. As the author has pointed out, the data are rather limited for the drawing of conclusions with high confidence. This, of course, is generally a problem—very large samples are required for estimating low failure rates with high confidence. The failure rates obtained should serve as reasonable approximations useful for design purposes, and the results of the experiments contribute to knowledge of failure mechanisms in this type of radiation environment.

85 DEMONSTRATION/MEASUREMENT

R67-13259 ASQC 851; 814; 844

RELATIVE COSTS OF DIFFERENT RELIABILITY SCREENING TECHNIQUES.

C. M. Ryerson (Hughes Aircraft Co., Culver City, Calif.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 408–419.

Available from IEEE, New York: $8.00.

The five basic types of component part screening techniques are described, and their advantages and disadvantages in regard to cost and effectiveness are explained. Detailed cost considerations for the four modern types applicable to weapon and aerospace systems are compared for their similarities and differences. Basic physical principles, timing of screening efforts, impact of modes and mechanisms of failure, selection of indicator parameters, timing-cost comparisons, cost tradeoffs, and potential savings are covered. Actual and relative cost figures establish a springboard for the validation of specific screening effort costs so that future screening programs can be based on deliberate cost control objectives. Author

Review: The background which is presented in this paper leading to the relative cost material per se is in itself a good introduction to screening techniques. A rationale for screening techniques is given and some subtleties are brought out. Screening for reliability purposes is oriented in the cost discussion to treat the hardware complexity level and the time at which screening is conducted. Here the orientation is toward determining the relative amounts of screening at the different levels of hardware aggregation and times which will result in minimum total screening cost. The cost discussion is reasonable although it does not go into the relative effectiveness of screening at the different levels. For instance, it would seem that the screening conducted at say the unit test level would not identify the same or as many piece parts for elimination as would have been identified for elimination at the receiving inspection level. All in all, this is timely material on screening tests, which have turned out to be one of the more solid tasks of a reliability program.

R67-13269 ASQC 850; 815

FUSES—SOME QUALITY AND RELIABILITY CONSIDERATIONS.

E. Jacks

Electronics and Power, vol. 13, Jan. 1967, p. 11–15.

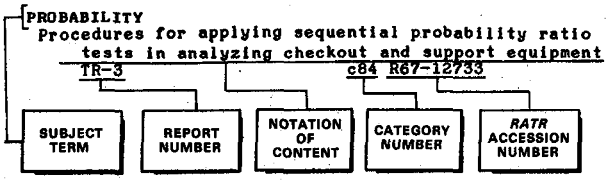
Fuse reliability determination is discussed in terms of both function, primarily safety, and economy; and quality and reliability standards for fuses are reviewed. Attention is given to unavoidable faults and their prevention, environmental conditions that affect fuse performance, and the active functions of fuses. Safety margins are discussed, as are the control and measurement, loading devices, range of applicability, and characteristics of fuses. M.W.R.

Review: Because of its role as a protective device, the fuse is a rather special component. It must be at least as reliable as the system which it protects. A good installation should not be weakened by inadequate protective devices. At the same time it is poor practice to depend on protective devices to bolster up a skimped installation. A fuse should remain as effective up to the end of its useful life as it was at the beginning. Yet lifespans are completely unpredictable. Problems involved with both the active function and the passive function of the fuse can be quite complex. This article is a rather general discussion of how quality and reliability can be determined and proved for fuses. Some of the ideas may well be applicable to fuses for aerospace applications.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 7

Typical Subject Index Listing



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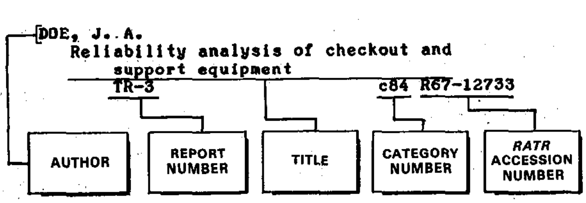

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 7

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Reliability Abstracts and Technical Reviews

AUGUST 1967

Volume 7
Number 8

R67-13286—R67-13345

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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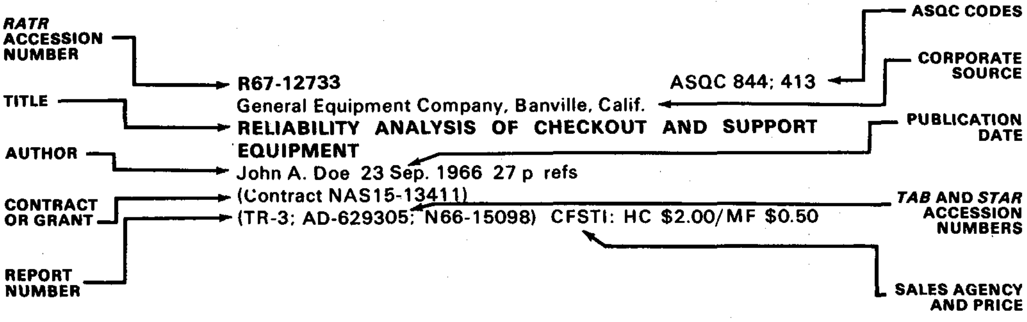
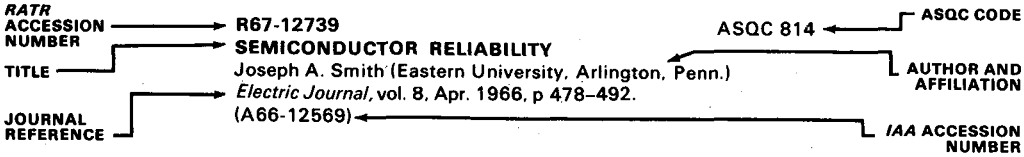
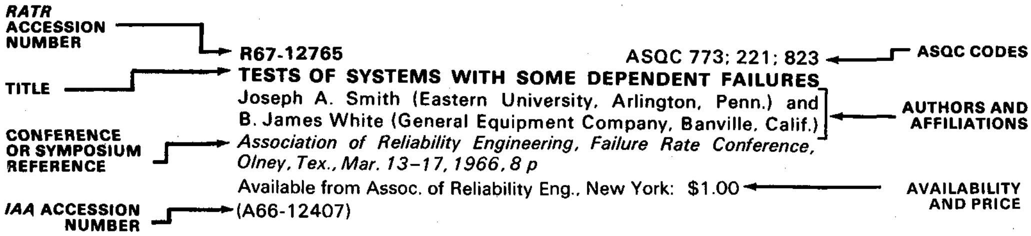


R67-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N66-15098) CFSTI: HC $2.00/MF $0.50



R67-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A66-12569)



R67-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A66-12407)

VOLUME 7 NUMBER 8

Reliability Abstracts and Technical Reviews

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August, 1967

80 RELIABILITY

R67-13286 ASQC 800
RELIABILITY ENGINEERING AND SUCCESS IN SPACE EXPLORATION.
N. E. Golovin (Office of Science and Technology, Washington, D. C.).
In: Active Reliability: Annual West Coast Reliability Symposium, 6th, University of California, Los Angeles, Calif. February 20, 1965. Symposium sponsored by the Reliability Div. of the Los Angeles Section, American Society for Quality Control, and the College of Engineering and University Extension, University of California. North Hollywood, Western Periodicals Co., 1965, p. 1–19. 10 refs.
(A65-26052)

Attempt to understand the problem of how a spacecraft development and test program is to be conducted so that the operational flight readiness of a manned space system can be assured with a minimum number of flight test mission cycles, with discussion of some of the methods which must be applied if quantitatively justifiable solutions are to be found. Classical reliability engineering concepts are examined critically. It is considered that important advantages may ensue from organizing complex system developments in general and reliability engineering efforts in particular in cybernetic form—i.e., so that the assignments and separations of functions, definitions of the flows of information, and specifications of control relationships provide the optimum practical structure for learning from, and changing because of, new experience. IAA

Review: This is essentially the same paper as that covered by R67-12910.

R67-13304 ASQC 800; 810; 870
THE FUTURE OF RELIABILITY AND MAINTAINABILITY.
Leslie W. Ball (Boeing Co., Aerospace Group, Seattle, Wash.).
American Institute of Aeronautics and Astronautics, Annual Meeting, 3rd, Boston, Mass., Nov. 29–Dec. 2, 1966, Paper 66-859. 6 p.
(AIAA PAPER-66-859; A67-12260) Members, $0.75; Nonmembers, $1.50.

Discussion of the theoretical and practical requirements for integration of reliability, maintainability, and all other engineering disciplines. The principle objectives of program management technology as practiced by DOD and NASA are defined, and reliability and maintainability are related to these objectives. IAA

Review: This is a concise, well-written paper which defines the objectives of program management technology as practiced by DoD and NASA, with specific reference to the roles of reliability and maintainability. An important message conveyed is that reliability and maintainability engineers must adapt to today's rapidly-changing technology if they are to stay alive professionally. The author has a wealth of experience in the areas discussed in the paper; it will be worthwhile reading for reliability and maintainability management personnel.

R67-13313 ASQC 801; 844
STRESS VS. DAMAGE.
R. A. Evans (Research Triangle Institute Research, Triangle Park, N. C.).
In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc.; 1967, p. 633–635. 1 ref.
Available from IEEE, New York: $8.00.

A stress-strength model and a damage-endurance model are developed to determine the cause of failures in electronic equipment. The simple stress-strength model is based on the failure of structural metals in uniaxial tension, while the damage-endurance model asserts that damage only uses up some of the endurance of a component. Distinction is made between the two models that explain failure; and is noted that in the first, no damage is done if the stress is less than the strength; and the process is reversible. In the latter model, damage is irreversible. M.W.R.

Review: In the day-to-day engineering practice of problem solving, it is easy to forget certain fundamentals about the physical processes that cause the problems in the first place. For example, does temperature really age a particular device or are its effects just reversible? This paper serves as a reminder of some basic concepts so often forgotten. The narrative discussion presented is thought-provoking and down-to-earth and will be interesting to most engineers. The terminology used departs somewhat from convention but is employed fairly effectively, especially in emphasizing the distinction between stress and damage as two different things that cause failure. The fact that the term "damage" was not explicitly defined demands very meticulous reading to discern *exactly* what is meant. To illustrate, damage, as a technical term, has generally been assigned only a qualitative meaning. The author uses it in the damage-endurance model in a quantitative sense to designate the cumulative effect of "damagers" applied over a period of time. Damagers are thus presumed to be things such as thermal conditions, mechanical forces, and electrical environments. Also, in the author's words, "The damaging effect is not reversible in the ordinary sense, although negative damage can be done." The term "stress," on the other hand, is reserved in the paper to designate things that cause failure in a time-independent process. Stresses are physically the same things as damagers but their designation is different because of the different effect produced. There is an implication in the paper that damage can be caused by stress only if failure occurs, i.e., if stress exceeds strength. Thus, the statement "... damage less than failure has no meaning" would imply that a permanent irreversible change, such as permanent deformation of an item, is not damage even though some other criteria for failure, such as total collapse, were satisfied. Such a concept may be entirely acceptable for certain test and design criteria, but could be meaningless in certain situations, e.g., when considering degraded operation resulting from obvious damage of this type. In a private communication the author acknowledges this as a limitation on the applicability of the model rather than on its consistency. In the discussion of the use of the damage-endurance model, endurance is equated to the unit of life and damage is the fraction of the life. Assuming that aging (reviewer's definition: a permanently irreversible process occurring with the passage of time) is related (but not necessarily equated) to fraction of life, damage has thus been related to aging. This use of damage seemingly synonymously with aging may be misleading to some readers. Since aging can actually be beneficial in certain cases, not all aging is really damage in the conventional sense. Also, if the stress-caused damage concept as introduced above is allowed, then not all damage is really aging. This, also, does not demonstrate inaccuracy in the logical construction of the model but is presented mainly for clarification. As a slight correction for the notation used, "step-damaging test" as a substitute for "step-stress test" should be "step-damager test." When aging is involved as in accelerated testing, damage (and damaging) is a cumulative effect of a damager applied over time. Damage could thus hardly be applied in steps. Some numerical examples or figures would have been helpful for illustrating concepts, especially for those associated with the less-familiar damage-endurance model. The already-familiar stress–strength model finds many applications in explicit form. As a reminder, the proposed damage-endurance model does not provide a new method of analysis. It merely provides a way of viewing and better understanding the underlying processes when cumulative effects with time are involved as in conventional life estimation. Fatigue damage and damage to dielectrics by electrical fields are cited as familiar examples of applicability for the damage-endurance model concepts. Keeping the presented concepts in mind can assist the engineer in reliability analysis and test planning.

81 MANAGEMENT OF RELIABILITY FUNCTION

R67-13287 ASQC 810

OPERATIONS REVIEW PLAN FOR RELIABILITY MANAGEMENT.

Galen N. Willis and W. Bruce Dalrymple (Boeing Co., Aero-Space Div., Seattle, Wash.)

In: Active Reliability; Annual West Coast Reliability Symposium, 6th, University of California, Los Angeles, Calif., February 20, 1965. Symposium sponsored by the Reliability Div. of the Los Angeles Section, American Society for Quality Control, and the College of Engineering and University Extension, University of California. North Hollywood, Western Periodicals Co., 1965, p. 21–35.

The mechanics and procedures of an operations review (or audit) plan for the management of reliability and the creation of an effective system are presented. Characteristics of the successful manager and his role in implementing this periodic review program are outlined, and a description is offered of its application to a program or a project. Primary objective of the review is research to determine problems and deficiencies at all design and production levels and to provide corrective action. Checklists, prepared to indicate failure experience and other development aspects, can be enlarged to prevent past mistakes from occurring in future reliability programs. It is emphasized that feedback of information developed from these reviews is of vital importance in improving reliability management. M.W.R.

Review: This paper shows the importance not only of attention to detail during design and manufacturing, i.e., the technical aspects of a system, but the importance of detail in management to assure that things are being done correctly. It is a good presentation of the outlines of a suitable program. As is so often the case, it is difficult to tell from the paper just how well the program is working in practice. Programs of this sort, in order to be truly effective, require the enthusiastic participation of many people and succeed approximately in proportion to the fraction of the people who are able and anxious to carry them out. If all the programs described in the reliability literature were working as they are described, our reliability problems today would be much different than they are. This paper is specifically directed toward management and would be of little use to design engineers.

R67-13288 ASQC 810

STATISTICAL APPROACHES FOR MINIMUM TEST COSTS.

Harry G. Romig (Southern California University, Los Angeles, Calif.; International Telephone and Telegraph Corp., ITT Federal Laboratories Div., Nutley, N. J.).

In: Active Reliability; Annual West Coast Reliability Symposium, 6th, University of California, Los Angeles, Calif., February 20, 1965. Symposium sponsored by the Reliability Div. of the Los Angeles Section, American Society for Quality Control, and the College of Engineering and University Extension, University of California. North Hollywood, Western Periodicals Co., 1965, p. 37–48. 8 refs.
(A65-26053)

General review of the role of reliability engineering in the successful building of any new system at minimum cost. Various critical tests are evaluated, and the statistical approach, using the analysis of variance method, is outlined. The establishment of economical testing programs is discussed, and some examples of savings secured by the statistical approach are cited. To secure maximum reliability at minimum cost it is considered necessary that good engineering notebooks should be maintained so as to have a record of what changes have been made and are associated with the various sets of test results. Some comments on organizing for statistical savings are presented. F.R.L.

Review: The author's abstract which accompanies this paper lists a variety of topics virtually any one of which could be the subject of extensive discussion. Some of them have a rather tenuous connection with the title. The paper is a qualitative discussion of testing for the purpose of achieving maximum reliability at minimum cost. The main points are made through the medium of examples. It will be useful chiefly for generating interest in the subject, but not for providing directions on the use of specific techniques. The paper notes in particular that much more information is generated through the use of the method of variables than through the method of attributes. For the same confidence level much less data are required than corresponding attributes data with its weaker methods of analysis. The author's reference to the statistical design of experiments and the analysis of variance prompts the comment that these techniques have not played the role in reliability analysis that the more ambitious statisticians would like. The main reason, of course, is paucity of data in most cases. Often the data are so sparse that conventional statistical techniques cannot help. It is simply a fact of life that statistical techniques, however high-powered, cannot compensate for a lack of good data. There is also a need for statisticians used to small samples and skilled in small-sample theory to make the most of the data that are available. (In parts of this paper there is a use of initial capital letters which will appear rather curious to most readers. The author in a private communication explained that the capitals are used for emphasis per a system used in certain communication patterns.)

R67-13289 ASQC 810; 610; 864

REAL TIME RELIABILITY VIA O.R. TECHNIQUES.

Arthur A. Daush (Hughes Aircraft Co., Space Systems Div., Systems Eng. Dept., El Segundo, Calif.) and Walter R. Kuzmin (Hughes Aircraft Co., Space Systems Div., Reliability Sec., El Segundo, Calif.).
In: Active Reliability; Annual West Coast Reliability Symposium, 6th, University of California, Los Angeles, Calif., February 20, 1965. Symposium sponsored by the Reliability Div. of the Los Angeles Section. American Society for Quality Control, and the College of Engineering and University Extension, University of California. North Hollywood, Western Periodicals Co., 1965, p. 49–64.
(A65-26054)

Decision-making in a typical spacecraft program having high reliability requirements. Constraints of the program, such as development to tight schedules, use of current technology, weight, new environments (space vacuum), complexity, and diversification of controls are described. Major elements of such programs are the fundamental resolution of failures when they occur and provision of visibility so that actions may be taken to avoid failures. The discussion is limited to the decision-making actions pertaining to the failure-reporting aspect of a spacecraft reliability program. IAA

Review: This paper is useful in arousing interest in the subject. The approach is known by a number of names, Operations Research being only one of them. Generally the emphasis is on taking a broader approach than that now used. Having relevant information available in real time and displayed properly are both quite important. This paper can arouse interest in the subject, but the reader will need to look elsewhere to gain knowledge about specific techniques. No references are cited.

R67-13290 ASQC 816; 815; 833; 836

SMALL SUPPLIER RELIABILITY CONTROL.

W. W. Harter and P. Sitzer (Northrop Corp., Norair Div., Hawthorne, Calif.).
In: Active Reliability; Annual West Coast Reliability Symposium, 6th, University of California, Los Angeles, Calif., February 20, 1965. Symposium sponsored by the Reliability Div. of the Los Angeles Section, American Society for Quality Control, and the College of Engineering and University Extension, University of California. North Hollywood, Western Periodicals Co., 1965, p. 77–93.
(A65-26056)

Outline of the requirements established by Northrop Corporation's Norair Division for control of product reliability by small suppliers. Experience with small suppliers in trying to implement these requirements with no increase in cost is reviewed. It is considered that reliability control requirements must include (1) systematic reliability design reviews, (2) parts-selection policy implementation, (3) reliability testing, and (4) failure-mode analysis and corrective-action system. IAA

Review: This paper, as described by the authors, is a sharing of experiences in requiring formal reliability programs for small suppliers with no increase in the price of the product. There is good emphasis on systematic design reviews, on parts selection, reliability testing, failure mode analysis and corrective action. As the authors point out, most companies practice some of these at least on an informal basis. It is the formalizing and comprehensiveness which will be different and important. The suggestion that a common industry approach to this problem would be more effective than individual efforts is certainly worthwhile. This would essentially involve the creation of standards and is attendant with all the problems thereof. This sharing of experiences by the authors is good and will be informative for those who have both engineering and management responsibilities involving supplier-furnished parts.

R67-13294 ASQC 810

THE ELECTRONIC SYSTEMS DIVISION RELIABILITY/ MAINTAINABILITY PROGRAM ELEMENTS.

G. H. Allen and J. Horowitz (USAF, Systems Command, Electronic Systems Div., Bedford, Mass.).

In: Active Reliability; Annual West Coast Reliability Symposium, 6th, University of California, Los Angeles, Calif., February 20, 1965. Symposium sponsored by the Reliability Div. of the Los Angeles Section, American Society for Quality Control, and the College of Engineering and University Extension, University of California, North Hollywood, Western Periodicals Co., 1965, p. 147–166.
(A65-26060)

Description of elements of the reliability and maintenance (R/M) program of the Electronics Systems Division. Responsibilities are grouped into three general categories: (1) Stating requirements–quantitative expressions and contractor program requirements are incorporated into RFPs and IFBs; (2) evaluating proposals and selecting a contractor; bidder R/M responses to requirements are factors in the overall contractor selection process; the weight given to R/M is not constant but varies with such factors as nature of a given procurement, severity of requirements, etc.; a cursory examination of an RFP and IFB reveals several competing disciplines which influence ultimate contract award; (3) monitoring of contractor progress; this activity generally is performed by a systems-program team. It is considered that the competency of this team has greatly increased through the assignment of Air Force Institute of Technology graduates with an M.S. degree in system reliability. IAA

Review: This paper describes the elements of the ESD R/M Program. A more up-to-date and comprehensive description of ESD policy, practices, and requirements is found in the paper (with the same first author) covered by R66-12605.

R67-13295 ASQC 813

RELIABILITY PROGRAM FOR A LUNAR SPACECRAFT STAR TRACKER.

Melbourne D. Johnson (Hughes Aircraft Co., Santa Barbara Research Center, Goleta, Calif.).
In: Active Reliability; Annual West Coast Reliability Symposium, 6th, University of California, Los Angeles, Calif., February 20, 1965. Symposium sponsored by the Reliability Div. of the Los Angeles Section, American Society for Quality Control, and the College of Engineering and University Extension, University of California. North Hollywood, Western Periodicals Co., 1965, p. 167–177.
(A65-26061)

Description of a reliability program conducted at Santa Barbara Research Center for a typical lunar spacecraft star-tracker project. The statement of work required a reliability program plan describing the general reliability actions to be performed throughout the project. The requirements included a reliability organization having the responsibility to plan and direct the reliability program that would include design reviews, parts and materials selection, qualification testing, failure reporting, manufacturing reliability controls, and a reliability demonstration test as required to demonstrate a reliability of 0.970 to 80% confidence. IAA

Review: A concise description of a particular reliability program for a lunar spacecraft project is presented. It details the tasks and states succinctly what was done to accomplish them. Insofar as one can tell from the written description, this was an effective program. The paper should be of interest to those responsible for reliability programs on similar projects. The principles will have carry-over value, even though the specific will differ.

R67-13296 ASQC 810

A MANAGEMENT TECHNIQUE FOR ASSURING RELIABILITY CONTRACT PERFORMANCE.

John F. Beau (North American Aviation, Inc., Autonetics Div., Downey, Calif.).
In: Active Reliability; Annual West Coast Reliability Symposium, 6th, University of California, Los Angeles, Calif., February 20, 1965. Symposium sponsored by the Reliability Div. of the Los Angeles Section, American Society for Quality Control, and the College of Engineering and University Extension, University of California. North Hollywood, Western Periodicals Co., 1965, p. 179–188.
(A65-26062)

Description of technique for assuring reliability contract performance based on budgeting and measurement concepts. An example chart is presented and analyzed. The technique is considered to have certain advantages, such as (1) a simple single-page "snapshot" of quality performance as related to hardware, (2) results expressed in terms of escape defects which are directly related to reliability budgets, (3) a measure of inspection performance as well as manufacturing performance, (4) an objective basis for determining whether quality-control or manufacturing personnel should take corrective action, (5) performance of corrective action at a point in time which prevents catastrophic field problems at a later data, (6) easily verifiable corrective action, and (7) low cost. IAA

Review: The reliability management technique described in this paper appears to have worked effectively. The ideas could probably be adapted for use on other programs. Methods of this kind have a largely ad hoc basis, and the degree to which they are good can be judged only in terms of the actual results achieved with them. (The term "inherent reliability" used in this paper is not a very meaningful concept since it is not defined meaningfully. A designation such as "reference reliability" would be more appropriate.)

R67-13297 ASQC 810

ENGINEERS TO MANAGEMENT: RELIABILITY ENGINEERING.

C. D. Nash, Jr. (Rhode Island University, Dept. of Mechanical Engineering, Kingston, R. I.).
Mechanical Engineering, vol. 89, May 1967, p. 21–23. 7 refs.

Reliability engineering, assurance, testing, and analysis are defined and the interdisciplinary nature of the field is shown. The need for management familiarization with reliability and a general training program for engineers who lack a formal background in this subject are discussed. Also covered are the organization of a reliability group, problems in the organization structure of a reliability group, methods for dealing with engineerings suffering from technological obsolescence, and the establishment of a review board to provide a forum for the exchange of ideas on reliability. R.N.A.

Review: This paper is essentially the same as the one covered by R67-13305.

R67-13298 ASQC 817; 873; 883

RELIABILITY AND MAINTAINABILITY TRADEOFFS.

Sidney Orbach (Applied Science Laboratory, Brooklyn, N. Y.).
In: Proceedings of the NMSE Systems Performance Effectiveness Conference, Washington, D. C., Apr. 27–28, 1965. Conference sponsored by Naval Material Support Establishment. Brooklyn, N. Y., Naval Applied Science Laboratory, 1965, p. 117–126. 2 refs.

A reliability–maintainability tradeoff procedure is described which was developed as a tool for generating optimal system designs. The tradeoff procedure was applied to the AN/SQS-26 sonar to test its general feasibility, to make improvements and refinements, to provide useful tradeoff information, and to recommend further refinements. Results show that the tradeoff can be successfully applied to complex equipment such as the AN/SQS-26 sonar and that specific reliability and maintability design improvements can be obtained. Additional refinements were required before the tradeoff could be used efficiently. Additional mathematical sophistication can be used to simplify the procedure. The tradeoff was especially sensitive to the number of units to be built, the number of years the system will be in service, and the expected number of operating years. Using the reliability–maintainability tradeoff in conjunction with elaborate reliability and maintainability improvement programs considerably reduces the cost of conducting the tradeoff. R.N.A.

Review: The original tradeoff procedure referred to here was described in the paper covered by R64-11292. In the present work the procedure is described briefly, and some results of its application to a complex piece of equipment are given. Modifications of the original procedure to meet specific requirements are indicated. It is concluded that the procedure can perform effectively in conjunction with elaborate reliability and maintainability improvement programs. Some suggestions are given for future work towards making it a more efficient design tool. This paper will serve a useful purpose for those who want a not-too-detailed picture of the procedure and its possibilities. Those desiring more information will find it in the two reports cited by the author.

R67-13299 ASQC 817; 833; 870

DESIGN CRITERIA FOR THROW AWAY VERSUS REPAIR MAINTENANCE.

A. E. Rupp, Jr. (Vitro Corp., Silver Spring, Md.).
In: Proceedings of the NMSE Systems Performance Effectiveness Conference, Washington, D. C., Apr. 27–28, 1965. Conference sponsored by Naval Material Support Establishment. Brooklyn, N. Y.; Naval Applied Science Laboratory, 1965, p. 127–135.

A theoretical study was conducted to establish economic criteria on which to base a decision concerning whether to use throw away or repair maintenance for module packaged electronic equipment. The highlights of this study are presented along with the rigorous and simplified formulas that were developed and their application. The analysis provides an economic model from which the total cost of an electronic assembly can be calculated. A convention was adopted by which the cost terms can be expressed and easily manipulated. Definitions of these terms, the sources from which the values of the terms can be obtained, and a breakdown of the primary and secondary costs that contribute to the total cost of an assembly are given. Four decision rules were found which may be used to decide whether to use throw away or repair maintenance and are as follows: (1) the decision to repair or throw away is independent of population and expected number of failures; (2) in-service modules costing less than $120 may be economically thrown away; (3) module designs with parts costing less than $35 may be thrown away; and (4) module designs with parts costing more than $800 can not be economically thrown away. R.N.A.

Review: Reliability considerations cannot generally be divorced from those of economics. This paper is concerned with economic criteria pertinent to the two types of maintenance: throw-away and repair. The decision criteria are of direct importance to design engineers, while a less detailed acquaintance with the approach may be useful to those concerned with other indexes such as reliability. The paper will be most useful to the latter, as it is a brief presentation of the highlights of a longer report. The report itself should be consulted by those wishing to implement the procedures.

R67-13305 ASQC 810

DEVELOPING MANAGEMENT ACCEPTANCE OF RELIABILITY ENGINEERING.

C. D. Nash, Jr. (Rhode Island University, Dept. of Mechanical Engineering, Kingston, R. I.).
American Society of Mechanical Engineers, Winter Annual Meeting and Energy Systems Exposition, New York, N. Y., Nov. 27–Dec. 1, 1966, Paper 66-WA/MGT. 4 p.
(AMSE PAPER-66-WA/MGT-4) Members, $0.75; Nonmembers, $1.50.

The relationship of reliability engineering with other engineering and scientific areas is explored. Different kinds of training programs needed for management, general engineers, and specialists are reviewed from the standpoint of minimizing related costs without reducing effectiveness. The organization of a reliability group is studied together with the problems of integrating such a group into a research and development organization. Since reliability groups cannot operate successfully in a communications vacuum, the establishment of an interdisciplinary company-wide panel on reliability is recommended as one method of keeping open the channels of communication. Certain related sociological problems, such as resistance to change, technological obsolescence, and position insecurity, are discussed and solutions proposed. Author

Review: The author has some positive ideas on management, organization, and training as they pertain to the reliability function. He has expressed them clearly and concisely, citing references for a number of his points. These are topics on which ideas differ among many in the field—without anyone necessarily being categorically right or wrong. An idea which works well in one organization might not do so in another. With this point of view in mind, managers concerned with reliability will find the paper worth reading for possible ideas.

R67-13307 ASQC 810; 832

SPACE VEHICLE VERSUS GROUND SYSTEMS RELIABILITY.

James H. Rusk, Jr. (General Dynamics Corp., General Dynamics/Convair, San Diego, Calif.).
Society of Automotive Engineers, Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, Calif., Oct. 3–7, 1966, Paper 66–691. 5 p.
(SAE PAPER-660691; A67-15790) Members, $0.75; Nonmembers, $1.00.

Comparison of factors which determine space mission reliability requirements for space and ground systems and the characteristic problems involved in meeting them. It is shown why the required reliability should be achieved on ground systems at a lower cost than on space systems. IAA

Review: Despite the broader implications of its title, this paper is directed toward a very small audience—the managers of space launch sites. At least they would seem to be the only ones to make direct use of the ideas presented. The concern is mainly with human factors considerations in building an effective launch team. The author's suggestions are reasonable, but hardly outstanding, as any alert manager should be able to think of them for himself.

R67-13311 ASQC 813; 844

SEMICONDUCTOR RELIABILITY PROGRAM DESIGN.

B. L. Bair, A. Poe, and J. F. Schenck (General Electric Company, Syracuse, N. Y.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 612–624. 3 refs.

Available from IEEE, New York: $8.00.

Elements involved in a statistically sound physics of failure reliability program are developed for a high reliability silicon signal diode. Device knowledge is outlined; failure modes and mechanisms are presented; and screening, control lot, step–stress, and stress-in-time test results are reported. Techniques are covered for correlating the data to develop stress acceleration factors required by design engineers; and possible uses of some degradation models as well as advantages of standardized life tests are discussed. While the steps involved in the complex reliability program described in this paper were costly in terms of both time and money, the results obtained enable the prediction of stress response for a wide range of device ratings. It is possible to determine a good estimate of expected failure rate at several operating conditions by extrapolation, without the necessity of a specific set of tests for each different device specification. M.W.R.

Review: This is a good report on the design of a comprehensive reliability program. The point is well made that, even for the relatively simple case of a signal diode, the expense is large. Much attention is paid to what was or can be done, but few details and fewer actual results are given. The complexity of the program may necessitate this generality. This paper is good reading for the physics-of-failure and device-reliability specialist but it will be somewhat tedious for others.

R67-13317 ASQC 817; 814

MAKING TRADEOFFS FOR RELIABILITY, VALUE AND PROFIT.

Robert L. Crouse (Honeywell Inc., Minneapolis, Minn.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 675–682. 1 ref.

Available from IEEE, New York: $8.00.

The working relationship between value engineering and reliability are explained from an overall management viewpoint, and programming activities are discussed that achieve a balanced picture of the reliability, cost, and performance of systems, subsystems, and components. Steps required to make such necessary trade-off decisions are outlined, and a tree-type output is summarized that isolates problems and measures their significance at various operational levels. This trade-off tree is considered a step in developing a presentation of adequate information, showing relevant experience and clearly drawing all variables into view with a minimum time elapsing for management to make judgments. The tree initiates a PERT or PERT-COST event chart with a solid and evaluated base of functions and identification of items required; only the events themselves or the action sequences remain for the "PERTING" activity. M.W.R.

Review: A completely qualitative discussion of trade-offs in a broad sense is given in this paper. The material is largely "common sense" and is what is usually done. The trade-off tree, which is the main content of the paper, is a method of concisely presenting information about a trade-off study. This could be of mild interest to some.

R67-13319 ASQC 817; 814

A METHOD FOR RELIABILITY-COST TRADE-OFF ANALYSIS.

George G. Younger (Lockheed Missiles and Space Company, Sunnyvale, Calif.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 693–704. 5 refs.

Available from IEEE, New York: $8.00.

A mathematical model with a constant percentage increase in mean-time-to-failure (MTTF) is used to develop two general reliability-cost trade-off characteristics from space, ground, and missile systems program data. These characteristics relate reliability improvement to total program cost, as well as reliability program cost to achieve a given reliability. System design improvement, components improvement, and redundancy are the major improvement sources embodied by the model; and the average MTTF-cost trade-off characteristic provides a gross measure of predicted improvement costs for complex systems. Optimized reliability goals indicate large savings as compared to the use of non-optimum goals for a typical spacecraft system. Since results can be given in parametric form, the choice of optimum conditions is permitted for a wide range of variables. Details of the MTTF-cost characteristic determination are included for the three types of systems. M.W.R.

Review: Of main interest here is that the author presents relationships between reliability and cost for some major subsystems of a space system. Apparently the data which he has go along with the assumed exponential form of the relationship. Others than the author have also suggested this form, and some of these are referenced in the paper. The Lagrange multiplier approach is the basis of the method which is proposed for obtaining optimum subsystem reliabilities. No background is given on the Lagrange multiplier, but this can be found readily in many calculus or operations research books. The Lagrange multiplier approach leads to a simple method for finding the optimum values of subsystem reliability when system reliability is the product of subsystem reliabilities and when the subsystem reliability-cost is readily differentiable. The method is well suited for a graphical approach with impetus from the fact that more accurate approaches are often not warranted because subsystem reliability-cost relationships are usually based on such meager information. The method used by the author is to have as an input a graph for each subsystem on semi-log paper of the relationship between the product of failure rate and time as a function of cost, where the function is negative exponential, or $\lambda_i t = B_i \exp[-A_i \Delta C_i]$. The optimization procedure in this paper involves reading

B_i on the graph and calculating A_i for each subsystem, assuming ΔC_i for one of the subsystems, calculating a slope, then calculating the ΔC_i for each subsystem from another relation involving this slope. The procedure is repeated until a range of system costs is obtained from which the desired value is selected. The procedure could have been simplified and the ΔC_i for each subsystem read directly by either plotting the functions noted above on linear paper and reading the optimum ΔC_i at the same slopes which can be read graphically, or by plotting the derivative of the function noted above on semilog or linear paper for each subsystem and directly reading the ΔC_i for each subsystem. Note further that such curves can be reused for other serial systems and that for the negative exponential form proposed by the author the derivative is a straight line on semi-log paper and therefore easy to plot. See the paper covered by R64-11480 for some discussion on the first method. These methods involve less work than the procedure in this paper and do not just compound the error inherent in reading graphs. The idea is to construct the input graph such that results can be read directly from it with no further calculation. In Table 1 the results are summarized for an optimum subsystem design for a mission of 9 months and again for a mission of 1 year. The optimum subsystem design is identical for both missions, and all the table really shows are inherent inaccuracies when reading graphs and using the sliderule plus the different reliabilities which come about from plugging 9 months or 1 year into the same equation. The author has some brief discussion of this on page 697, where he says the fact that the optimum system design applies for all t is revealed by the optimum values of subsystem cost being the same for both mission times and by a study of graphical results. This conclusion is also revealed directly and without being susceptible to the inaccuracies of reading graphs and to the unnecessary work of developing tables for different values of t by observing in the equation shown above that t proportionately affects all subsystems and any changes in t will not affect the relative relationships of the derivatives. In summary, the author is calling attention to a potentially useful approach. The paper is timely. Those interested in details of cost trade-off analysis will want to be familiar with this approach.

R67-13320 ASQC 817; 814

COST VERSUS RELIABILITY TRADEOFF.

L. T. Benware (International Business Machines, Electronics Systems Center, Owego, N. Y.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 705–710. 3 refs.

Available from IEEE, New York: $8.00.

Determining a cost-reliability trade-off requires not only a simple ranking of the slope $\Delta MTBF/\Delta C$, but also the cost increment used in computing each of the slopes. Widely varying costs may be associated with equal or nearly equal slopes, and what appears to be an optimum trade-off condition may well be associated with an unnecessarily high cost. An illustration is included of a condition in which the slope is less than optimum, but electronic equipment requirements are exceeded with great savings nonetheless. Data are included for integrated circuits, semiconductors, resistors, and other part types; and cost and MTBF data are tabulated for all combinations of reliability screens. M.W.R.

Review: The key point of this paper is valid and worth noting: Do not blindly follow a particular optimization procedure. Such a "blind following" leading to one decision when another decision is actually preferable is apt to be done by someone just following some rules but not understanding where the rules came from, or by using the decision made by automatic computation without doing some probing around. In a sense the approach of blindly following the procedure and making the wrong decision means that the procedure is incompletely stated. In the introductory discussion the author touches on redundancy. When he brings in an equation for overall system reliability he uses the familiar exponential form, and then goes on to speak of optimization in terms of system MTBF versus system cost. A contradiction is implied here as it is unlikely that the use of any kind of redundancy would result in a system reliability equation of exponential form. When the system reliability equation is nonexponential, the approach the author has in mind and the caution he raises are still valid, but optimization here would be in terms of system reliability and not in terms of system MTBF. The reliability improvements which the author cites are achieved only by screening parts. There are, of course, other possible ways to reliability improvement, such as screening at module or equipment levels or by various fabrication approaches. Any of these other approaches as well as redundancy are candidates suitable to the reliability-cost trade-off approach and the cautions which are covered in this paper.

R67-13324 ASQC 810; 814; 833

A SECOND GENERATION OF RELIABILITY FOR SERGEANT.

Richard H. Brashear, Jr. (Sperry Utah Company, Salt Lake City, Utah).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 773–782. 10 refs.

Available from IEEE, New York: $8.00.

Interface among reliability, cost, and performance resulting from the application of microelectronics is discussed for the Sergeant artillery guided missile ground electronics. Aspects of packaging design, selection of integrated circuit logic, standardization of components and assemblies, assembly process selection, equipment performance, and maintenance and repair philosophy are considered. Parameters used for a trade-off study of the basic integrated circuit types available in 1965 are tabulated; and from these, a digital logic was selected for use in second generation Sergeant ground support equipment. The standardization program for Phase II ground support equipment is concluded to result in a superior design, shorter development/production cycle, increased reliability, and cost savings. While the application of integrated circuitry can increase equipment reliability and reduce hardware/maintenance cost, it can at the same time introduce difficulties that may negate this potential reliability gain. More reliability data based on actual use is required before meaningful IC failure rates can be determined. M.W.R.

Review: A case history report on the Sergeant missile, with emphasis on changes in ground support equipment, is given this paper. It is mainly for those with specific interest in the Sergeant missile; there is little here of general concern. The impression is given of the usual type of electronic hardware-producing environment, where the actions which really affect hardware operational reliability would have been the same either with or without the "reliability engineers."

R67-13327 ASQC 810

ESTIMATING RELIABILITY FOR FUTURE SPACE SYSTEMS.

Eugene Rygwalski (General Electric Company, Radnor, Pa.). *In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 816–823.
Available from IEEE, New York: $8.00.

The establishment of quantitative complexity factors is recommended for more accurate identification of space system effectiveness tradeoff parameters. These factors can be used to extrapolate data from past experiences in space, and to thereby estimate reliability of future space systems. Typical effects on a pilot were analyzed for certain failures that might occur in space. Data from past space flights indicated the following subsystems as experiencing the greatest failure rates: (1) recovery, 28%; (2) camera, 22%; (3) booster, 21%; (4) guidance and control, 14%; and (5) telemetry, tracking, and command, 12.5%. As compared to an *n*-times redundant system, the pilot was found to contribute most to guidance and control; tracking, telemetry, and command; communications; separation; and power. There is very little change in booster efficiency due to the pilot. The rate of increase in reliability per pound of added weight per subsystem is greater in a manned system with maintainability than in an unmanned system with redundancy. M.W.R.

Review: A reaction to this paper is wonderment that such a study has not been attempted previously. Trying to develop some reliability conclusions from a concerted analysis of real-world flight experience on space systems seems quite worthwhile because of the typical lack of opportunity for significant operational flight tests and because of the typically small number of systems. The conclusions will be of interest to those concerned with spacecraft. This is not to say that others studying the same data would not have arrived at different conclusions. It is suspected that the resources open to the author, who is with a contractor, would be somewhat limited. A government agency such as NASA would probably be able to conduct such a study fully in the sense of applying needed manpower and of "opening doors" to get full information. For the benefit of those who may not see the paper, the conclusions generally support a manned system over emphasis on redundancy in an unmanned system.

R67-13330 ASQC 817; 612; 831; 838

AUTOMATED RELIABILITY TRADE-OFF PROGRAM—ARTOP II.

Van B. Parr (Collins Radio Co., Reliability Div., Dallas, Tex.). *In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings.* Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 847–857. 8 refs.
Available from IEEE, New York: $8.00.

A modified topological approach to reliability modeling, which greatly simplifies input data preparation, is incorporated in the Automated Reliability Trade-off Program (ARTOP II). The system reliability flow diagram is structured into a series of blocks, each of which is describable by one of the general equations in the Function Generator Source File (FGSF) of the program; and this file is open-ended so that more general equations can be added to accommodate more block models. A reliability tradeoff curve versus cost or weight is generated by ARTOP II; and a sample problem and a printout are included for a hypothetical system run against a reliability goal of .95. Assumptions for block configuration models are discussed, and the FGSF general equations are described. Derivation is given of the algorithm for the iterative technique which will yield the greatest increase in system reliability per unit increase in system weight when redundancy is added. The computer program and some typical uses are described. M.W.R.

Review: Pursual of the cost-effectiveness approach is leading to the development of more computerized trade-off techniques specifically aimed at reliability and at other "...abilities." The reliability trade-off program described in this paper is for general redundancy optimization. A nice feature is that an input is the reliability logic diagram rather than the reliability equation. The usual assumptions, e.g. independence and exponential distribution, are made and are cited. An example is given, which is desirable as this facilitates understanding. Another redundancy optimization computer program with some different features is described in the paper covered by R66-12815. The approach in this paper is to add redundant items one at a time until the desired system reliability or penalty is met. The criterion for selecting which item to make redundant is to add the item which will yield the highest increase in system reliability per unit of penalty increase. For items in straightforward series-parallel this will be the parallel items which have the largest ratio of the percentage increase of the reliability of the parallel items over the penalty of the added item. Each ratio is retained and used until an item is actually selected, when the ratio is recomputed. The interesting feature of the program in this paper is that it accommodates other than straightforward series-parallel redundancy. That is, the starting system may already contain some redundancy other than a straightforward series-parallel arrangement, which the author calls a complex network. Any item in the complex network could be a candidate for additional redundancy. Observe that when an item in the complex network is made redundant, the item to add is the one with the largest ratio of percentage increase in the reliability of the entire complex network over the penalty for the added item. Further, when an item in the complex network is added, then the ratios must be again computed for all items in the complex network. These points concerning the complex network items are not clearly made in the paper although nothing is said to contradict them; someone who is initially considering the use of this approach could easily be confused. The penalty of weight is the main concern, but the paper notes that the program could be used for cost instead of weight. Dynamic programming with Lagrange multipliers can be used in this type of problem for simultaneously considering more than one penalty.

R67-13331 ASQC 810; 811

MANAGEMENT AND ORGANIZATION OF SPACE-AGE RELIABILITY PROGRAMS.

J. Kimmel (RCA, Astro-Electronics Division, Princeton, N. J.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 858–864. 1 ref.
Available from IEEE, New York: $8.00.

Management and organizational structure are described for a reliability program dealing with space-age project; and a typical spacecraft reliability program is detailed that is based upon a three-pronged control program, namely control of the design, the fabrication and assembly, and the purchasing processes. Essential tasks for this reliability program are: (1) requirements study and analysis; (2) reliability prediction and allocation; (3) trade-off studies, (4) stress analysis; (5) worst-case and degradational analysis; (6) failure mode, effects, and criticality analysis; (7) design review; (8) failure reporting and correction; (9) parts and materials selection, application, and control; and (10) vendor control. Effectiveness of this reliability approach is demonstrated by a tabulation of the reliability growth of the TIROS (ESSA) weather observation satellites, as well as a summary of total part failure rate during orbit. M.W.R.

Review: The management and organizational structure of a company prominently engaged in space programs is presented. The essential tasks in a typical reliability program are described, and details on their implementation are given. This is a mature program, the effectiveness of which has been demonstrated on the successful TIROS (ESSA) weather observation satellites. Thus the paper will be of interest to managers of other reliability programs and to those who are planning such programs.

R67-13333 ASQC 810; 770; 844
General Electric Co., Daytona Beach, Fla. Apollo Support Dept.

SCREENING—A TECHNIQUE FOR RELIABILITY IMPROVEMENT

Frank A. Applegate [1965] 31 p refs Presented at Tri-Service Reliability Symp., Schenectady, N. Y. 9–10 Feb., 1965
(N67-83876)

To improve reliability programs in the aerospace industry, a screening technique is recommended in preference to the simple Hi-Rel (high reliability) parts approach. With this in mind, the sources of unreliability in components, design, assembly or manufacture, and operation are discussed; and costs are related to reliability improvement programs. Screening for electrical and mechanical discrepancies is detailed, and it is shown how such screening can be applied to the three sources of unreliability: parts, design, and assembly. This type of parameter screening permits a quantitative evaluation of the potential reliability improvement. For electrical systems, illustrations are offered for screening of parameter drift (burn-in), discriminant analysis, semiconductor junction, RF noise, and infrared. Mechanical defects screening techniques described include environmental exposure, X-ray means, infrared and RF noise, mechanical signature, penetrating liquid. M.W.R.

Review: This is apparently a transcription of a talk and thus is unlike a paper designed to be read. The author has used terminology somewhat different from that now used—all the various kinds of screening he suggests we would now call "parts screening for reliability," whereas, for example, he classifies those designed to reduce part tolerance deviations as design screening. He has two other categories—manufacturing and operation screening. Screening is an important technique for obtaining parts which are within proper tolerances to begin with, and which are likely to remain so. This is a qualitative paper (as befits a talk), easy to read, and will be most suitable for those who wish an introduction to the subject. Similar articles have appeared from time to time in both the professional and trade magazines.

R67-13338 ASQC 810; 770

TESTING TECHNIQUES FOR AIRCRAFT RELIABILITY.

John C. Dussault (Cessna Aircraft Co., Wichita, Kan.).
In: Society of Automotive Engineers, Business Aircraft Conference, Wichita, Kan., May 6–8, Proceedings. New York, Society of Automotive Engineers, 1965, p. 26–33.
(A65-25499)

Review of the history of light aircraft development and the need for reliability which was created by this history. Testing techniques are presented which show an application of basic mechanical principles which are applied in a unique manner to assist in the search for a reliable product. The techniques used and the span of time covered are considered to indicate that this portion of the industry has now achieved the stature required for producing a reliable product for customers of widely varied experience levels. Author (IAA)

Review: This article serves its purpose well. It discusses field experience, accelerated service tests, and accelerated laboratory tests that are performed on the entire aircraft and its parts in order to provide a higher probability of longer life. Each of several tests is given a brief description. The paper will be useful mainly for those who wish to get a qualitative idea of what is going on and an introduction to the subject. It will have little value as a permanent reference.

R67-13339 ASQC 810; 813; 833; 836; 864

BEECH AIRCRAFT RELIABILITY PROGRAM.

William H. Chestnut and C. E. Miller (Beech Aircraft Corp., Wichita, Kan.).
In: Society of Automotive Engineers, Business Aircraft Conference, Wichita, Kan., May 6–8, 1965, Proceedings. New York, Society of Automotive Engineers, 1965, p. 34–39
(A65-25500)

Discussion of a typical reliability-program plan, with requirements similar to existing military reliability programs, which is now required by each of the Beechcraft family of aircraft. Emphasis is placed on design considerations, testing, design reviews, data feedback, vendor data, and management. Examples of recent reliability activities are presented. Implementation methods including reliability training programs for both management and design personnel are also reviewed. Although results of the programs are still incomplete, judging from complaints received, it is thought that a general trend of customer satisfaction can be seen. IAA

Review: The program appears to be reasonably complete and adequate. The description is brief but understandable. Those who are not familiar with reliability programs in the light aircraft industry, or any industry for that matter, and wish a brief introduction with examples will find this paper of help. It will have little value as a permanent reference.

R67-13340 ASQC 810
GULFSTREAM RELIABILITY.
H. J. Schonenberg (Grumman Aircraft Engineering Corp., Bethpage, N. Y.).
In: Society of Automotive Engineers, Business Aircraft Conference, Wichita, Kan., May 6–8, 1965, Proceedings. New York, Society of Automotive Engineers, 1965, p. 40–44. (A65-25501)

Development of reliability (defined as readiness to go when needed) in the Grumman Gulfstream through design, support, and product improvement. Wherever possible, redundant and multielement structures have been inserted. Systems design is conservative throughout unless new systems or equipment shows significant improvement. The Grumman support program includes training for flight and ground personnel, maintenance systems, material, and technical support. The aircraft is constantly being improved as a result of evaluation of reliability data, failure reports, and records of exchange, rental, and spare procurement. IAA

Review: This paper gives a general over-all description of how the company provides a reliable aircraft. It is suitable for managers and others who want the broad picture rather than details. While it has value for that purpose, it has none as a permanent reference.

R67-13344 ASQC 815; 830
SPECIFICATION AND DESIGN OF ESTABLISHED RELIABILITY POWER RELAYS.
John A. Quaal and James E. Davies (Cutler-Hammer, Inc., Milwaukee, Wis.).
(1965 Aerospace Technical Conference and Exhibit, Houston, Tex., June 21–24, 1965, Paper). IEEE Transactions on Aerospace, vol. AS-3, June 1965, Supplement, p. 598–602. (A65-31141)

Description of work on established reliability for power relays by the National Association of Relay Manufacturers and a committee (appointed by the Air Force) working cooperatively with SAE Subcommittee A-2R. A practical means of specifying established reliability for power relays using MIL-R-6106 as a basic specification is proposed. Life cycles from qualification, acceptance, and requalification tests are combined to establish a reliability of 1% per 10,000 cycles. Principles and procedures for the design and manufacture of established reliability power relays are also discussed. Author (IAA)

Review: Essentially two short, well expressed papers are contained here; each is on a separate aspect of power relay reliability and there is no smooth continuity from one aspect to the other. The power relay has traditionally been an inherently reliable part which is conservatively applied, and on this basis it has thus far escaped high-reliability specification coverage. However, its turn has come, and the first part of this paper discusses the throes of marrying the high reliability specification to the power relay. As no surprise, the cost associated with testing tends to be the dominating factor. The second aspect of this paper is a handbook-type discussion of designing high reliability into power relays. Overall, the subject is rather specialized to be of general interest, but the discussion probably contains nothing new for those who have been working with power relays. Thus it is the sort of paper most useful to someone with a new-found interest, such as a circuit designer who is for the first time using power relays in a high-reliability application.

82 MATHEMATICAL THEORY OF RELIABILITY

R67-13291 ASQC 824; 831; 844
DEVELOPMENT EFFORT TO ACHIEVE RELIABILITY.
G. M. Clark and K. B. Haigler (North American Aviation, Inc., Rocketdyne Div., Canoga Park, Calif.).
In: Active Reliability; Annual West Coast Reliability Symposium, 6th, University of California, Los Angeles, Calif., February 20, 1965. Symposium sponsored by the Reliability Div. of the Los Angeles Section, American Society for Quality Control, and the College of Engineering and University Extension, University of California. North Hollywood, Western Periodicals Co., 1965, p. 95–116. (A65-26057)

Reliability prediction considered as a dynamic concept, constantly altered by development effort. Since achieving reliability consumes the greater part of engine development expense, the concept selection phase will be actively concerned with reliability as a design and program parameter. It is considered that an advance planning effort should not only select an inherently reliable design concept, but also one that is capable of being efficiently developed. Appropriate provisions for allocating development effort to assure efficient reliability growth must be incorporated in the development plans. Because these characteristics adversely affect engine weight, performance, and development cost, it is believed that a qualitative evaluation does not adequately support sound decisions. IAA

Review: This is essentially the same paper as that covered by R66-12824.

R67-13292 ASQC 824; 412
RELIABILITY PREDICTION—WHAT CONFIDENCE?
Arnold A. Rothstein and Eugene R. Carrubba (Avco Corp., Research and Advanced Development Div., Wilmington, Mass.).
In: Active Reliability; Annual West Coast Reliability Symposium, 6th, University of California, Los Angeles, Calif., February 20, 1965. Symposium sponsored by the Reliability Div. of the Los Angeles Section, American Society for Quality Control, and the College of Engineering and University Extension, University of California. North Hollywood, Western Periodicals Co., 1965, p. 117–131. (A65-26058)

Summary of four techniques which were explored to introduce a confidence aspect into system prediction. The techniques are (1) nth-root confidence level, (2) failure-time ranking, (3) failure-time proportion, and (4) confidence-level conversion. Each of the alternative prediction methods is described, including the assumptions used. The studies show the differences resulting from each method. The techniques are considered to be heuristic rather than rigorous. Use of one or more of them makes it possible to discriminate better between system failure rate estimates at common confidence levels and to examine the degree of sensitivity of system failure rate estimates evaluated at varying confidence levels. IAA

Review: The problem of confidence interval estimation of system reliability based on component data has not been properly solved. This paper calls attention to the need for mathematical/statistical work in this area. The authors suggest some approaches which have intuitive appeal, but are not based on rigorous statistics. Without some mathematical/statistical research on them, one cannot be sure that any of these has a truly valid basis. In fact it is quite possible that some technique other than those suggested might have desirable properties. Pending proper investigation, it would be best to regard *all* of the authors' proposed techniques as questionable from a mathematical point of view. Thus the principal contribution of the paper lies in calling attention to the need for research in this area. (Two minor difficulties in the text are the following on p. 121. (1) "Assuming the confidence levels to be independent events,..." Confidence levels are not events at all, independent or otherwise. (2) "...best estimate (50 per cent confidence level) failure rates..." Unless the best estimate is the median failure rate the implication in this statement is not necessarily correct.)

R67-13293 ASQC 824

ESTIMATING CYCLICAL LIFE FOR EQUIPMENT EXPERIENCING ONLY WEAROUT FAILURES.

J. E. Comer (Gulton Industries, Inc., Engineered Magnetics Div., Hawthorne, Calif.).

In: Active Reliability; Annual West Coast Reliability Symposium, 6th, University of California, Los Angeles, Calif., February 20, 1965. Symposium sponsored by the Reliability Div. of the Los Angeles Section, American Society for Quality Control, and the College of Engineering and University Extension, University of California. North Hollywood, Western Periodicals Co., 1965, p. 133–146.

(A65-26059)

Calculation of an approximate lifetime requirement to serve as a guide for arranging a program of reliability testing for any individual part failing primarily by wearout. It is assumed on the basis of experience that the distribution of the failure rate about the wearout point is Gaussian, and that the effect of random failures is negligible. Formulas are developed which make it possible to calculate minimum average lifetimes. IAA

Review: This is essentially the same paper as that covered by R65-12340. As indicated in that review, it is a grossly inadequate treatment of the subject.

R67-13300 ASQC 824

Wisconsin Univ., Madison. Mathematics Research Center.

GROUP THEORETIC TECHNIQUES FOR THE SIMILARITY SOLUTION OF SYSTEMS OF PARTIAL DIFFERENTIAL EQUATIONS WITH AUXILIARY CONDITIONS

R. A. Gaggioli and M. S. Moran Aug. 1966 94 p refs

(Contract DA-11-022-ORD-2059)

(MRC-TSR-693; AD-648194; N67-254081) CFSTI: HC $3.00/MF $0.65

A systematic formalism is presented for reducing the number of independent variables in some systems of partial differential equations with boundary and initial conditions. The procedure is a further modification of the one-parameter group methods (Birkhoff, Morgan). Basically, two techniques are presented which yield an orderly attack of practical problems: (1) Boundary and initial conditions are taken into account explicitly when establishing a suitable transformation group. (II) The invariants of a transformation group are determined via group theory. Viscous flow and heat transfer problems serve as illustrations. Author (TAB)

Review: Although this report is directed toward important problems in reliability, e.g., the two-sample life-testing problem, tests for exponential models, etc., the discussion is quite theoretical and the reader will need a substantial background in this area of statistics for complete comprehension of the material. The practical implications of the paper are the following: Whenever one is trying to decide which one of two devices (or systems) has the longest mean life in the two-sample life-testing problem, one should use the Savage *statistic because it guards best against having a large probability of making a type II error for a wide class of distributions* (IFRA distributions). Modified Savage statistics can be used for censored samples, k-samples and estimation.

R67-13301 ASQC 822; 424

California Univ., Berkeley. Operations Research Center.

RELIABILITY APPLICATIONS OF A BIVARIATE EXPONENTIAL DISTRIBUTION

Robert Harris Dec. 1966 21 p refs

(Contract Nonr-3656(18))

(ORC-66-36; AD-645138; N67-23114) CSFTI: HC $3.00/MF $0.65

The paper examines some two-unit systems in which the lifetimes of the two units in service are not independent but depend upon one another in a particular way. This dependence is characterized by the bivariate exponential distribution of Marshall and Olkin (AD-634 335), which has exponential marginal distributions and other physically motivating properties. Two measures of reliability are determined: the first is the *distribution* and *mean of the time to system failure* (i.e., when all units are failed) and the second gives steady-state probabilities of the number of working units. Some graphical results are given to illustrate the deviation of these quantities from the values obtained under the classical assumption of independent lifetimes. Author (TAB)

Review: A very pleasing application of the bivariate exponential distribution of Marshall and Olkin (see R67-13096) is given in this report. It is clear in practice that the assumption of items failing independently is often untenable. The report represents a solid step toward the analysis of certain types of dependent failures.

R67-13302 ASQC 824; 424

Purdue Univ., Lafayette, Ind. Dept. of Statistics.

SOME ASPECTS OF SELECTION AND RANKING PROCEDURES WITH APPLICATIONS

Shanti S. Gupta and William J. Studden Jul. 1966 17 p refs *Its* Mimeograph Series No. 81

(Contract Nonr-1100(26); AF 33(657)-11737)

(AD-639619; N67-13916) CFSTI: HC $3.00/MF $0.65

The purpose of the paper is to discuss the problems of ranking and selection in a more or less unified form and suggest some applications to problems in reliability. More specifically, the authors discuss the problem of selecting a sub-set of k populations or processes which in some sense is a best subset. TAB

Review: This report presents a nice discussion of certain aspects of selection and ranking procedures. The material is presented quite clearly and in an interesting way. Several good properties of the procedures are derived and specific examples of applications to multivariate normal populations and to reliability problems when the underlying lifetime distribution is negative exponential are given.

R67-13303 ASQC 824
Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.

SOME STATISTICAL ASPECTS OF THE DETERMINATION OF A SAFE LIFE FROM FATIGUE DATA

Sam C. Saunders Apr. 1966 26 p refs *Its* Mathematical Note No. 455
(D1-82-0515; AD-634980; N66-35058) CFSTI: HC $3.00/MF$0.65

The probability that within a future large second sample no failures will occur before the expiration of a safe service life estimated from a small first sample and the probability that the proportion of all future observations failing before the estimated safe service life is smaller than a given proportion, are the two measures of safety that we adopt here. Assuming the logarithm of the fatigue life is normal with known variance, we derive formulae for these measures of safety. Setting the safe life as some fraction of the mean estimated by the first sample, we then compare the influence of other parameters on these measures of safety. From this assumption it is shown that one has virtually as high an assurance of safety, measured by the first criterion, when using only the minimum of the first sample, as one does by using all the observations in the first sample. If one uses the standard second criterion, namely, the confidence level of a lower tolerance bound, as a measure such an advantage is not retained. Author (TAB)

Review: This report presents some straightforward calculations for the very special case when the logarithm of the fatigue life is normally distributed with known variance. A question which may occur to some readers is: why was the derated life chosen as a fraction of an estimate of the mean life? The author in a private communication has pointed out that this was simply because some military specifications for fatigue life qualification presently call for it to be in this form.

R67-13306 ASQC 824; 837

THE TRUE DESIGN STRENGTH OF MATERIALS AND JOINTS.

Frank C. Smith (LTV Aerospace Corp., Michigan Div., Warren, Mich.).
Machine Design, vol. 38, Dec. 8, 1966, p. 181–189.
(A67-14705)

A method for calculating a statistically valid design strength of a material, weld joint, or other part is given. The method, which is general and can be applied to any material or structural component, consists of three steps: (1) a desired reliability level is selected for the strength of the material or part, (2) a number of specimens of the part are fabricated and tested, and (3) the data are analyzed and the value of strength giving the desired reliability level is calculated. This value is then used to calculate the usual factor of safety or to estimate the structural reliability of a part in service under various operational loads. The method is used successfully to establish and control design strength levels of fusion welds used in missile propellant tanks which operate at pressures in excess of 1000 psi with an ultimate safety factor of only 1.33. M.M.

Review: The application of elementary statistical methods to a practical design engineering problem is described in this paper. The author's evaluation of the technique indicates that it is simple to use, has been used, and gives useful engineering results. However, perhaps as a result of over-simplification, the description could be misleading on the relationship between statistics and engineering. It is true, of course, that other papers in the engineering literature have had this problem. It is also true that the resulting difficulties do not always cause practical trouble, but some of them may do so. Some examples of these difficulties in the paper are the following. (1) The concept of confidence level is inaccurately presented. The confidence level is the fraction of occasions on which a given type of statement, asserted to be true, will in fact be true. If you test a sample and from it estimate the 99% lower tolerance limit at a 95% confidence, you would expect that the tolerance limit so stated would be correct on 95% of the occasions and incorrect on the other 5%. In the author's example, assume that you sample the weld strength from a particular population, that you make the appropriate calculations shown in the text, and you set the design strength at the 99% lower tolerance limit at a 95% confidence level. Further suppose that this number is 30 ksi. Suppose for the moment that the actual 99% point lies below the design strength, say at 20 ksi. It is easily seen, assuming a Gaussian distribution, that virtually all of a great number of samples taken will have their 99% points well below the design strength. A similar argument would apply to the case in which the true 99% point lies above 30 ksi, the samples then yielding values above the design strength. The question is not academic, for once the decision is made for a particular weld type on the basis of a sample, you have no way of knowing what fraction of the population actually does lie above your design strength. (2) The number of test specimens required to establish a statistically valid sample is not the subject of any controversy. The problem arises in formulating a measure of the engineering usefulness of a sample. (3) It is important to phrase the inferences from goodness-of-fit tests in such a way that they are not misleading as to the actual conclusion which they support. Suppose that the data are from a normal distribution having the mean and variance calculated from the sample. What then are the chances that the test statistic (the value of Chi-square in this example) would be as bad as it is for this sample? If these chances are very low, the engineer will generally feel that he is not that unlucky and will reject the hypothesis that the sample did come from that particular normal distribution. On the other hand, if the probability is rather high, the engineer must resort to prior information to make a decision. He may wish to say, for example, from my knowledge external to this sample, I believe the data will be normally distributed and unless I am forced to reject the hypothesis, I will accept it. Another way of expressing the attitude when the probability is large of having gotten a statistic that bad is, "The test was insufficiently sensitive to detect any difference from normality should it exist." In a practical engineering sense, the difficulty with statistical tests for normality is the following: If there are not much data, the discriminating power of the test is going to be very low. That is, the probability of getting a test statistic as large as yours is likely to be pretty high, but it is also likely to be pretty high for many other distributions which are quite different from the normal. On the other hand, if a great amount of data are taken, the test becomes very sensitive and very minor deviation (minor to the engineer, that is) from normality will cause the probability to be very low that a test statistic that large will be obtained if the data were truly a sample from the normal distribution. Of course the Chi-square test is not the only quantitative test of significance. Others are given in *Biometrika Tables for Statisticians, Volume I*, pp. 183–184. A graphical procedure may also be used as a quantitative test by approximate methods given in Hald (Reference 3 in the paper, pp. 138–139). (4) The section on rejecting suspicious data gives the conventional treatment including the usual cautions about carrying the methods too far. Where high reliability is important in a stress–strength situation, two modifications are in order: (a) In the strength data, generally the lower bound is the only consideration; that is, one wishes to estimate the lower 99% point for the strength. It is only the weak ones that are likely to fail. Therefore, it might be wise to put more emphasis on the lower values of strength and less on the higher values, since in this way the hypothesis of the specific distribution becomes less important. For example, if there were enough data, one could use nonparametric statistics completely. (b) Rejection of data should be based on engineering *reasons when possible. The author uses Chauvenet's* criterion. Other test criteria for the rejection of out-liers are given in Hald (Reference 3 in the paper, pp. 333–337). (5) The paper states, "Table 3 shows that the use of only 4 or 5 specimens requires that the difference between the sample mean and the design allowable strength be 6 to 7σ, which *probably results in an* unduly pessimistic value of design allowable strength." The numbers in Table 3 of the paper are worked out so that the resulting estimate of the tolerance limit is neither pessimistic nor optimistic, but right on the nose, according to the confidence desired. The main reason that the factor is so large for small samples is that it reflects the variation from sample to sample in both the mean and the standard deviation. From an economic standpoint there is a preferred sample size, somewhat larger than 4 or 5, for estimating the lower tolerance limit.

R67-13308 ASQC 824; 431; 838; 872

THE RELIABILITY OF MULTIPLEX SYSTEMS WITH REPAIR.

F. Downton (Birmingham University, England).

Journal of the Royal Statistical Society, Series B, vol. 28, 1966, p. 459–476. 18 refs.

Expressions are derived for the life-time distributions of systems consisting of a number of components in parallel, where repairs to these components are possible. These distributions reduce to those of first-passage times in a birth–death process or in a semi-Markov (or Markov renewal) process, and have application outside reliability theory. In the reliability context, the effects of altering the number of components and of increasing the repair facilities are compared, as are different repair distributions. Author

Review: The paper derives failure probabilities of some systems which fail only in case *m* or more among *n* independently functioning parts are in a state of failure and wherein, when a part fails, a mechanism exists for repairing it. The paper thus solves a problem more realistic than the no-repair problem which has previously been considered (see [1] and [2]). Rather than exploiting related results in birth–death processes, the author obtains relatively simple solutions to interesting special cases by using methods appropriate to these cases. The special case of Section 3 is, in fact, quite interesting since the linear failure rate $\lambda_i = (n-i)\lambda$ obtains when failures are generated by n–i independent Poisson processes each with parameter λ, for then $\Pr\{1$ failure in $(t,\ t+\delta t)\} = (n-i/1)(\lambda\delta t+(\delta t))(1-\lambda\delta t+o(\delta t))^{n-i-1} = (n-i)\lambda\,\delta t + o(\delta t)$ and $\Pr\{2$ or more failures in $(t,\ t + \delta t)\} = o\ (\delta t)$. The final paragraph of this section discusses relative ease of application of this method compared with the general method described in Section 2. Redundant systems which can be repaired are conceivably of great potential use for ensuring reliability of system performance. Examples where the approach has been of use are cited in Sections 1 and 6 of the paper.

References: [1] Springer, M. D. and Thompson, W. E., Bayesian confidence limits for reliability of cascaded exponential subsystems (1966) Abstract #26, p. 1420, *Ann. Math. Statist.* 37 [2] Briggs, N. H. and Yarnell, J. (1965) Multiple faults and confidence levels, Microelectronics and Reliability, 4, p. 235–40. (See R67-13013)

R67-13309 ASQC 822; 431

A NOTE ON THE WEIBULL RENEWAL PROCESS.

Z. A. Lomnicki (Boulton Paul Aircraft Ltd., Wolverhampton, England).

Biometrika, vol. 53, 1966, p. 375–381. 7 refs.

Power series expansions for the case of a Weibull Renewal Process are discussed, and it is proposed that an infinite series of Poissonian functions is a more suitable means for numerically evaluating such a process. Mathematics are included for both types of expansions and coefficients are tabulated for one selected value of the Weibull shape parameter for the infinite-series expansion. M.W.R.

Review: This mathematical paper numerically evaluates functions which describe the Weibull Renewal Process. An infinite series of Poissonian functions is proposed as being more suitable than the power series used previously. The mathematics is clear and competent; and appropriate references are cited to indicate the orientation of the work relative to other publications on the subject. Application of the Weibull failure rate in practice is discussed in sections 1 and 3 of [1], in which a Taylor series is given for the expected number of renewals before time t.

Reference: [1] Smith, W. L. and Leadbetter, M. R. (1963). On the Renewal Function for the Weibull Distribution. Technometrics 5, 393–6.

R67-13321 ASQC 824; 540

RELIABILITY MEASUREMENT BY REGRESSION ANALYSIS.

D. R. Jackson (Martin Co., Denver Div., Denver, Colo.) and D. R. Taylor (IBM Systems Manufacturing Div., Boulder, Colo.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 711–716. 4 refs.

Available from IEEE, New York: $8.00.

A method is presented for using reliability growth equation regression analysis techniques to estimate operational reliability of space systems as a function of test articles. The IBM 1620 computer program, which analyzes Titan flight data on the basis of an iteration (trial and error) process, is described; as are trade-offs resulting from variables in moving sample sizes, ultimate reliability asymptotes, and several growth equations. An evaluation of the effect of varying the ultimate reliability found that a minimum least squares sum resulted from an ultimate reliability value of 1.0. Reliability measurement by regression analysis can be initiated early in a test program and can be performed by sequential test phases. A three-dimensional plot of the *relative reliability estimates* resulting from different equations and moving sample sizes indicates that the best regression line results from a moving sample size of one and whichever equation gives the minimum sum of the squares regression curve. M.W.R.

*Review: This paper describes the application of regres*sion analysis to reliability growth as a function of article (or vehicle) number. The four growth functions considered are all nonlinear in the parameters (or unknown constants) to be estimated, and thus an iterative solution by a general least squares program is required. For example, a SHARE program SDA 3094 is available for this purpose and the Research Triangle Institute has a similar program, NOLLES, for nonlinear problems. The authors vary the parameters over a matrix of values and select those which result in a minimum value of the sum of squares of deviations. This procedure is not very efficient for locating the minimum in problems of this type. In addition, one should use the variance (residual sum of squares divided by the degrees of freedom) as a criterion of selection of the appropriate growth curve in preference to the residual sum of squares of deviations. However, in the examples treated in this paper the degrees of freedom for each of the functions was the same—the number of observations less two (the number of parameters being estimated); thus either criterion results in the same comparison of the models for this particular case. In the simple least squares analysis the usual implicit assumptions are that the observations are independent and have the same variance for all values of the independent variable(s). In the example in this paper the variances depend on n (the article number) and are given by $R_n(1-R_n)$, that of a binomial variable. (R_n is the reliability at the n th test.) Hence the variances are not homogeneous and the results will be biased, as equal weight is given to all the points. Either a transformation of the data or a weighting function must be used to avoid this difficulty. Some papers in the literature have made use of a stochastic model; this approach is to be recommended when possible. (See, for example, the papers covered by R63-10895 and R67-13060.)

R67-13332 ASQC 824; 425

Oklahoma Univ., Norman. Graduate Coll.

STRUCTURAL DESIGN CRITERIA BY STATISTICAL METHODS

James Eugene Hayes (Ph.D. Thesis) Ann Arbor, Mich., Univ. Microfilms, 1965 126 p refs

(Rept.-65-6185; N67-83875)

Statistical methods are used to establish a design criterion that can calculate an allowable design stress level for any desired structural reliability. Vertically rising boost vehicles were used in the study because it was considered desirable to select a vehicle for which loads were caused by a more or less random process, such as atmospheric winds. Normal, log normal, double exponential, and Weibull distributions were investigated for determining the statistical approach that would best fit the loads data, and chi square and psi square tests were made. Curve fitting of the empirical data was also employed. Attention is given to the loads and strengths. The double exponential distribution was found to best represent the maximum bending load, while the normal distribution was best for strength distribution representation. M.W.R.

Review: This is a rather detailed, somewhat tedious dissertation. Certainly the methods have nothing new in them. The specific application may be new, but that is all. Well-known techniques are used for generating reliability, according to the probability of a strength exceeding a stress. However, it is not obvious why the author did not use straightforward numerical integration of the convolution of the two distributions to calculate the reliability integral. The paper will serve mainly as a long example of the application of these techniques.

R67-13335 ASQC 820; 872

Joint Publications Research Service, Washington, D. C.

ON IDLE DOUBLING WITH REPAIR FOR ANY LAW OF DISTRIBUTION OF FLOW OF BREAKDOWNS AND TIME OF REPAIR

A. F. Zubova *In its* Tech. Cybernetics, No. 5, 1964 4 Jan. 1965 p 153–158 refs (See N65-14762 05-10) CFSTI: $6.00

(N65-14775)

A method is proposed for determining the probability that a system consisting of a main circuit and a reserve circuit will be in operating condition after a time t. When the main circuit breaks down, the reserve circuit is placed into operation, and the time necessary for the main circuit to be repaired is τ. Two methods of investigating the probability are considered: (1) In order for the system to operate for a duration of time t it is necessary that either (a) the operating device does not break down in the time t, or (b) the operating device breaks down after the time τ but the reserve circuit functions until after time t. (2) For a trouble-free time of operation t, it is necessary that either (a) the operating device does not break down during the period of time t, or (b) the operating device breaks down at a time t_1 but the reserve circuit operates trouble-free for a time $t-\tau$, or (c) the operating device breaks down at a time T, the reserve circuit breaks down at a time $\Theta (0 \leq \tau \leq \Theta \leq t)$, but the basic main circuit has been repaired before time $T\Theta$. P.V.E.

Review: These three articles (R67-13335–R67-13337) which appear in a translation of a Russian journal, are about duplicating a system with repair allowed. In some cases the failure rate of the spare element is considered to be different from that of the operating element. In general this type of work is adequately represented in the American literature and probably need not be consulted here, except by the theorist who wishes to be sure that he is up to date on the work going on everywhere. Not all the mathematics was checked, but it appears to be quite adequate.

R67-13336 ASQC 820; 872

Joint Publications Research Service, Washington, D. C.

ON DOUBLING WITH REPAIR

B. V. Gnedenko *In its* Tech. Cybernetics, No. 5, 1964 4 Jan. 1965 p 159–169 refs (See N65-14762 05-10) CFSTI: $6.00.

(N65-14775)

The distribution of length of trouble-free operation of a double system is found. It is proposed that the length of trouble-free operation of a device is subject to a known distribution; the repair of a broken down device means total restoration of its properties. The length of repair has an arbitrary distribution. The reserved device is in the light conditioning. Two limiting theorems are proved under the assumption that the length of repair is significantly less than the length of trouble-free operation of the device. Author

Review: See R67-13335

R67-13337 ASQC 820; 872

Joint Publications Research Service, Washington, D. C.

ASYMPTOTIC DISTRIBUTION OF LIFETIME OF A DOUBLED ELEMENT

A. D. Solov'yev *In its* Tech. Cybernetics, No. 5, 1964 4 Jan. 1965 p 170–173 ref (See N65-14762 05-10) CFSTI: $6.00

(N65-14777)

Considered is a system in which two identical elements are placed in parallel. One of the identical circuits is placed in reserve, while the second one carries the load. By combining laws for the distribution of the lifetime of each individual element and for the distribution of the time repair of an individual element, a law is developed for the lifetime of the element. P.V.E.

Review: See R67-13335.

R67-13345 ASQC 822; 838

FIRST FAILURE DISTRIBUTIONS FOR SIMULTANEOUS AND SEQUENTIAL PARALLEL SYSTEMS.

E. G. Enns (Northern Electric Co., Ltd., Ottawa, Canada.).

Proceedings of the IEEE, vol. 54, Dec. 1966, p. 2005, 2006.

A two-unit parallel system with specified failure rates is considered in order to determine the first failure distributions for simultaneous and sequential parallel systems. Laplace transformed density function and mean time to the first system failure are derived for (1) a simultaneous system in which both units are operating and repaired independently, and system failure occurs when one unit fails while the other is under repair and (2) a sequential system in which unit *b* operates only when unit *a* is under repair, and the system fails with the failure of unit *b*. It is assumed that the same failure distribution is in effect after each repair, and that in case (2) unit *b* does not deteriorate while not in use. The process is made Markovian in continuous time by using the method of supplementary variables. It is shown that the mean time to failure is greater in the sequential system. M.W.R.

Review: This note is a mathematical derivation of the first failure time distribution for parallel systems of two units. The technique is a good example of the use of supplementary variables (for which a reference is cited in the note) in solving complex problems. As such it will be of interest to the theorist rather than the reliability engineer.

83 DESIGN

R67-13326 ASQC 831; 844

METHODS OF DESIGN STAGE RELIABILITY ANALYSIS.

C. A. Krohn, A. C. Nelson, Jr., and W. S. Thompson (Research Triangle Institute, Durham, N. C.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 803–815. 14 refs.

(Contract NASw-905)

Available from IEEE, New York: $8.00.

Basic mathematical techniques available for reliability analyses are described and their utility in the design stage is assessed. The four basic reliability tasks in performance and life testing analysis during design of equipment are considered to be: (1) failure modes and effects analyses, (2) performance variation analyses, (3) component stress analyses, and (4) reliability prediction. Major assumptions, advantages, disadvantages, and recommended applications are tabulated for the end-limit, fixed time distributions, time-varying distribution, and random processes performance variation analysis techniques. Reliability-life, or probability-type, techniques and their applications are discussed with two examples: (1) performance variation analysis of the voltage regulation loop and (2) redesign of timing section output circuits. It is emphasized that a failure mode and an effects analysis program should be initiated early in equipment design, and that more stress be placed on selection of the technique to match each specific problem. M.W.R.

Review: The authors have done a creditable job of listing the methods of analysis that are useful in the design stages. Their emphasis is largely on electronic equipment, as are all of their examples. It is presumed that the reader is familiar with most of the techniques at least by name since this paper is more of a comparison than a description. Often the authors state very simply that lack of data may be a hindrance in a certain method—in several cases this is a masterpiece of understatement. A prominent place in principle, if not in the amount of space, is given to failure modes and effects analysis as a practical means for insuring equipment of very high reliability. It is part of what the authors call "infinite attention to detail" which is so necessary. Their emphasis is most appropriate. One does not get a perspective on the costs of the various techniques nor of the amount of background and experience necessary to use them. The examples are the usual success stories. This paper can be recommended to electronics design engineers who have enough experience to understand it. It appears to be tutorial rather than innovative.

R67-13334 ASQC 832

National Aeronautics and Space Administration, Washington, D. C.

HUMAN RELIABILITY IN SPACECRAFT CONTROL SYSTEMS [PROBLEMY NADEZHNOSTI CHELOVEKA V SISTEMAKH UPRAVLENIYA KOSMICHESKIM KORABLEM]

P. K. Isakov, V. A. Popov, and M. M. Sil'vestrov Jun. 1965 11 p *refs Transl. into ENGLISH of Paper presented at 2d* Intern. Symp. on Basic Environ. Probl. of Man in Space, Paris, 14–18 Jun. 1965 11 p

(NASA-TT-F-9428; N65-27714) CFSTI: HC $3.00/MF $0.65

The special problem of man's reliability as operator in different spacecraft control systems necessitates models permitting estimating stability of optimum and prescribed working characteristics and their physiological mechanisms. Weightlessness, alternating time allowances to function, and multiple information transfer determine peculiarities in constructing systems. Author

Review: This paper is apparently a translation from the Russian and deals in qualitative terms with the problems of how a person reacts in a situation where he must exert control. It discusses problems rather than solutions, again in a rather general way. The main use for those who will want to read it is for knowing what was not said rather than what was said.

R67-13343 ASQC 830

RELIABLE ENERGY CONVERSION POWER SYSTEMS FOR SPACE FLIGHT.

John T. Lingle (Honeywell, Inc., Hopkins, Minn.).

(1965 Aerospace Technical Conference and Exhibit, Houston, Tex., June 21–24, 1965, Paper). IEEE Transactions on Aerospace, vol. AS-3, June 1965, supplement, p. 543–549. (A65-31134)

Description of low-voltage converter-regulators, which provide the key to the utilization of new energy-conversion power sources in future space applications. It is now possible to use transistor-converters to boost the low voltage level of thermionic, fuel-cell, thermoelectric, and electrochemical sources to a higher, more usable regulated voltage. Improved low-voltage converter-regulators have efficiencies between 70 and 90%. This approach will allow the designer of space power systems to achieve higher reliability with single-cell sources coupled to low-voltage converter-regulators.

Author (IAA)

Review: Despite the implication in the title, this paper discusses little in the way of reliability per se. Three systems are considered to begin with: a series stack of cells, a series-parallel stack of cells, and one cell plus a converter–regulator. No quantitative comparison is made between the three, but the engineering judgment is made that one cell of enough capacity plus a highly-reliable converter–regulator would be the best system. The bulk of the article is devoted to the design and performance analysis of the converter–regulator. However, no life or failure figures are given.

84 METHODS OF RELIABILITY ANALYSIS

R67-13310 ASQC 844

DEVICE FAILURE DISTRIBUTIONS FROM FAILURE PHYSICS.

E. P. Moyer (International Business Machines, Electronics Systems Center, Owego, N. Y.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 598–611. 4 refs.

Available from IEEE, New York: $8.00.

Failure rate patterns for semiconductor degradation modes are determined by applying failure physics from three stress-aging experiments to basic physical parameters. These experiments show time dependence of the (1) junction capacitance of a silicon mesa diode, (2) base current of germanium mesa transistors, and (3) forward junction voltage of silicon planar diodes. In each case, an explicit mathematical expression shows the degradation; and in all three cases, failure patterns depend upon: (1) the proportionality constants relating to the electrical characteristics to the physical parameters and (2) activation energies associated with the physical processes. All examples show a sound physical justification for the 1/T vs. log-time relation for given percentile failure values, and an Eyring-type physical relation appears to hold in each case. Pre-system burn-in and screening can be performed in all cases to achieve good reliability within the limits of the physical processes. M.W.R.

Review: This kind of investigation and the principles put forth in this paper are very good and can be instrumental in improving the reliability of devices. The analysis of the data as reported here is not as good. Some examples of the difficulties in the text are the following: (1) It is all right to draw lines among the data points and to repeat this process several times, each time taking data points from previously drawn lines to find suspected relationships. But when the final equation is developed, such as Eq. 1 for the capacitance of a diode, all of the unknown parameters in the equation should be re-evaluated with all of the data at one time if possible. In the case of Eq. 1, for example, it would emphasize that some of the parameters are difficult to evaluate since the so-called activation energies (E_a and E_b) are apparently determined from the data rather than being given a value based on prior knowledge. The sense in which an activation energy is associated with the voltage is not clear at all. It does not have the physical basis that the activation energy associated with the temperature does. In support of this assertion and in saying "This equation shows an exact Eyring-type reaction dependence upon both voltage and temperature" the author gives a standard text coauthored by Eyring as a reference. There is nothing in the text about a voltage activation energy nor is it known what an "exact Eyring-type reaction dependence" is. Possibly an intensive variable x is said to have an Eyring-type dependence if it is in the form $y = \exp(-a/x)$. If so, this is not common usage and should have been explained. (2) The fitting of curves to data shows the usual kind of optimism with regard to the fit. Two examples are: (a) the curves that are asserted to " . . . appear almost log normal with time" have a definite observable curvature drawn in by the author, and (b) in the graphs described by " . . . the devices follow an exact linear change . . . " obviously the points do not all lie on the straight line. In the latter case the author may have meant that the mean behavior is quite closely linear. Obviously there would be a fair amount of scatter about this mean. (3) In Eq. 4 the reciprocal temperature appears on both sides of the equation, yet that appearing on the right-hand side is ignored with no explanation. Perhaps the variations in this term are negligible over the temperature and time ranges of interest, but the author has not so stated. (4) The discussion of activation energy for the base current change is poor. The expression does not follow the Arrhenius form in any way; therefore, the meaning of the term activation energy is not at all clear. (5) In Fig. 11 where an exponential behavior is asserted to hold, the points do not fit the line very well, especially in the short-time tail region. In the author's behalf, it may be said that the lines may fit the points well enough for his (unknown) purposes. The emphasis in this review on distributions stems from the title and the first sentence of the paper. The kinds of data the author has obtained can be very valuable in improving the reliability of the devices. In the actual analyses performed on these data, the author seems to have failed to heed fully his comments on restraint.

R67-13314 ASQC 844; 771

UNDERSTANDING FAILURE REQUIRED FOR MEANINGFUL TEST SELECTION.

R. C. Stinebring (Avco Corp., Space Systems Div., Materials Development Dept., Lowell, Mass.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 636–648. 4 refs.

(Contract AF 33(615)-2855)

Available from IEEE, New York: $8.00.

Nondestructive testing (NDT) screening techniques are reviewed that are sensitive to the variable or deficiencies that cause failures in diffusion-formed coating systems for refractory metals. Failure mechanisms were postulated from the appearance of the failure sites and the methods by which the failures occurred, and these along with NDT methods are tabulated for three different alloys for each case. High temperature and plasma arc testing results are summarized, along with the screening steps taken. The NDT methods used in the program were based on material-energy interactions associated with the variables that might occur in the various zones of the coating, and forty specimens (each 2×2×0.020 inches) were prepared from each of the three substrate alloys. M.W.R.

Review: This paper is concerned with the physics of failure and nondestructive tests of coatings for refractory materials which are used at high temperatures. One of the primary reasons that coated refractory alloys have not been fully utilized is the lack of adequate nondestructive test techniques for controlling quality and assuring reliability. This paper will help in that regard. The basic approach is worthy of note by reliability engineers. The details of the tests are of concern largely to other metallurgists who are involved in running such tests or in recommending such materials. This kind of work is most important in improving the reliability of our aerospace vehicles.

R67-13318 ASQC 844; 814

COST IMPROVEMENT AS A RESULT OF RELIABILITY EFFORTS ON MINUTEMAN II INTEGRATED CIRCUITS.

D. A. Hausrath and D. C. Fleming (Autonetics, Anaheim, Calif.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 683–692. 20 refs.

Available from IEEE, New York: $8.00.

A failure mode model and a measurement system are described that were used to reduce failure rates in Minuteman II integrated circuits; and the programs used in this reduction and their costs are considered. Costs of the reliability program are compared with total costs of the integrated circuits as well as with projected costs without such a reliability program. A method of calculating these costs is described, along with the savings of the reliability program to the Minuteman circuitry. A comparison is also included of Minuteman and commercial integrated circuit costs. While the average commercial IC price in 1966 was $8.40 less than the Minuteman IC average, the Minuteman total cost per IC to the user was $16.80 less because of the lower failure rates obtained by reliability programs that cost $1.99 per IC. The ratio of savings versus expenditures is 4.2. M.W.R.

Review: The authors deserve a "well-done" for reporting the integrated circuit (IC) cost, failure-mode, and failure rate data which are in this paper. In these days of what seems to be a sparcity of significant data which have been analyzed, such case reports are welcome. The information in this paper is from the Minuteman IGS program, which continues to contribute to the state-of-the-art improvement of reliability. IC reliability improvements here have been achieved mainly by working with suppliers on corrective action of specific failure modes, where cost incentives were used. Two important conditions which were necessary to achieve the IC reliability improvements are: (1) large enough quantities of IC's in order to be able to obtain measures of various failure rates of failure modes so that it is known where to start corrective action, and (2) a dollar budget during development other than the often heard "absolute minimum development cost." As generally seems to be the case when data can be pulled together, it turns out here that the cost of getting the additional IC reliability is quite low compared to the costs which would have been experienced without the additional reliability. The authors conclude that for every dollar spent on the IC reliability program, 4.2 Minuteman program dollars were ultimately saved. Quite a return on investment!

R67-13322 ASQC 840; 841; 842

A SYSTEM FOR THE RECORDING, REDUCTION AND REPORTING OF COMPONENT RELIABILITY TEST DATA.

William P. Hart and David K. Sanders (ITT Cannon Electric, Los Angeles, Calif.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 717–727. 5 refs.

Available from IEEE, New York: $8.00.

A failure rate determination test program on electrical connectors provides a precise measurement of reliability by measuring the actual performance of each contact in each connector every 1000 hr. The data is recorded in variables form, reduced, and reported by the IBM 1050/1070 data acquisition system in conjunction with an IBM 7094 computer. In addition to the standard reliability concepts in military specifications and ETA guidelines, the program uses a matrix test program that includes multiple regression analysis that expresses each dependent variable as a linear function of the independent variables. The matrix is broken down into all possible stress groups by an analysis of variance. M.W.R.

Review: This paper is a rather detailed and technical description of the reliability test data system. The number will have meaning for reliability engineers who are in the connector testing business, but will be of little value to anyone else. The paper is more useful as a reference than as an aid to design engineers.

R67-13328 ASQC 844; 851; 853

PHYSICS OF FAILURE ANALYSIS FOR HI-REL ASSESSMENTS.

A. J. McCormick and H. S. Hammer (Autonetics, Anaheim, Calif.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 824–835.

Available from IEEE, New York: $8.00.

A system of reliability assessment is reported that uses the limited, but comprehensive failure data documented during in-house functional and qualification testing. These failure analyses are followed by a physics of failure search to establish trends and likelihoods with respect to future applications. The result is a component and system reliability numeric that tells the impact of the failure on system reliability. Specific examples used to develop the theoretical presentation are: (1) transistor internal bonding problems, (2) connector socket intermittency, (3) metallic particles inside stud-mounted diodes, and (4) particle contamination inside relay cans. Laboratory tests were performed to substantiate theoretical conclusions and to further define failure trends by controlled stress on suspected problem areas. To demonstrate the high-reliability assessment techniques, the individual component reliability numerics are applied to the system reliability model. M.W.R.

Review: Four case histories illustrate a reliability assessment procedure. The general description is adequate as an outline of the approach. However, it would have been desirable to present a little more detail on some of the analyses. For example, the probability charts, Figures 5 and 6, are essential to the analysis in the first case history, yet no information is given as to precisely how they were obtained. This leaves the reader wondering how much extrapolation was involved in getting the estimates of the probability of bond failure—i.e., how accurate are these figures? The quantity identified on p. 829 as a pdf is actually a constant—the pdf is not the result of integrating out all of the random variables. A clear statement of what is intended here would have taken very little additional space. The paper will be useful mainly to those who wish to get a general impression of the procedure without delving very far into the details.

R67-13329 ASQC 844

FOREIGN PARTICLES AND SPACE EQUIPMENT RELIABILITY.

R. P. Boylan (International Business Machines Corp., Electronics Systems Center, Owego, N. Y.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 836–846. 4 refs.

Available from IEEE, New York: $8.00.

Simple reliability analysis models are presented that make use of component part, circuit, and system data to assess the extent to which equipment reliability is affected by particle-contaminated devices. An expression is given for determining the reliability of a single device. Probability of a device containing a particle capable of producing a short must be derived from a component part analysis; and effective failure rate for devices with contaminating particles is composed of a solid failure rate, and intermittent failure rate, and a duty cycle. The necessity of differentiating between the failure rates arises from the effect of the short's impact on equipment operation. Careful attention to particle contamination in electronic devices is recommended early in program planning phase, and component part selections for critical applications should be made from devices having inherent design protection from failures caused by foreign particles. M.W.R.

Review: This kind of treatment of contaminate particles is not often found in the literature and thus is quite welcome. The models are quite simple, since, as the author points out, there are not enough data to support the more complicated ones. (In equation 1 the expression following the ϵ is actually an exponent.) The section on the average energy of the particles does not contain much justification for the model. In particular no reference is made to Brownian motion, either whether the particles have it or why they do not. The remarks on inspection procedures are good, but one cannot help but wonder why there are so many foreign particles in a semiconductor's can in the first place. This seems to be an area where manufacturers' quality control procedures could be vastly improved for high-reliability applications.

R67-13341 ASQC 844; 814; 871

EXTENDED ENGINE LIFE THROUGH IN-SERVICE DEVELOPMENT.

J. F. Leamon and J. T. Pratt (Trans World Airlines, Inc., Kansas City, Mo.).

Society of Automotive Engineers, National Aeronautic Meeting and Production Forum, New York, N. Y., Apr. 25–28, 1966, Paper 660313. 8 p.

(SAE PAPER-660313; A66-29838) Members, $0.75; Nonmembers, $1.00.

Consideration of factors for extending the life of an aircraft engine part beyond that already available. The life restricting factors to which a jet engine is subjected are multiple–complex vibratory modes, gas bending loads, high thermal stresses, structural loads, and wear from relative motion. The problems concerning the in-service development of component replacements are classified into three categories: (1) replacements in which no fundamental design improvement is involved, (2) repairs in which there is an element of design improvement, and (3) repairs in which the replacement involves total redesign. Part utilization can be maximized by incorporating the in-service design developments into improved component design. IAA

Review: This paper exhorts both the airlines and the manufacturers to learn at a faster rate from the failures that are occurring in service and thus to extend the lives of engine components which in turn have a pronounced effect on engine overhaul life. Considerable use is made of examples which illustrate quite well various problems and typical methods used to correct them. The reliability of many kinds of equipment which are repaired over and over again can be improved by the same methods. This paper is written by representatives of one of the airlines, a consumer, and it is always interesting to contrast the consumer's view of the reliability of a product and problems associated therewith with that given in papers authored by representatives of producers. In the latter papers, most of the problems appear to be solved, with reliability and life being at all-time highs. While it certainly is not the primary intent, a paper such as the present one can help to give a better perspective on the overly-enthusiastic papers.

R67-13342 ASQC 844; 716; 814; 851

AN EVALUATION OF ZENER DIODES TO DEVELOP SCREENING INFORMATION.

C. L. Hanks (Battelle Memorial Institute, Engineering Physics Dept., Columbus, Ohio).

Semiconductor Products and Solid State Technology, vol. 8, Apr. 1965, p. 30–35. Research sponsored by North American Aviation.

(A65-22184)

Description of a screening program, derived using linear discriminant analysis, for the Zener reference diodes used in high-reliability missile guidance systems. Diodes were monitored throughout various operating conditions, with parameters measured at selected intervals in order to classify the diodes as either operative or failed. Analysis of the results indicates that various given combinations of eight parameter measurements can be used to predict failures. The results demonstrate that the use of linear discriminant analysis for screening reference diodes should remove the units most likely to fail in actual service, and should thus improve the reliability of the system for which they are intended. IAA

Review: In this paper the parameters of the diodes were measured and then the diodes were run on accelerated tests to induce failures. The initial measurements of the parameters were then analyzed to see what combination would distinguish best between those which did and those which did not fail the accelerated tests. The optimum discriminant refers to a least cost figure of merit and it is necessary to to give cost ratios for misclassification of units. The paper has a reasonable amount of detail and anyone interested in the subject would do well to refer to it. The subject of linear discriminant analysis is described only briefly, but a reference to it is given.

85 DEMONSTRATION/MEASUREMENT

R67-13312 ASQC 851; 775; 844

MODERN APPROACHES TO MICROCIRCUIT RELIABILITY ASSESSMENT.

R. C. Hilow, E. P. O'Connell, and A. L. Tamburrino (Rome Air Development Center, Griffiss Air Force Base, N. Y.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 625–632.

Available from IEEE, New York: $8.00.

While it is usually impractical and impossible to demonstrate the reliability of the monolithic microcircuits required in present systems, the need for continuing reliability assurance is ever present. The techniques and data available for reliability assessment of microcircuits are discussed, including in-process control, nondestructive screening, device study, high stress tests, and life and operating testing programs. Failure mechanisms and analyses are treated, and the use of extrapolated data is discussed. Complete responsibility for life testing and identification of failure mechanisms is considered to be with the manufacturer, although the user must generate data beyond that supplied by the manufacturer. Available reliability data must always be integrated with failure mechanism information. M.W.R.

Review: This is a comprehensive review of microcircuit reliability assessment and is useful reading for those concerned with this subject. The limitations of the physical factors involved in assuring high reliability in microcircuits are covered well. The physical factors, however, must be supplemented by concern with the motivations and responsibilities of the microcircuit manufacturer, the equipment manufacturer, and the equipment user. In essence, the equipment manufacturer, is motivated to make and sell devices at a profit and his only responsibility is to see that they meet whatever specifications are prepared for them. Any modification of this role is a pipedream unless a real motive is established! The use of extrapolated data, abstracted and edited data, and flexible screens is justified and allowed by these motivations. The equipment manufacturer and equipment user each has unique motives different from those of the microcircuit manufacturer. Only when all of these are considered, are factors such as life tests, inprocess measurements, and failure mechanism studies given rational meaning in reliability assessment. This comment does not detract from the solid treatment given each of these physical factors in the existing procurement system. The views in the paper are representative of the attitude of the Air Force in considering microcircuit system proposals.

R67-13315 ASQC 851; 775

TESTS DEVELOPED WITH MATERIALS PROCESSES ASSURE OPTIMUM RELIABILITY.

Seymour W. Carter (Avco Corp., Space Systems Div., Materials Development Dept., Lowell, Mass.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 649–667*C*. 10 refs.

Available from IEEE, New York: $8.00.

Nondestructive testing (NDT) techniques are discussed in terms of assisting in the prediction of the inherent reliability of aerospace systems, as well as in offering improved measures for overall quality control. Several aspects of the Apollo command module project are discussed in this light, including the heat shield program and material design and development in the initial stages of the program where reliability and quality control are considered to interface jointly with developmental NDT techniques. Areas in which quality control uses NDT as a tool are noted, namely in the structural bond systems, in the blending of the ablator material, and in the composite heat shield. M.W.R.

Review: This is a case history of assuring reliability by means of nondestructive testing. The example is not too detailed as befits a lecture but does show how the various nondestructive tests were applied. Its use will be in familiarizing design and reliability engineers and management with the principles involved.

R67-13316 ASQC 851; 770; 813; 864

C-141 RELIABILITY FLIGHT TEST PROGRAM.

L. A. Adkins, Jr. (Lockheed-Georgia Co., Reliability Engineering Dept., Marietta, Ga.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 668–674. 2 refs.

Available from IEEE, New York: $8.00.

Reliability aspects of an accelerated service test program, consisting of 2,500 flight hr during 11 mo operation, is reported under the Category II systems evaluation testing of the C-141A aircraft. Operational and subsystem reliability efforts were evaluated with respect to mission objectives; and problem areas in the reliability program are noted, including failure reporting and the overall data collection procedure, the allocation of efforts in terms of specific items and engineering personnel, and the allocation of funds for optimal results. It is concluded that an accelerated test program produces an extremely high reliability in terms of problem identification and corrective action, and that for most effective use of a system with limited manpower, activities should be directed to a few specific items. M.W.R.

Review: A summary is given in this paper of the C-141 transport aircraft accelerated reliability flight test program. The author is enthusiastic over the opportunity to measure the reliability of the aircraft. His enthusiasm is appropriate, as a great many of the frustrations stem from the lack of measurements of reliability. The conclusions in the paper are what would be expected from an author who is sold on reliability field tests. Two of the conclusions which catch the eye are: (a) special field personnel are necessary to gather data, as the usual maintenance personnel just do not give what is needed; and (b) where reliability funding is small, essentially all of it should be used for operational reliability tests. This paper is worth reading by those with an interest in reliability tests.

R67-13323 ASQC 851; 844

WELD RELIABILITY OF A SPACE STRUCTURE.

J. L. Lebach and R. L. K. Morris (Philco-Ford Corp., WDL Div., Palo Alto, Calif.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 766–772.

Available from IEEE, New York: $8.00.

A procedure is described whereby the simplest statistical relationships between ultimate and yield strengths of coupons and between ultimate strengths of coupons and clusters can be used to predict the in-use yield strength of structural cluster welds and their reliability. Both reliability growth potential and means of improving weld reliability are discussed; and consideration is given to heat control, size of center ball in the cluster, size of weld, and other conditions under which cluster welding can be accomplished. The application of a product assurance approach to system reliability is demonstrated; and the interdisciplinary coordination of design, production, quality control, and reliability is stressed. It is found that process and quality control in preparation of welded clusters and test coupons can be measured effectively by the size of the standard deviation for any batch in production. Knowledge of mean strength, nominal load, and applicable standard deviation for any production run can be reduced to a meaningful numerical reliability coefficient. Reliability of the single cluster weld is discussed, and data are included for 68 welded custers. M.W.R.

Review: This paper reads reasonably well and if not studied critically, appears quite satisfactory. From the limited amount of information given in the text, it is difficult to tell whether the engineers have picked the most appropriate statistics for their examples and whether the most appropriate statistical procedures have been used for the problem. Examples are the following. (1) In determining the ratio of yield to ultimate strengths, apparently the average yield and average ultimate strengths were used rather than averaging the ratio for individual specimens. Since there is likely to be considerable correlation between the two kinds of strengths on a given specimen, the latter method might appear more appropriate. (2) One is generally concerned only with the lower strengths in a distribution, not with the higher ones. So in analyzing a strength distribution it is more appropriate to put the best straight line on probability paper through only the lower half (or even less) of the points and ignore the upper half. (3) In the 25 cluster welds one might not be interested in the average strength, but rather in the minimum or near minimum strength. These sorts of questions are addressed to the engineers rather than to the statisticians, since the latter can adequately service the former regardless of the exact nature of the demands. Apparently tensile strength was the only criterion for joint quality; no metallurgical examinations of the welds are reported.

R67-13325 ASQC 851; 775

RELIABILITY SCREENING TECHNIQUES.

James N. Perry (Fairchild Semiconductor Corp., San Rafael, Calif.).

In: 1967 Symposium on Reliability, Annual, Washington, D. C., Jan. 10–12, 1967, Proceedings. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, Institute of Electrical and Electronics Engineers, Inc., 1967, p. 783–788.

Available from IEEE, New York: $8.00.

Twenty-three screening techniques for semiconductors are examined in terms of both effectiveness and cost. These include screens to determine operating and storage life, environmental stresses, hermeticity, and appearance. A specification writer's check list of 24 questions is included to help in cost reduction and reliability improvement. M.W.R.

Review: Practical evaluation of the screening techniques used for semiconductor devices is very desirable, and this paper does it well. While the attitude is that of the device manufacturer, the evaluation of the different techniques considers, as it must, their value to the customer. The description and evaluation of the screens are brief but are given with the assurance of broad experience. The reliability generalist, and the specification writer in particular, will profit by reading this article.

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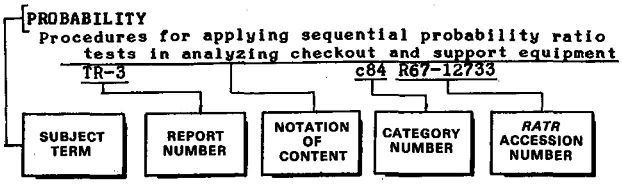

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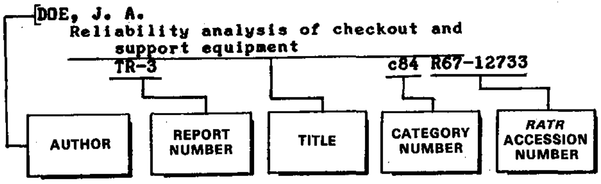
Typical Personal Author Index Listing



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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 8

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This may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number preceded by the category number for locating the abstract-review in the abstract section of *RATR*. For purposes of this index, AD, N, and A numbers *(accession numbers from TAB, STAR, and IAA, respectively)* and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

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NASA-Langley, 1967

Reliability Abstracts and Technical Reviews

SEPTEMBER 1967

Volume 7
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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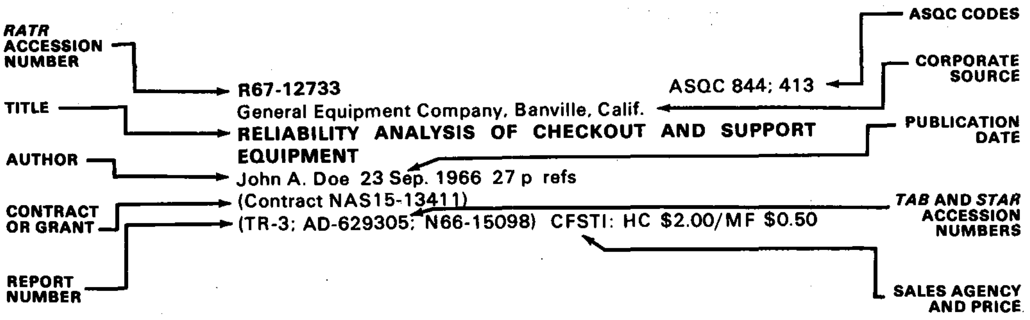
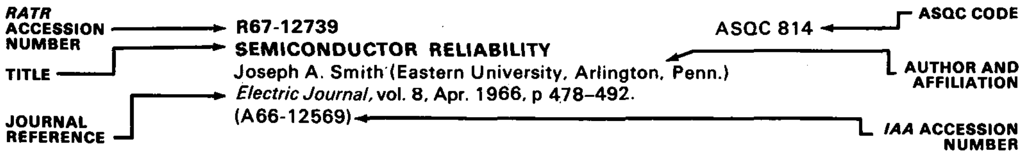
The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

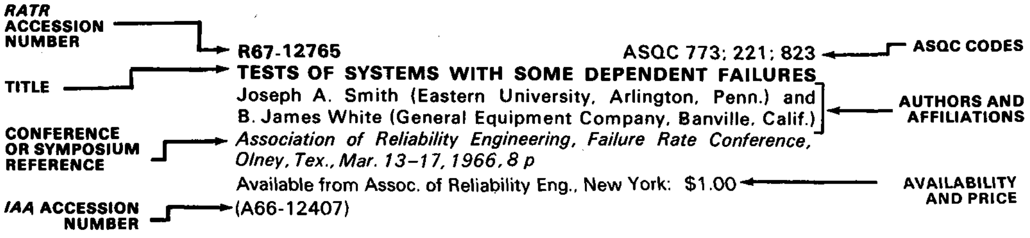
EXAMPLES OF CITATIONS IN *RATR*



R67-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N66-15098) CFSTI: HC $2.00/MF $0.50



R67-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A66-12569)



R67-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A66-12407)

VOLUME 7 NUMBER 9

Reliability Abstracts and Technical Reviews

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September 1967

80 RELIABILITY

R67-13380 ASQC 800
RELIABILITY AND QUALITY CONTROL.
Charles A. Bicking (The Carborundum Co., Niagara Falls, N. Y.).
Industrial Quality Control, vol. 23, Apr. 1967, p. 490–493. 8 refs.

A reliability model for missile systems defines reliability as the probability that the miss-distance of a missile will be within a predicted interval. Probabilities considered by the model are (1) human error, (2) imprecision in component parts of the system, (3) system bias, (4) inadequate life of components, and (5) catastrophic failures. A partial model involving bias and precision may be investigated by statistical quality control techniques; and the results may be a single probability estimate that includes these factors and, perhaps, human factors. It is noted, however, that even within the scope of the partial model, few reliability persons have successfully combined all of the elements affecting bias and precision. The proposed model is an accuracy one, since accuracy consists of bias plus precision. Since the mean radial miss distance and the second moment about it are the preferred measures of bias and precision, respectively, the definition of reliability used here permits a dynamic model in which a distribution of miss distance is dependent upon the five factors mentioned above. M.W.R.

Review: The idea presented in this paper is that in analyzing or simulating the reliability of a missile system, all of the relevant "sub-events" should be taken into account. The latter range from human error to catastrophic failure of components together with their interdependencies. The approach is outlined in sufficient detail to convey its main features, and a number of references are cited for more information on some points. It would seem reasonable for implementation in situations where appropriate data are available. The presentation would have been improved, however, by the inclusion of a realistic example showing specifically how the analysis can be accomplished. For example, it is one thing to say that interdependencies should be taken into account, but something else again actually to do this properly. In the concluding section on "Using the Model" there are several clues which an individual with a probabilistic approach could understand and follow. (The following typographic errors were noted. On p. 490 under Definition of Reliability one or more lines of text are missing. The word "impression" in item 4 on p. 491 should be "imprecision"; also "affects" in the last sentence of the Introduction should be "effects." The superscript 14 in the first column on p. 492 should be 4.) The author in a private communication has indicated that the typographical errors crept in at the galley-proof stage. The third sentence under Definition of Reliability should read: The current, widely-used definition of reliability as being "the probability that the equipment will give . . . . "

R67-13381 ASQC 800; 300
RELIABILITY AND QUALITY CONTROL—CONFLICT OR CO-OPERATION?
Edward M. Stiles (Chandler Evans Corp., West Hartford, Conn.).
In: Quality Control Seminar Papers. Seminar sponsored by SAE Southern New England Section and Hartford Section of American Society for Quality Control, Mar./Apr. 1965. New York, N. Y., Society of Automotive Engineers, Inc., Jul. 1965, p. 8–13. 4 refs.
(SP-273; SAE Paper-650397)

Realistic objectives, reporting procedures, and necessary corrective programs are considered basic to any quality control and reliability program in industry. Problem areas that are found in industrial reliability programs include (1) restrictive and generally unsatisfactory tradeoff procedures, (2) overuse of engineering judgment at the expense of quantitative data, (3) lack of standardized procedures, and (4) inadequate predictive systems. Reliability is discussed in terms of customer demands and these general problem areas. Following an overview of the concept of reliability, attention is given to the definition of reliability terms, causes of reliability failures, and the actual determination of reliability. The politics of reliability determination is considered, and a listing is included of the basic steps where check points must be established and reliability decisions made. M.W.R.

Review: A good introduction to some of the problems of reliability and quality control is presented in this paper. The conflict alluded to in the title is not discussed at any length, and happily so, since it is better dropped than pursued. The author's advice seems to be to make the optimum use of available human resources in order to achieve a reliable product. Other papers have appeared in this general vein, emphasizing different aspects of the general problem. They are of value mainly to the novice, who should read several of them in order to get a broad picture. Some reliability terms are defined in the paper, including "inherent reliability." The definition given is the one which most users of the term appear to have in mind. The fact remains, however, that it is not a very meaningful term; and its unqualified use can be misleading.

R67-13382 ASQC 801; 431; 872

THE EHRENFEST URN MODEL AND A MACHINE MAINTENANCE PROBLEM.

P. A. Lee (Monash Univ., Victoria, Australia).

Proceedings of the IEEE, vol. 55, Mar. 1967, p. 455–456. 13 refs.

A machine repair problem in which both the failure and repair probability density functions are exponential is identified with the continuous-time Ehrenfest urn model, which is a generalization of the classical model with balls drawn from the urns at random times. This urn model, a discrete approximation to diffusion of particles with centrally directed force is a subclass of the more general birth and death process. The Markovian process solution presented by Enns is evolved into the urn model by using a bilinear generating function, a system of discrete orthogonal polynomials with respect to a binomial distribution, and a spectral representation formula of the transition probability. The factorial moments are then defined, evaluated in closed form, and verified using the Leibnitz rule of differentiation. M.W.R.

Review: An alternative solution is given for the problem formulated in the paper covered by R67-13117. The pertinent mathematics is concisely presented and the results are adequately documented to make clear the relationship to other published work on the subject. The paper will be of interest to the theoretician rather than the practicing reliability engineer.

81 MANAGEMENT OF RELIABILITY FUNCTION

R67-13346 ASQC 810; 830; 844

TRENDS IN RELIABILITY OF SPACE POWER CONDITIONING EQUIPMENT.

James E. Comer (Gulton Industries, Inc., Engineered Magnetics Div., Hawthorne, Calif.).

In: Wescon/65; Proceedings of the Western Electronic Show and Convention, San Francisco, Calif., August 24–27, 1965, Technical Papers. Part 3—Power Electronic. North Hollywood, Calif., Western Periodicals Co., 1965. 5 p.

(A66-11283)

Review of the organization, stress analysis, component part specifications, and failure of space power conditioning equipment. It is concluded that major potential failure mechanisms can be avoided by timely reliability design and stress reviews, and that for many semiconductors peak power measurements are more important than average power. IAA

Review: Some of the considerations pertinent to the specification and production of reliable power sources for space vehicles are discussed. A simplified example is given to illustrate the importance of analyzing for peak power. The desirability of watching for unusual conditions in making failure analyses is emphasized. Although the paper is short, it has some ideas which could be useful to designers of this specific equipment.

R67-13347 ASQC 816; 814; 815

RESISTOR RELIABILITY AND COST EFFECTIVENESS—MEETING THE TWAIN.

W. E. Mc Lean (Electra Manufacturing Co., Independence, Kans.).

Electronic Procurement, vol. 5, Dec. 1965, p. 24–27.

Cooperative efforts between consumer and producer are stressed as the means of obtaining resistor reliability minimum costs. Techniques that permit savings in reliability programs include making use of recent life test data, using standardized data reporting systems, sampling plans to verify critical attributes of product performance, and making use of resident government inspection services. With respect to resistors, noise criteria are considered useful screening parameters; and noise as a cost factor is discussed. Mention is made of the Ericsson distortion analyzer to measure nonlinear distortion, and the importance of overall screening techniques is stressed in effecting cost reduction and reliability improvement. M.W.R.

Review: The demonstration of high reliability at a high confidence level is very expensive. The product must be made better than specified in order to provide reasonable assurance of being accepted. The paperwork, too, can be overwhelming. The author, who represents a supplier of resistors, makes some positive suggestions for alleviating this problem. These include appropriate use of documented failure rates, post-manufacturing screening, certification of compliance plans followed by periodic verification, and the establishment of mutual confidence between producer and consumer. Their implementation is certainly feasible, given the right attitudes on both sides of the customer-vendor relationship. Almost half the paper is devoted to a description of current noise as a screening parameter. This concept has not yet been fully accepted by engineers mainly because there is too little evidence of how well the noise measurements are correlated with lifetimes. (For papers on this topic see R64-11371, R64-11374, R64-11460, and R67-13204.) More investigation will be needed before this technique can make a contribution to alleviating the problem addressed in this paper.

R67-13366 ASQC 815; 833

F-111 TEAM BOOSTS RELIABILITY THROUGH PARTS CONTROL.

Electronic Procurement, vol. 7, Apr. 1967, p. 26–29.

A unique cycle of upgrading reliability, encouraging standardization, and improving maintainability for the Air Force has been evolved by the electronic parts control team working on the F-111 aircraft. A schematic depicts the series of steps which go into tightened JAN procedures to produce the JANTX part. The TX (test extra) procedure interposes 100 percent stress screens (environmental drift screening) into the sampling tests of tightened JAN procedures. Any transistor, diode, rectifier, capacitor, and resistor that has a catastrophic failure during the tests is rejected, as are any that display drift beyond acceptable operating parameters. Higher reliability TX parts will cost less in the long run, and improved performance leads to increased use which encourages standardization. This in turn improves reliability and maintainability. R.Ll.

Review: This is a short descriptive article which presents the background and philosophy of the JAN TX specification.

Briefly, that philosophy involves "extra testing" as a means of achieving components with desired reliability at an economical cost. Its implementation involves buying parts with failure rates which are "on the bottom of the bathtub curve." The idea is to improve *equipment* MTBF by starting out with "test extra" components. With more reliable standardized parts, equipment has a better chance of meeting MTBF goals at a minimum cost. The paper will be of value mainly to those who want a bird's-eye view of the subject; it does not go far into specifics or discuss the problems involved. It also avoids discussion of the internal "politics" of DoD concerning JAN TX. Another article which promotes support for the TX specification is covered by R67-13399.

R67-13367 ASQC 813
National Aeronautics and Space Administration, Washington, D. C.

AN INTRODUCTION TO THE EVALUATION OF RELIABILITY PROGRAMS

D. S. Liberman and A. J. Slechter (ARINC Res. Corp., Washington, D. C.) 1967 67 p refs Prepared jointly with ARINC Res. Corp.
(Contract NASw-1012)
(NASA-SP-6501; N67-19275) CFSTI: HC $3.00/MF $0.65

A basic orientation to the task of evaluating the effectiveness of a reliability program is presented. Primary emphasis is devoted to discussing the assurance task as it relates to project requirements and resources and to describing the factors which determine effectiveness in program implementation. The general fundamentals which apply to the treatment of reliability program objectives, the criteria for judging task effectiveness, and the approach to evaluating the various tasks for meaningful accomplishment are discussed. A failure reporting procedure selected as typifying most of the key features of the better systems presently in use in the aerospace industry is also described. A.G.O.

Review: Overall, this will be a handy document for reliability management. These evaluation guidelines are keyed to the NASA reliability specification, NPC 250-1. The intended use of the document is for the evaluation of reliability programs of typical contractors by NASA Centers, but it will find broader application. Some other uses are in providing: guidance for reliability program planning, a NASA interpretation of NPC 250-1, assistance to contractors in evaluating sub-contractors and to NASA Centers in evaluating government and university hardware efforts. The guideline is somewhat lengthy for an all-word discussion without a summary section. The discussion per se has broad coverage while the lone illustration is a supplement on failure reporting—a curious mixture.

R67-13374 ASQC 814

TOTAL VALUE CONCEPTS IN THE CONTRACT DEFINITION PHASE.

S. Robinson (Radio Corporation of America, Defense Electronic Products, Missile and Surface Radar Div., Moorestown, N. J.). *IEEE Transactions on Aerospace and Electronic Systems*, vol. AES-2, July 1966, p. 402–408. 5 refs.
(A66-34251)

For large military research and development projects, Contract Definition type contracts are meeting the cost-effectiveness challenge by an intensive study of the total value considerations in a project before it starts. This has extended the application of total value concepts throughout all project activities and broadened their scope. Total value concepts are discussed and applied to various aspects of system effectiveness. The effects of configuration, reliability, and system availability upon overall costs are considered, and cost vs performance optimization curves are shown. Practical measures of service life are calculated. Break-even curves relating acquisition and operational costs are shown. A decision matrix method for assessing a system value is included. A case study graphically showing the effects of value considerations on a typical radar antenna tower is contained in the paper. Author (IAA)

Review: A clear and concise discussion of the topic indicated in the title is given in this paper. A case study serves to illustrate the points which are made. For reliability engineers and reliability managers the paper serves to point up the fact that reliability should not be considered in isolation, but rather in its relationship to the other aspects of system effectiveness. The theme is that of total value concepts applied throughout the entire spectrum of management and engineering, and some worthwhile ideas for the implementation of this theme are presented. While the whole system must eventually be considered, the engineering advantages of considering small segments of both hardware and software should not be overlooked.

R67-13376 ASQC 811; 813

ORGANIZING FOR PRODUCT RELIABILITY.

T. A. Daly (Westinghouse Electric Corp., Baltimore, Md.). *Electro-Technology*, vol. 76, Aug. 1965, p. 57, 59–66. 6 refs.

Twelve steps are outlined for implementing a division reliability program, which begins with the appointment of a mature and aggressive reliability manager. In conjunction with the various department heads, this reliability manager should assess existing efforts for achieving reliability. A reliability panel should be appointed, and the responsibilities of all functions affecting reliability must be clearly defined. In addition, the reliability manager should define the overall reliability objectives, develop a reliability program, and develop a system for the collection and analysis of product data to assure necessary corrective action. Reliability goals and estimating methods should be established by both the reliability panel and manager, and the latest techniques should be introduced to implement the program. A formal procedure for verifying product reliability is recommended, and adequate procedures must be established to insure the production of a reliable product. Periodic assessment of the effectiveness of the program is considered a must, as is the utilization of the advisory and research services of the reliability staff. M.W.R.

Review: A recommended step-by-step procedure for implementing a comprehensive organization program for product reliability and service is presented. The basis for it is a program developed in three years at Westinghouse. This lends the advice offered a flavor of realism which would be lacking in a more abstract discussion of principles. The first and most important step is the appointment of a mature and aggressive reliability manager. The qualifications and duties of this person are outlined in the paper, as are the other steps in implementing the program. This paper will be worthwhile reading for those concerned with management of the reliability function in aerospace organizations. While the specifics of implementation may well differ from one organization to another, the presentation covers the essential considerations.

R67-13378 ASQC 815; 770; 782; 844

SPECIFYING RESISTOR RELIABILITY.

Charles Wellard (American Components, Inc.).
Electro-Technology, vol. 76, Aug. 1965, p. 42–44.

Various ways in which resistor reliability can be determined are discussed, and a method presented for indicating component reliability is based on data accumulated over a total test time of more than 8.2 × 10^7 hr. Reliability based on selected environmental tests as well as on load-life tests is stressed. Reliability curves are included for conformal-coated and molded resistors at the 40% and 90% confidence levels at temperatures of 25°, 75°, 100°, and 125°C. For these the weighting factors are related to load, moisture, and temperature. Curves based on the load-life tests are also shown. M.W.R.

Review: This paper is based on some good ideas, e.g., (1) the use of weighting factors to account for moisture, temperature cycling, and overload, and (2) the presentation of sufficient test data to enable the user to make an easy, intelligent decision. The author feels that tests such as moisture, temperature cycling, and short-time overload have as much relationship to reliability as does a straight life test. His use of weighting factors is a realistic means of taking this relationship into account. The description in the paper, though brief, should be sufficient for those who are close to the problem. It serves to illustrate a useful method of presenting reliability figures on components.

R67-13391 ASQC 813; 844
Rome Air Development Center, Griffiss AFB, N. Y.
MINUTEMAN II, PHYSICS OF FAILURE PROGRAM—OPENING REMARKS
J. F. Wiesner *In its* Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 423–427 (See N67-10101 01-34) CFSTI: HC $3.00/MF$0.65
(N67-10125)

The Component Quality Assurance Program was conducted to improve the reliability of the Minuteman II weapon system. Because life testing was impractical, the program applied various step stresses such as temperature, voltage, heat, vibration, etc., to uncover weak links in the device construction or fabrication techniques. Corrective actions were then applied in the form of design material, or process changes. The Physics of Failure Program was set up to identify the causes and mechanisms underlying the failures uncovered by the application of the step stresses. Some of the general features of these two interrelated programs are discussed. R.N.A.

Review: This short paper is worth reading for anyone not familiar with the general outline of the Minuteman II reliability program. Specifically this paper discusses the Component Quality Assurance Program and its complement, the Physics of Failure Program. These are a departure from the extensive life testing under Minuteman I and indicate the directions that reliability testing is taking with the advent of very long-lived parts. The step-stress to failure test is quite valuable in uncovering potential failure modes and mechanisms. These defects would eventually have been found in the field and corrected, but this way the time is considerably shortened. The existence of this program has given a big boost to those who have felt that the importance of engineering considerations in reliability was being considerably and consistently underestimated, especially by the electronics branch of reliability.

R67-13399 ASQC 815
TX—THE ANSWER TO OUR RELIABILITY DILEMMA.
R. D. Winters (Dickson Electronics Corp., Scottsdale, Arizona)
Evaluation Engineering, vol. 6, Mar./Apr. 1967, p. 36–39.

Testing Extra or TX requirements are considered the answer to the Department of Defense's multitude (in excess of 213,000) of reliability specifications for semiconductor parts supplied to prime contractors. In many instances, it is pointed out, there are several different prints for the same device used by the same contractor on different contracts. The use of TX with the F-111 tactical fighter is noted, as is the difficulty in implementing TX procedures because of controversies among reliability personnel. The MIL-STD-701 has now been amended to incorporate all TX types, and military component specifications are being updated to include TX requirements. Standardization, reliability, and price and delivery benefits are discussed as the advantages to both suppliers and users of TX parts. M.W.R.

Review: This is a short easily-read article. It is intended to promote support for the TX specification and does that job quite well. It is definitely an enthusiastic, favorable comment; it includes virtually no negative criticisms of the concept. (Even though the TX specification is a big step in the right direction, there are surely many people who have had problems with it.) One of the things that standardization does is to make available very good parts sometimes at the risk of not providing potentially excellent parts. It is with the latter area that many people object to standardization—the main answer to which is the old saying "a bird in the hand . . . . " The TX specifications definitely need the support and guidance of the industry—in both their use and their improvement.

82 MATHEMATICAL THEORY OF RELIABILITY

R67-13355 ASQC 821; 431; 838
FORMULAS FOR THE MEAN TIME BETWEEN FAILURES AND REPAIRS OF REPAIRABLE REDUNDANT SYSTEMS.
B. Epstein
Proceedings of the IEEE, vol. 53, Jul. 1965, p. 731–732.

Formulas given by Einhorn are generalized for computing the mean uptime and the mean downtime of repairable redundant systems. The Einhorn assumption that there are n-independent repair facilities is not used because it is restrictive and frequently not satisfied. The key idea in computing times, however, remains the same in that cycles are measured from the instant of the first failed state. As an example, a system composed of n=5 units is considered in which three units are active and have a common failure rate and the other units are inactive and have a zero failure rate until put into use. Einhorn considers that associating zero failure rate with inactive equipment is not always a good idea, since he has seen studies that suggest failure rate is smaller in active electronic equipment than in standby equipment. M.W.R.

Review: The formulas given in the paper covered by R63-10719 are generalized through removal of the assumptions that all n units in the system are active and that there are n repair facilities. An error in the example in the earlier paper is also pointed out. This is a concise mathematical note which makes a contribution to reliability theory. The removal of the restrictive assumptions in the paper covered by R63-10719 serves a useful purpose in practical applications.

R67-13356 ASQC 821; 431

CURVE CROSSINGS BY NORMAL PROCESSES AND RELIABILITY IMPLICATIONS.

M. R. Leadbetter and J. D. Cryer (Research Triangle Institute, Durham, N. C.).
SIAM Review, vol. 7, Apr. 1965, p. 241–250. 14 refs.
(A65-25525)

Demonstration that certain system "performance indices" based on excursions of a certain normal process above a fixed level may be generalized to include fairly arbitrary curves, rather than just fixed levels. The criteria chosen were those which have been found useful in reliability studies, although usually in their two-sided form, and are not the only possible ones. Four types of principal curve crossing results are evaluated.
IAA

Review: This paper provides a derivation of solutions to some generalizations of level-crossing problems which are of special interest in reliability studies. Previous results concern crossings of a fixed level by a stationary Normal process. The present generalizations, as listed in the concluding paragraph (p. 249) of the paper, provide tools for evaluating system reliability of a stationary Normal process when this is measured in any of the following ways: (a) as the number of periods the process spends above a given curve; (b) as the number of periods the integral of the process spends above the curve; (c) as the length of time the process spends above the curve; or (d) as the area the process cuts off above the curve. The tools provided are moments of the random variables (a)-(d). These can be used to bound system reliability either using the formula $P_0 \geq 1-M(u)$ on p. 242 or using Chebyshev inequalities.

R67-13365 ASQC 824; 838

FORMULA FOR THE MEAN LIFE OF "BINOMIALLY REDUNDANT EXPONENTIAL LAW ELEMENTS IN SERIES WITH NON-REDUNDANT EXPONENTIAL LAW ELEMENTS" (RELIABILITY MATHEMATICS CORNER).

J. M. Shapiro (TRW Systems, Redondo Beach, Calif.).
Evaluation Engineering, vol. 6, Mar./Apr. 1967, p. 35.

The reliability block and formula are presented for determining the mean life of an array of similar items in cascade or series exponential elements. The formula for the mean life of binomially redundant exponential law elements defines successful operation in terms of a certain "i" or more surviving items. The resultant mean life is approximate since the ratio of the failure rate of the series element to that for each redundant element must be rounded off to an integer so that the factorials can be determined. The formula for mean life of parallel redundant items is also given. M.W.R.

Review: This formula could be useful to a small group of people, although the problem is usually in trying to find such a formula when you need it. Unfortunately not all of the original assumptions are stated explicitly. The two important ones which are missing are (1) statistical independence between all failure events and (2) the hazard rate of each of the redundant devices is independent of the number of failed items. No derivation of the formula is given in the paper but it is available from the author. A check of the author's derivation indicates that it is correct (assuming that the starting formula he uses is correct—it is not readily derivable in that form). However, the use of factorials (gamma functions) in both the starting formula in the derivation and the result in the paper may be an unnecessary complication for many calculations. It can be shown that the result reduces to $\mu\lambda_2 = 1 - n/\nu{+}n \cdot n{-}1/\nu{+}n{-}1 \cdots i/\nu{+}i$, where $\nu = \lambda_2/\lambda_1$ and the rest of the notation is as defined in the paper. The author's starting formula can be reduced to $\mu\lambda_2 = \sum_{k=0}^{n-i} \nu/i{+}k \cdot n/\nu{+}n \cdot n{-}1/\nu{+}n{-}1 \cdots i{+}k/\nu{+}i{+}k$. For several special cases, e.g., $i = 0$; $i = n$; $n = 2, i = 1$; $n = 4, i = 2$; these give exactly the same answers whether ν is an integer or not. From the form of both (when put in the form of rational polynomial fractions in ν with the denominators equal, the orders of the numerators are the same) it seems not unlikely that the two above formulas can be shown to be identical regardless of whether ν is an integer. (The algebra is likely to be tedious.) The use of the above formula makes for easier calculations since no tables of factorials are required, and it is probably not restricted to integral values of ν. When redundancy is involved the failure rate or hazard rate is often a better indicator of the worth of a device than the mean time to failure especially when mission time is short compared to element MTBF. This is so because there can be a tremendous drop in early failure rate due to redundancy, without very much of an increase in mean time to failure.

R67-13369 ASQC 824

EXPONENTIAL LIFE TEST PROCEDURES WHEN THE DISTRIBUTION HAS MONOTONE FAILURE RATE.

Richard E. Barlow (California University, Berkeley) and Frank Proschan (Boeing Scientific Research Labs., Seattle, Wash.).
Journal of the American Statistical Association, vol. 62, Jun. 1967, p. 548–560. 20 refs. Research partially sponsored by the Office of Naval Research.
(Contract Nonr-3656(18))

Tests and estimates for mean life and other parameters derived exponentially are investigated when the distribution has either an increasing (IFR) or decreasing (DFR) failure rate. Censored sampling to establish a specified mean life or a specified quantile life is discussed, as is sampling with replacement. Truncated life test plans are also considered. A lower bound is obtained for the expected value of two estimates of reliability appropriate under the exponential assumption for an IFT distribution, assuming a censored sampling plan. It is shown that the usual sampling procedures based on mean life generally favor the producer in the IFR case, and the consumer in the DFR case. Procedures based on the qth quantile tend to favor the consumer in the IFR case when the q is small. Positive bias in IFR distributions and negative bias in DFR distributions are noted for usual estimates.
M.W.R.

Review: This paper is part of the continuing effort of the authors to show how certain "standard" procedures, based on the assumption of negative exponentially distributed lifetimes, behave under "non-standard" conditions. In particular, this paper concentrates on the methods used for estimating mean life and distribution quantiles when sampling has been censored or truncated. The discussion is uniformly good with all requisite assumptions clearly given.

R67-13372 ASQC 820; 838; 872

RELIABILITY CONSIDERATIONS FOR A TWO ELEMENT REDUNDANT SYSTEM WITH GENERALIZED REPAIR TIMES.

Burt H. Liebowitz (Bellcomm, Inc., Washington, D. C.).
Operations Research, vol. 14, Mar.–Apr. 1966, p. 233–241.
(A66-28189)

The mean time to failure for a two element, redundant repairable system is derived. The system consists of identical elements each having a constant failure rate λ and a general repair time distribution, fR(x). The increase in expected time to failure of the system over a single nonrepairable element is calculated and found to be $M = 1 + \{1/2[1 - L_R(\lambda)]\}$, where $L_R(\lambda)$ is the Laplace transform of the probability density function of $f_R(x)$, with s equal to λ. M is plotted for elements having several different repair time distributions. For these cases M is found to be relatively independent of the distributions and primarily a function of the product λR (where R is the mean time to repair for a single element). The conclusion is drawn that redundancy and repair can greatly increase the operating time of the system described. Author (IAA)

Review: The improvement in mean time to system failure of a two-element redundant repairable system over a single nonrepairable element is calculated. Some asymptotic properties of the improvement factor are inferred by means of a computational example. It is shown in a subsequent note [1] that the asymptotic behavior can be inferred directly, and a discrepancy in the present paper is explained. In [1], a shorter derivation of the improvement factor is given, and dominant asymptotic terms for an N-element redundant system are given. These papers will be of interest mainly to theoreticians concerned with the mathematics of the standby redundancy problem, although the results could be of interest to engineers. In view of the broader picture which it gives, [1] should be studied together with the present paper.

Reference: [1] W. S. Jewell, Comments on "Reliability Considerations for a Two-Element Redundant System with Generalized Repair Times," *Operations Research*, vol. 15, p. 157–159, Jan.–Feb. 67

R67-13373 ASQC 821

SOME PROPERTIES OF STATISTICAL RELIABILITY FUNCTIONS.

Siv Carlsson and Ulf Grenander (Stockholm University, Sweden).

Annals of Mathematical Statistics, vol. 37, Aug. 1966, p. 826–836. 7 refs.

Networks with independent components are considered, and the functioning probability of these components is the basis for determining network reliability. It is assumed that all of the components have the same probability of functioning, and approximation and exact derivatives of reliability are developed for this restrictive case. It is shown that an arbitrary or randomized network can be approximated by a pure one with an approximation error of the order n^{-1}. Bounds are obtained for the maximum difference quotient and for the first and second order maximum derivatives, and an asymptotic result is obtained for the best possible approximation of a Lipschitz-type function. M.W.R.

Review: Some mathematical results are given pertaining to the reliability function for networks consisting of statistically independent components, all of which have the same probability of functioning. Attention is centered on networks of order n; in this respect the work is an extension of that in the papers covered by R61-10032 and R63-10850. These and other pertinent references are cited in the paper. While the original motivation for studies in this topic area had a technological background, the present work will be of interest only to those concerned with the mathematical theory of reliability.

R67-13375 ASQC 824; 838

RELIABILITY WITH STANDBY UNITS.

W. K. Rapp (Honeywell, Inc., Aeronautical Div., St. Petersburg, Fla.).

Electro-Technology, vol. 76, Sep. 1965, p. 68–70. 5 refs. (A66-24821)

Method for determining the reliability of series elements and interchangeable standby or spare units, so that standard redundancy techniques can be used in obtaining reliability in complex systems where several identical units are used in series. The technique uses a simple modification of the Poisson distribution for n or less failures, with the assumption that switching and replacement functions are not subject to failure. IAA

Review: This is a short, straightforward presentation of the mathematical analysis of series systems with standby units. It pertains to the case in which failures are statistically independent and follow the Poisson law. All elements are assumed to be identical. These restrictions place rather severe limitations on the practical usefulness of the results. However, this is no reflection on the work in the paper, which is of good quality.

R67-13385 ASQC 823; 844; 851

Ministry of International Trade and Industry, Tokyo (Japan). Electrotechnical Lab.

CUMULATIVE DEGRADATION MODEL AND ITS APPLICATION TO COMPONENT LIFE ESTIMATION

Hiroshi Shiomi *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 74–94 refs (See N67-10101 01-34) CFSTI: HC $3.00/MF $0.65
(N67-10106)

The degradation accumulation principle and stress-time transformation of reaction theory are useful estimation tools of component life. The difference between failure rate acceleration factor and life acceleration factor is pointed out. Given the Weibull shape parameter m, two factors are related by $aX = A_L{}^m$. The generalized cumulative degradation rule, $E(t_i/L) = 1$, is introduced. Using this rule, estimation and prediction of component life under successive different stress levels are possible both for drift and catastrophic failure. The advantage of the method is economic evaluation of component life by combining its past knowledge of life and stress history. Assuming the knowledge of drift pattern or shape of failure time distribution, 1nL: stress plot is estimated from the information of accmulated drift or failure versus stress plot obtained by one step stress experiment. Author

Review: This is a very difficult paper to read, perhaps because of the language problem. It is not always clear when the author is discussing the consequences of his model and when he is discussing what really happens. The term hysteresis is used in an unconventional and unclear way, since in a step-stress test there is never any chance for ordinary hysteresis. There are quite a few misprints in the algebra and in several cases it is not clear which of the equality signs refer to a definition and which are consequences of that definition. The author's statement is well taken that the linear accumulation of damage rule is often used, especially in mechanics, and there is considerable evidence that it is not too accurate. The algebra was not all checked in detail, so it is not known just how much the author used the linear accumulation of damage and how much he used something else. The reaction rate equation, Equation 2, attributed to Eyring, is in fact not his, although it does bear some resemblance. Equation 1 is a statement of faith in an ability to find a function, rather than a statement about the physical world. All in all the early parts of the paper tend to put a tremendous block in the way of the reader and the language problem aggravates it further on; so getting anything at all from the paper will require probably more effort than it is worth. In a private communication the author has stated that he feels that there are some valid contributions in the paper.

83 DESIGN

R67-13351 ASQC 838
INTRODUCING REDUNDANCY IN ANALOG SYSTEMS.
P. A. Jensen (Westinghouse Electric Corp., Atomic, Defense and Space Group, Defense and Space Center, Baltimore, Md.).
Electro-Technology, vol. 76, Nov. 1965, p. 75–77.
(A66-24733)

Description of the implementation, with logic circuits, of redundancy at the subsystem level in analog systems with one output error detector. The provision of subsystem redundancy with a single error detector is described, and logic circuits are analyzed. Circuits for standby redundancy at the system and subsystem level and for low level redundancy with a single error detector are indicated schematically. IAA

Review: A straightforward discussion is given of the implementation of redundancy at the subsystem level using logic circuits and a single error detector at the system output. This approach is particularly useful for analog systems because of the difficulty of error detection at internal points. The material is concisely presented and well illustrated. Four references are cited as the sources of some of the author's statements, and will be useful to those who desire more detail on these points.

R67-13352 ASQC 838; 817
REDUNDANCY DESIGN FOR THE VELA SPACECRAFT.
E. M. Noneman and T. J. Maxey (Space Technology Laboratories, Inc., Redondo Beach, Calif.).
IEEE, Proceedings, vol. 53, Dec. 1965, p. 1969–1981.
(A66-19970)

Various redundancy tradeoffs with respect to weight, power, reliability, and testing ability are discussed for the Vela spacecraft. The types of redundancy considered were complete circuit (such as quads), standby automatic switchable, standby command switchable, and fully automatic. Complete circuit redundancy was rejected because of weight and power limitations. Standby automatic switchable redundancy was rejected because of possible failure modes and complexity of the automatic detection circuits. Fully automatic redundancy was applied to those portions of the system where a failure would cause loss of the mission. Standby command switchable redundancy was applied to those portions of the system where a failure could be detected and corrected by command switching. The final redundant system is compared with a nonredundant system to indicate the additional weight and power required to accomplish the redundancy design. Author (IAA)

Review: This is a reasonably detailed discussion of the redundancy design of a particular spacecraft and its systems. It serves as an excellent example of various redundancy tradeoffs with respect to weight and power. The accomplishments of this spacecraft attest to the success of the design in achieving a reliable system. The principles applied have applicability to the design of similar systems.

R67-13353 ASQC 838
REDUNDANCY IN SYSTEMS DESIGN.
D. W. Lewin (Brunel College, London, England).
Wireless World, vol. 71, Nov. 1965, p. 557–560. 11 refs.

Component redundancy and logic subsystem redundancy are considered for use in data handling systems. Disadvantages of component redundancy are cited, including the restraints it places on the design of logic circuits. The increase in current and power required in combination with deterioration of performance tend to diminish any advantages that component redundancy may offer. Illustrations are presented of redundant logic systems using the voting principle and the switched standby principle, and binary codes in general as well as error detecting and correcting codes are discussed. It is concluded that when redundancy is necessary to obtain a high degree of reliability in real-time or on-line systems, the most economical method is to use switched hardware redundancy at subsystem level together with automatic fault location and switching on a routine test basis. For maximum reliability, error detecting and correcting codes and program checks should be included. M.W.R.

Review: A brief introduction to some of the concepts pertaining to redundancy in systems design is presented. These include hardware redundancy and error-detecting and correcting codes. The paper will serve a purpose for those who want a quick look at these topics; 11 references are cited for those who wish to delve deeper.

R67-13364 ASQC 830; 810
DOES MINIATURIZATION REALLY HELP RELIABILITY?
W. P. Wood (Martin Marietta Corp., Martin Co., Orlando, Fla.).
In: Wescon/65; Proceedings of the Western Electronic Show and Convention, San Francisco, Calif., August 24–27, 1965, Technical Papers, Part 1—Military Electronics. North Hollywood Calif., Western Periodicals Co., 1965. 3 p.
(A66-11464)

Review of a miniaturized component product improvement program in which mathematical modeling and data analysis showed that miniaturization would improve availability, transportability, and would enhance spares, stocking, and building block circuit replacement as well as reduce size and weight of such systems as the Pershing weapon ground support system. IAA

Review: A philosophy, the implementation of which can provide an affirmative answer to the question in the title, is stated in this paper. The author places the prime responsibility for reliability on the designer. Perhaps the most significant statement in the paper is the following sentence on p. 9: "The most effective reliability engineer is the designer." While this may be axiomatic to many, it seems to be overlooked by some. The paper is worthwhile reading for designers and reliability managers, more for the philosophy which it expresses than for technical details. Zero Defects is mentioned, giving this paper something in common with the author's later paper covered by R67-13124.

R67-13370 ASQC 830
FAILSAFE CIRCUITS.
Robert A. Solomon (Bendix Corp., Teterboro, N. J.).
EEE-Circuit Design Engineering, vol. 15, Apr. 1967, p. 94–96.

A failsafe circuit can be represented mathematically as a circuit that operates on two sets of input Boolean variables to yield a single output, and the equation and a model for such a circuit are illustrated. This equation is applied to a specific circuit in two steps to determine if the network is failsafe, and a proof is offered for a circuit interconnection. The design of failsafe circuits is accomplished by applying the failsafe criterion continually when developing each isolatable circuit function, and the procedure is illustrated with a simple amplifier circuit. Both internal and external failure modes are discussed. M.W.R.

Review: This is a brief description of a mathematical model representing the general characteristics of failsafe circuits, accompanied by a design example. The presentation is straightforward and clearly illustrated. It should be of value to designers of these circuits, which are finding application in complex aerospace systems. For the novice it should be pointed out that "failsafe" is a limited concept and applies only to some of the failure modes. Obviously there exist some failures for which a failsafe system does not "fail safe."

R67-13379 ASQC 830; 814; 835

2.5 RELIABILITY AND COST IN MICROELECTRONICS.

Akihiko Sato (Nippon Electric Co., Tokyo, Japan).
Electronics and Communications in Japan, vol. 49, Apr. 1966, p. 49–61. 12 refs.

General reliability considerations, failure modes and rates, and production costs are considered for semiconductor integrated circuits (IC) as well as for vapor-deposited thin film integrated circuits. Failures in such semiconductor circuits are classified according to their causes as due to defective structure of the semiconductor material, defective surface of the semiconductor, or defective connection; and failures in resistors, capacitors, and tantalum thin film are discussed in this light. Reliability and production design are detailed for these ICs, as is the demonstration of existing reliability. Prediction of costs is mentioned briefly, with the notation of the inherent difficulty in making such estimates. The development of new techniques for IC fabrication and the application of computers in circuit design and quality control should lead to significant decrease in cost, but these aspects are not discussed. M.W.R.

Review: This is a rather abstract discussion of reliability and cost considerations for semiconductor and thin-film integrated circuits, predominantly the former. Reliability receives the most attention, including failure classification, reliability design, and reliability demonstration. Some figures on the present reliability of integrated circuits are given. The section on cost analysis consists of discussing a few elementary cost functions. The presentation is reasonable for its intended level of depth, and will be useful to anyone desiring a general picture of these topics. Some 12 references are cited as sources of additional information on some points.

R67-13394 ASQC 838; 817

Stanford Univ., Calif.

IMPROVING THE RELIABILITY OF DIGITAL SYSTEMS BY REDUNDANCY AND RESTORING ORGANS

John Knud Knox-Seith (Ph.D. Thesis) Ann Arbor., Mich., Univ. Microfilms, 1964 104 p refs
(Rept. 65-2882)

The use of redundant circuits and restoring organs as a technique for improving the reliability of digital systems is evaluated, and guidelines for a near-optimum use of the technique in practical systems were established. Two types of restoring organs, majority vote takers and simple adaptive vote takers, were considered. A series of nomograms were developed for determining the optimum trade-off between the number of redundant circuits and the number of vote takers to be used in any given situation, and for determining the resulting increase in system reliability. Several conventional measures of reliability were considered. It is shown that the proper use of the redundancy and restoring organs technique can be a highly efficient one for increasing the useful life of a system, particularly when the acceptable probability of failure must be very small. In contrast, the efficiency of the technique with respect to increasing the mean time between system failures is quite modest. An example to illustrate the use of the technique in a practical system is included. Author

Review: This dissertation is a very comprehensive and useful presentation of the approach to reliability improvement using the "vote taker" method. It puts all of the current theory and some of the current practice as well in one place, with a lucid text and copious illustrations. The inclusion of nomograms for solving the cost-reliability trade-off problem is particularly useful. The paper has a sound statistical basis, is a very readable presentation, and the most thorough one since the von Neumann paper appeared in 1956. Every aspect of the theory is covered well. It should be in the library of everyone who is concerned with the design of reliable systems.

84 METHODS OF RELIABILITY ANALYSIS

R67-13348 ASQC 844; 851

SILICON PLANAR RELIABILITY AND THE FUTURE—PARTS 1 AND 2.

G. R. Latham (Ferranti, Ltd., Oldham, England).
Electronic Components, vol. 7, May 1966, p. 453–461. 1 ref.; Jun. 1966, p. 561–564. 2 refs.

Reliability problems associated with silicon planar devices are discussed in terms of the increasing complexity and high cost of failure of newly-developed equipment. Normal methods for assessing reliability, a series of reliability experiments, and overstress testing and integrated circuit reliability are considered. Failure stress distribution is illustrated for a mass production unit, and screening techniques applied to planar transistors and integrated circuits are shown. It is noted that the ultimate in component reliability might be defined in terms of two requirements: (1) There shall be no premature catastrophic failures. (2) The changes in characteristics over the use period shall be so small so as not to affect the circuit. Laboratory results suggest that aluminum wire bonds to aluminum contact pads give a less serious increase of saturation resistance under overstress conditions, although the aluminum bond does not exhibit the strength of a gold bond in integrated circuits. The importance of hermetic seals to integrated circuitry is also noted. M.W.R.

Review: The message of this paper is that silicon planar devices are inherently highly reliable; the most important sources of failure are (1) "foolish failures in manufacturing," those "not of any fundamental nature but the stupid, obvious type of mistake, usually mechanical in nature, which no sane engineer would permit if he could but foresee it," and (2) misuse by the customer. To eliminate "foolish failures" screens and accelerated tests are required. This paper describes in readable language those screens chosen to eliminate the "rogues" and the results of their use. One of the screens is a hot store at 300°C for 100 hours. For devices containing gold to aluminum bonds this screen probably shortens device life (see, for example, the Autonetics papers in the Physics of Failure in Electronics Volume 4). P-channeling in the n-type collector region is cited as an oxide-related failure. No doubt that is possible but by far the most common channeling failure is n-type channeling on a p-type region. No remedy for customer misuse is suggested.

R67-13349 ASQC 844; 720; 775; 851

STUDYING AND CONTROLLING IC RELIABILITY.

H. T. Go

Electronic Industries, vol. 25, Feb. 1966, p. 40–45.

(A66-20565)

Consideration of techniques for determining and controlling integrated circuit reliability. The reliability of a product is set by its design and process of manufacture. In order to obtain a continuous measure of process performance statistical control charts are a requirement. Reliability verification for semiconductor devices can be a stabilization bake, burn-in, step-stressing, or add-on life testing. Reliability measurement and verification are discussed and an expression is presented for a correlation index. Reliability screening may involve several alternative nondestructive methods such as scanning electron microprobes, IR techniques, noise measurements, or linear discriminant analysis. IAA

Review: A large number of subjects are covered in this brief article. The emphasis is both on the statistical monitoring of the dependent variables of integrated circuit production and on the use of improved nondestructive analytic tools such as the scanning electron microscope and IR thermal plotters. This emphasis seems to suggest that the major IC reliability problems are either unknown (need better tools to find them) or highly complex (need statistical data and analysis to sensibly control them); yet, nearly all the major problems cited for failure (Table 2) are of the "foolish failure" type—somebody made a mistake. Hence, improved quality control seems a more logical conclusion. Nearly every facet of integrated circuit reliability is touched upon. A knowledge of the terminology and techniques of statistical quality control will be needed in order to follow the methods recommended for production charting.

R67-13350 ASQC 844; 775

DETECTING FLAWS IN INTEGRATED CIRCUITS.

Richard A. Grossman (Sperry Rand Corp., Univac Div., Bluebell, Pa.).

Electronic Products, vol. 8, May 1966, p. 26–28.

A method presented for determining and photographing flaws in industrial-type integrated circuit packages is based on the use of long-wave ultraviolet light. The circuit unit is exposed under pressure to a fluorescent penetrant dye, which penetrates the flaws and fills all unsealed areas in the package. This makes to defective area glow in the presence of ultraviolet light. Test method, equipment, and materials are described, as are the techniques for both black and white and color photography. M.W.R.

Review: The title of this paper could be more specific; it actually describes a method for detecting flaws in an integrated-circuit package. The steps of the procedure are clearly described and in sufficient detail to be reproducible. Interpretation of the illustrative photos of dyed units including the color cover photo is less obvious but the reader is generally convinced of the ability of the technique to display flaws as claimed.

R67-13354 ASQC 840; 815; 844

Department of Supply, Melbourne (Australia).

PREDICTING THE RELIABILITY OF ELECTRONIC COMPONENTS

J. H. Sharpe [1965] 29 p Presented to the Electrical and Communications Engineering Branch of the Institution of Engineers Australia, 16 Aug. 1965

A lecture and subsequent discussion related to the prediction of electronic equipment reliability are presented. Failure rates for various types of equipment and the use of sampling tests to predict failures are considered. Attention is given to the interpretation of these predictions, the confidence levels of these predictions, and the established reliability specifications for the equipment. It is stressed that measuring the failure rate of electronic components is not an end in itself, and the use of other approaches for improving reliability is mentioned. Nondestructive screening techniques are discussed, and some failure rate data are included. M.W.R.

Review: This is a tutorial paper covering some of the fundamental concepts in the topic stated in the title. It is well written and will serve the needs of those who want to know something about reliability prediction without becoming involved with the details. Some of the discussion which ensued when the paper was presented is also reported, and contains some additional information. Included at the end of the paper is a short table of electronic component failure rates (reprinted from the paper covered by R67-13145).

R67-13357 ASQC 844; 835

Autonetics, Anaheim, Calif.

FAILURE MECHANISMS IN MICROCIRCUITS

G. V. Browning Jun. 1966 41 p refs

To improve circuit reliability of the Autonetics' microcircuit program, several failure mechanism studies were conducted. Technical results are presented for oxide studies, constitution and defects in oxide, package gas ambients, and mechanical-stress-generated failure mechanisms. In relation to nuclear or space radiation in industrial application, two factors are considered for failures: peak gamma dose rate, and neutron level. It was concluded that of the failure modes occurring with integrated circuits, many can be eliminated by improved screening and acceptance techniques. R.Ll.

Review: The scope of this paper is the entire spectrum of Autonetics' program in the reliability of microcircuits. The highly successful Minuteman investigations are reviewed, including the studies of failure of gold–aluminum thermocompression bonds. The impact of succeeding investigations of oxide properties and radiation effects cannot be fully assessed as yet but appear at present to be less significant. Several interesting techniques for delineating pinholes in oxides are described. Here, as in the entire paper, the presentation is a second-hand summary of the work of other individuals. The prime value of the report is to make the reader aware of the many practical, materials-related problems that Autonetics has investigated or is investigating.

R67-13358 ASQC 844

CHARACTERIZATION OF FAILURE MODES IN GOLD–ALUMINUM THERMOCOMPRESSION BONDS.

L. E. Colteryahn and D. D. Shaffer (North American Aviation, Inc., Autonetics Div., Anaheim, Calif.).

In: Wescon/65; Proceedings of the Western Electronic Show and Convention, San Francisco, Calif., August 24–27, Technical Papers. Part 2—Integrated Circuits. North Hollywood, Calif., Western Periodicals Co., 1965. 8 p.

(A66-11153)

Classical metallographic polishing procedures have been used to reveal failure modes in miniaturized electronic components such as integrated circuit devices. The accuracy and reliability of the observations made on polished cross sections depends upon the care used in preparing the specimen whose defective region may be often smaller than a few thousandths of an inch along any dimension and the knowledge of the analyst of materials and functions of the device. Careful metallographic examination of polished cross sections of electrically open and intermittently open gold–aluminum (Au–Al) thermocompression (TC) bonds in integrated circuit devices was the key to recognizing the existence of various failure modes in TC bonds. These failure modes could be associated with the presence of Au-rich intermetallic compounds once etching procedures were developed. Fracture along interfaces of what appear to be three intermetallic phases, along the interface between the aluminization and the oxide film, along the interface between the oxide film and the silicon chip, and along the interface between the band of intermetallic compounds on gold were identified as the major modes of failure from a metallurgical point of view. A postulated failure mechanism will be discussed in another paper. Author (IAA)

Review: The content of this paper is very similar to that of the paper by Browning, Colteryahn, and Cummings in Physics of Failure in Electronics Volume 4. Roughly half the illustrations are identical in the two publications. This paper together with the one by the author and J. F. Kersey also presented at WESCON 65 constitute an earlier version of the Physics of Failure paper. All the key ideas of the earlier papers appear in the latter. Thus the reader who is familiar with the Physics of Failure paper can probably skip this paper with a clear conscience. The Autonetics work, however, is too significant to skip altogether for anyone seriously concerned with the reliability of electronic devices using aluminum–gold thermocompression bonds.

R67-13359 ASQC 844

FAILURE MECHANISMS AND KINETICS OF INTERMETALLIC FORMATION.

L. E. Colteryahn and J. F. Kersey (North American Aviation, Inc., Autonetics Div., Anaheim, Calif.).
In: Wescon/65; Proceedings of the Western Electronic Show and Convention, San Francisco, Calif., Aug. 24–27, 1965, Technical Papers. Part 2—Integrated Circuits. North Hollywood, Calif., Western Periodicals Co., 1965, 10 p.

Several mechanisms were postulated to explain the various modes of failure that have been observed in gold TC bonds to aluminum metallized integrated circuits. The most important of these mechanisms are (1) notch initiated cracks along strained interfaces due to lattice mismatch between intermetallic phases and (2) void formation due to mass transfer (Kirkendall Effect) at phase interfaces. Observation of these modes and confirmation of the mechanisms are discussed. Both of these mechanisms are associated with the growth of the various intermetallic regions, and the second is directly connected with gold diffusion external to the bond. Consequently the kinetics of phase growth and gold migration are investigated. Activation energies are calculated and are found to agree in magnitude with published data for various processes in the gold–aluminum system. Author

Review: This paper presents a clear description of the model hypothesized for both the open and the intermittently-open type of gold–aluminum thermocompression bond. This model is not explicitly explained in a subsequent paper (see Browning, Colteryahn, and Cummings in Physics of Failure in Electronics Volume 4), presumably on the assumption that the reader is already familiar with it. The experiments verifying the Kirkendall effect in the aging of gold–aluminum bonds are clear-cut and convincing, a refreshing experience in a technology so often based on guesses and intuition. This does not mean that the problem is therefore solved; it is not, but it is much better understood.

R67-13360 ASQC 844; 775

Philco Corp., Lansdale, Pa.

RELIABILITY PHENOMENA IN ALUMINUM METALIZATIONS ON SILICON DIOXIDE

W. M. Berger, R. S. Keen, and G. L. Schnable *In* RADC Phys. of Failure in Electron., Vol. 4, Jun. 1966 p 1–31 refs (See N67-10101 01-34)
(Contract AF 30(602)-3610)
(N67-10102) CFSTI: HC$3.00/MF$0.65

Phenomena observed during operation life, and results of analysis of operating circuits using a high resolution thermal plotter as a tool to determine localized temperatures are discussed. The effects of storage life are reviewed, with a discussion of the phenomena involved. The limitations of aluminum metalization on silicon integrated circuits and devices are summarized and conclusions drawn relative to the mechanisms involved. Possible techniques for improving device or circuit reliability are outlined. Author

Review: These investigations are among the few employing a thermal plotter (IR detecting cell) to evaluate solid state electronic devices. Among other results, the authors have here quantitatively measured the temperature rise attributable to a current-carrying metal layer passing over an oxide step or turning a corner. The temperature rise itself is not surprising; a quantitative measurement of the temperature rise, however, is new. Other effects and phenomena can also be studied using the thermal plotter as an investigative tool. Here again, its value lies primarily in providing quantitative temperature measurements to confirm postulated reactions. This paper is a continuation of the work previously discussed in the paper covered by R67-12932 and reported in greater detail in [1].

Reference: [1] G. L. Schnable and R. S. Keen, "Study of Contact Failures in Semiconductor Devices," RADC-TR-66-165, April 1966, Final Report, Contract No. AF 30(602)3610, Rome Air Development Center, Griffiss Air Force Base, N. Y. (AD-483 847)

R67-13362 ASQC 844; 813

THE RELIABILITY OF SOLID-STATE TRANSDUCERS.

R. P. Heile (Electro-Optical Systems, Inc., Pasadena, Calif.).
In: National Telemetering Conference, Houston, Tex., April 13–15, 1965, Proceedings. Conference sponsored by the Instrument Society of America, American Institute of Aeronautics and Astronautics, and Institute of Electrical and Electronics Engineers. Edited by Lewis Winner. New York, Lewis Winner, 1965, p. 111–115. 9 refs.
(A65-24206)

Description of procedures for evaluating the reliability of solid-state aerospace transducers. To illustrate these procedures, the program developed to evaluate a pressure and temperature transducer is reviewed. The transducer consists of a voltage regulator, dc–dc converter, filters, current regulator, four semiconductor piezoelectric sensors, and a low-gain differential amplifier. The test program includes an electrical stress analysis and associated failure computations; thermal, mechanical, package, electronics, and circuitry analyses; an analysis of failure modes and their associated effects; a reliability analysis; developmental life tests; and a quality assurance program. IAA

Review: This paper is closer to sales literature than technical literature. A chief aim appears to be to convince the reader of the merits of a particular pressure transducer. As such, the paper serves its purpose well—no proprietary information is lost and the impression of a well-tested product, representative of the forefront of technology, does emerge. Very specific numbers for the predicted failure rate of the transducer are given but no statement is made about the assumptions involved in calculating these numbers from the failure rates of the component parts. The failure rates of many of the component parts are not explicitly stated; the transducer circuit is described by a functional block diagram only, not a circuit schematic. The reader must therefore accept the claims on faith. The audience for this paper is a potential user of the transducer—a "customer."

R67-13363 ASQC 844; 775

INFRARED DETECTION OF MICROCIRCUIT METALIZATION FAILURE MECHANISMS.

William M. Berger (Philco Corp., Lansdale, Pa.).

Spring Convention of the Society for Non-Destructive Testing, Los Angeles, Calif., Mar. 8–11, 1966. 29 p. 5 refs.

Operating life results and thermal plotter studies are discussed in terms of failure modes and infrared detection of microcircuit metallization. Effect of operating life on failure modes is considered, as are the effects of geometry on localized heating and the disappearance of metallization. Formation of an aluminum–silicon eutectic, which causes a metallization failure mode, is described; and causes of this growth are considered. Thermal resistance is discussed as a function of heat source area, and thermal resistance to a free-air resistor network is shown. Automatic infrared scanning with intensity modulate cathode ray displays is discussed. Specific approaches to counteract Al–SiO metallization are noted that will offer possible means of improving device and circuit reliability. M.W.R.

Review: This presentation is partly a restatement of the work described in the paper by the author and associates in Physics of Failure in Electronics Volume 4 (Reference 5 in the present paper). Figures 2 through 15 of this paper are also used in that paper. Portions of the text are identical—those which illustrate the use of a thermal plotter in understanding the various temperature-dependent reactions that can lead to device failure. The second part of the paper is a qualitative discussion of the role of the thermal plotter in circuit design and topological layout. Thermal design of microcircuits is still an art. Through use of a tool such as the thermal plotter, the possibility of making it more scientific seems real, although little more than ideas are presented here—no significant step toward that goal is taken.

R67-13368 ASQC 844

IDENTIFICATION OF THERMAL COMPRESSION BOND FAILURES.

D. G. Cummings (North American Aviation, Inc., Autonetics Div., Anaheim, Calif.).

In: Wescon/65; Proceedings of the Western Electronic Show and Convention, San Francisco, Calif., August 24–27, 1965, Technical Papers. Part 2—Integrated Circuits. North Hollywood, Calif., Western Periodicals Co., 1965. 3 p.

(A66-11152)

Investigation of the electrical opens caused by the separation of the bonds formed in making internal interconnects on the circuit boards of the advanced Minuteman guidance system. Physical characteristics of the system are discussed, together with processing which is performed after the lidding operation. Methods of troubleshooting are outlined, and procedures and manufacturing processes used to correct circuit board malfunctions are described. Processing changes are tabulated, and a circuit board with integrated circuits is illustrated. IAA

Review: This short, well written paper is an introduction to Autonetics' intensive investigation of gold–aluminum thermocompression bonds. It contains some surprising conclusions and provides dramatic insight into the intermittent open problem encountered with the integrated circuits of Minuteman. The Autonetics investigations reported in the papers by Browning, Colteryahn, Cummings, and associates, which are reviewed in this issue of RATR, have resulted in significant contributions to the understanding of the gold–aluminum thermocompression bond. This paper is an ideal starting point for the reader who plans to acquaint himself with that work.

R67-13371 ASQC 845

THE NEED FOR INTERNATIONAL EXCHANGE OF RELIABILITY DATA.

Torsten Gussing (Military Electronics Lab., Stockholm, Sweden).

Electronic Components, vol. 7, Jul. 1966, p. 657–660.

Efforts in Europe to promote the international exchange of reliability data on electronic components and equipment are documented, and the advantages and needs for such an exchange are stressed. Problems arising because of the international exchange of information are cited, such as the diversity of reporting procedures and the different kinds of testing procedures and standards employed. An objection to such a center is the cost of its implementation. It is stressed, however, that no company or country can afford to be without such a cooperative effort, which could set internationally accepted specifications to benefit both manufacturers and customers. M.W.R.

Review: In an earlier paper (see R66-12757), a plea was made for a British national assessment center for reliability data on electronic components and equipment. This paper goes a step further and suggests an international pool of reliability data, accessible to all participating countries. The need and desire for this information exchange are outlined, and some of the objections to it are raised and answered. Like the proposal for a national center, conceptually this is an excellent idea and hopefully will eventually come to fruition. For this to happen, the idea must get the attention of people in the various countries who are willing and able to work toward overcoming the difficulties and promoting an awareness of the benefits to be gained. A major obstacle, as the author has indicated, is the lack of internationally-known and accepted standard testing specifications. It should not be expected that these can be developed quickly or easily—they will likely be slow in evolving. As a practical matter, even the limited efforts in this country have such severe limitations (other than size) that their usefulness is severely compromised. The biggest problem is the unreliability of the data.

R67-13377 ASQC 844; 833

THE "LIFE" OF THE ELECTROLYTIC CAPACITOR.

Louis Kahn

Electro-Technology, vol. 76, Aug. 1965, p. 48–49.

Wear-out or gradual failures in electrolytic capacitors is considered in terms of reliability and quality control during manufacturing, handling, and storage processes. It is noted that the life expectancy of these capacitors is determined by external conditions rather than its own parameters; and the actual mechanisms involved in capacitor operation must be considered to determine the possible rate of change in the various parameters. The exponents for determining the life of an electrolytic capacitor are large, and any acceleration of life testing becomes difficult because precise control of temperature and voltage are required for accurate results. Since a reliable and useful accelerated life test has yet to be developed, it is suggested that the best method of assuring reliability is by material, manufacturing, and process control along with inspection procedures and a quality assurance program on the finished product. M.W.R.

Review: This paper presents a brief description of failure modes for a rather special component: the electrolytic capacitor. It will be of interest to those concerned with the testing or application of these components. In particular, the accelerated life testing of these capacitors presents special problems, and reference is made to the present lack of a reliable and useful accelerated life test for them.

R67-13383 ASQC 844; 775

Lockheed Missiles and Space Co., Palo Alto, Calif.

THE ROLE OF METALLOGRAPHY IN THE ANALYSIS OF FAILURES OF ELECTRONIC COMPONENTS

William C. Coons *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 32–45 refs (See N67-10101 01-34) CFSTI: HC$3.00/MF$0.65

(N67-10103)

Suggested techniques for preparing microelectronic components for metallographic analysis are outlined. To illustrate the role of metallography in analyzing failures of electronic components, three examples are presented. The examples show the results of a nondestructive examination of a PbS infrared detector; a 90-degree cross section examination through gold to aluminum thermocompression bonds on silicon transistors; and taper section studies of gold, molybdenum, and silica films on silicon substrates and of a gold to aluminum joint. R.N.A.

Review: The primary value of this paper is an introduction to metallographic techniques for the reader not previously familiar with them. The steps in sample preparation are clearly presented, and among the metallographic sections used to illustrate the techniques are several excellent photomicrographs of gold wire bonds to aluminum pads on silicon integrated circuits. The formation of the various gold–aluminum compounds are depicted with unusual clarity (the "purple plague" compound $AuAl_2$ evidently appears pink in this investigation); chemical etching was not required to delineate these phases, in contrast to the conclusions of other investigators (see the paper by Browning et al. pp. 428–446 in the same volume). The exposition breaks down in the section entitled "(3) Taper Section Studies. . . ." For example, the description of angle lapping is that "This is performed by providing a cross section of the film planes at such an angle to the planes that the cosecant of the angle would be sufficiently large to render the films sufficiently optically thick that they could be measured." Labels are omitted from Figs. 11 and 12 altogether, making them unnecessarily difficult to interpret.

R67-13386 ASQC 844; 833

Massachusetts Inst. of Tech., Cambridge. Instrumentation Lab.

THE APPLICATION OF FAILURE ANALYSIS IN PROCURING AND SCREENING OF INTEGRATED CIRCUITS

Jayne Partridge, Eldon C. Hall, and L. David Hanley *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 95–140 refs (See N67-10101 01-34) CFSTI: HC $3.00/MF $0.65

(N67-10107)

The procedure for testing, screening, and lot rejection of integrated circuits for the Apollo guidance and navigation computer is described. Based on a knowledge of failure modes, failure mechanisms, and contributing causes to failures in manufacturing, the method tries to increase integrated circuit reliability by screening and analyzing weak devices and using the generated data to quantitatively assess the lot for acceptance, rework, or rejection. Data are given showing variations among vendors and among procurement lots shipped from a single vendor. Factors contributing to the variations are discussed. The appended process documents include stress test procedures, failure modes, internal visual rejection criteria, and leak test procedures. The evolution of the process documents, which have the ultimate goal of eliminating or minimizing detected failure modes, is discussed. The described process is a continuous monitoring procedure for qualifying parts and vendors, and creates an incentive on the part of the vendor to eliminate causes of failures. R.N.A.

Review: This paper was covered by R66-12467.

R67-13388 ASQC 844

Electrical Research Association, Leatherhead (England).

FAILURE MECHANISMS OF ELECTRONIC COMPONENTS

H. F. Church and B. C. Roberts *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 156–177 refs Supported by the Elec. Res. Assoc. and the Min. of Aviation (See N67-10101 01-34) CFSTI: HC$3.00/MF$0.65

(N67-10109)

An attempt is made to summarize all known failure mechanisms which can affect conventional passive electronic components. The specific causes of component failure discussed include accidental damage during manufacturing or assembly; failure during storage; mechanical damage due to shock or vibration; mechanical wear; material instability which includes thermal instability, moisture effects, and material incompatibility; metal migration and electrolyte corrosion in the presence of moisture; electrochemical effects in the absence of moisture; surface failure (tracking); localized arcing initiated by mechanical defects; failure due to gaseous discharges; mould growth; and miscellaneous failures peculiar to particular components. The survey concludes that highly reliable electronic components are attainable only if the causes of failure are understood and eliminated in advance by correct design and production control. A specified level of performance in short term tests cannot insure reliability. Many of the conclusions reached, based on long term trouble shooting experience and component testing, are of a basic nature and are likely to apply to the recent developments in electronic devices, especially microcircuits. R.N.A.

Review: The scope and purpose of this paper are similar to those of Borofsky and Fleming (see p. 561 in the same volume)—a written record of electronic component failures and the measures taken to avoid their recurrence, presumably in the hope that others (both users and manufacturers of electronic components) might benefit from the experience of the authors and their organization. The facts are presented in a narrative form instead of in tables as in Borofsky's paper. The latter paper is consequently a more convenient reference; the present paper, a more complete discussion.

R67-13392 ASQC 844
Autonetics, Anaheim, Calif.
FAILURE MECHANISMS ASSOCIATED WITH THERMOCOMPRESSION BONDS IN INTEGRATED CIRCUITS
G. V. Browning, L. E. Colteryahn, and D. G. Cummings *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 428–446 (See N67-10101 01-34) CFSTI: HC $3.00/MF $0.65
(Contract AF 04(694)-247)
(N67-10126)

An investigation was conducted to determine the cause of failures encountered in gold–aluminum thermocompression bonds between gold wire and aluminum metalization on SiO_x-silicon dice in integrated circuit devices. The gold–aluminum interconnects in integrated circuit devices were found to display a time-temperature dependent mode of failure. This is the result of an interdiffusion of gold and aluminum and the tendency to form gold rich intermetallic compounds at elevated temperatures. There are some indications that air treatment causing oxidation of the pad and the associated circuitry has some retarding effect. The use of other metals, such as molybdenum, to act as diffusion barriers further retards interdiffusion. Temperature variation, static charges, and normal operating voltages can cause intermittent closure of open bonds. R.N.A.

Review: This paper is based on intensive experimental investigations of the Au–Al system, particularly as it occurs in a thermocompression bond. It is full of interesting information. Although all elements are presented, the reader must piece the complete picture together for himself from the large number of reported observations. The details of the postulated model are not explicitly stated and different readers may arrive at different models. The conclusions seem to be that complete opens are caused by bond separation at the boundary between two different gold-rich phases; intermittent opens are caused by the Kirkendall effect at the bond periphery. Neither effect depends on the formation of purple plague. The Au–Al system is declared "inherently unreliable" but the authors show that the failure rates of Au–Al bonds in Minuteman operations are expected to be quite low.

R67-13393 ASQC 844
Autonetics, Anaheim, Calif.
FAILURE MECHANISMS ASSOCIATED WITH THERMALLY INDUCED MECHANICAL STRESS IN MINUTEMAN DEVICES
C. G. Jennings *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 447–463 refs (See N67-10101 01-34)
CFSTI: HC $3.00/MF $0.65
(Contract AF 04(694)-247)
(N67-10127)

Metallographic examination of power transistors exposed to a selected assortment of thermal conditions indicated that their failure modes were associated with thermally induced mechanical stress. The evidence of plastic flow and abnormalities, also observed by metallographic examination, led to the postulation of three dependent failure mechanisms: (1) thin brazements between die and pedestal, and pedestal and header reduce plastic flow capability, (2) thermal cycling of devices as a screening technique causes strain aging in the brazement, and (3) nickel–silicon intermetallic formation reduces the strength and/or plastic flow capability of the brazement. Experiments are described which demonstrated the effect of thermally induced mechanical stress as an underlying failure mechanism in several semiconductor devices. The stress superimposes on other residual fabrication and service stresses to give a total composite stress. For the normal high reliability device, this stress is not sufficient to cause failure. However, when coupled with the above mentioned dependent failure mechanisms, it produces failures of significant importance in high reliability systems such as Minuteman. R.N.A.

Review: If a paper is sufficiently sloppily presented, even the most tolerant reader becomes hostile and tends to reject the ideas, almost independently of merit. If the author fails to spend the time required to straighten out the mechanical, "routine" details of a presentation, the inference is that the more challenging technical problem being discussed has received similar (or worse) shabby treatment. In short, the reader is prepared to reject rather than accept. This paper borders dangerously on doing this very thing by possessing a large number of petty faults: (1) *Inadequate labeling.* The symbols of Fig. 1 are not defined. If the reader is not already familiar with the equation, he must guess. Presumably E_A, E_B are elastic moduli; γ_A, γ_B are linear coefficients of thermal expansion; and τ_A, τ_B are thicknesses. The reader cannot verify the author's calculation of stress without looking up values for the elastic coefficients (which may not be easy to find) and guessing at the assumptions made by the author for the thicknesses involved. (2) *Misplaced emphasis.* The caption of Fig. 3b is probably a misprint. The items being described in Fig. 3 are not clearly indicated in the illustrations; irrelevant distracting markings (i.e., a large printed S in one photo, a large printed 9 in the other photo, and what apparently are instructions to the printer in both photos) dominate the figure. The location of the temperature sensor is not really clear from this illustration. It appears to be placed between the silicon die and the molbydenum pedestal, but this is a guess; the strain gauge apparently is placed on top of the silicon die. (3) *Vague statements.* "The principles of operation are the same for the strain and temperature gauges." This statement presumably means that the electrical measuring principles are the same in that the resistance of both gauges changes with the variable being measured—not that the physical principles of sensor operation are the same. (4) *Grammatical errors.* Experiment is used as an adjective—"experiment stress"; "is shown" should be "are shown" at the bottom of page 448. When all these examples occur in the first two pages of text, as they do in this paper, many readers will, in spite of themselves, feel unreceptive toward what follows. Probably no great harm is done since what follows is more of the same: temperature is sometimes measured in °F and sometimes in °C; in Figs. 8 and 11 both °F and °C appear; and in Fig. 13 the abscissa is labeled °F while the text describes the temperature for that data in °C. One could go on listing minor objections. The major shortcoming is that this account does not give the reader an unambiguous description of what the author means or what he has done. This is unfortunate, for many readers are vitally interested in this subject and would really like to know what the author has learned. The author's conclusion is: "The effect of thermally induced mechanical stress has been illustrated as being an underlying failure mechanism in a number of semiconductor devices. This stress superimposes on other residual fabrication and service stresses to give a total composite stress. For the normal high reliability device, this stress is not sufficient to cause failure. It does, however, couple with other dependent failure mechanisms to produce failures of significant importance in high reliability systems such as Minuteman."

R67-13395 ASQC 844; 711; 714
Autonetics, Anaheim, Calif.

PROPERTIES OF PLASTIC MATERIALS AND HOW THEY RELATE TO DEVICE FAILURE MECHANISMS

S. M. Lee, J. J. Licari, and A. Valles *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 464–492 refs (See N67-10101 01-34) CFSTI: HC $3.00/MF $0.65
(Contract AF 04(694)-247)
(N67-10128)

A search was made for factors pertinent to failure mechanisms in microdiode values which entailed design and screening evaluation of various experimental and analytical approaches. The resulting data was reviewed for applicability to known or conjectured failure mechanisms which were applied to these components to verify postulated hypotheses. An ammonia contaminant was discovered in a phenolic molding compound used by a diode manufacturer which produced increased and erratic reverse currents and was more pronounced in the presence of moisture. The presence of ammonia and other deficiencies in the molding compound induced an investigation of other materials. The high temperature resistivities of coatings were used as a measure of performance for these materials as protective systems over diodes under high temperature test conditions. In some plastic compounds, a correlation was found between high temperature resistivities and water extract resistivities. Teflon had superior performance under high temperature reverse bias and high humidity reverse bias test conditions. The resistivity of water extracts of evaporants was used to effectively indicate the amount of ionic and other conductive impurities in plastic materials.
R.N.A.

Review: This paper describes a series of diverse experiments designed to assess various properties of plastic encapsulants such as stability, permeability, chemical activity and electrical resistivity. The correlations between these properties of the plastic and its performance as a plastic encapsulant seem low enough that the reader may well conclude that the simplest, most sensitive, and perhaps most economical method for evaluating a plastic encapsulant is to go ahead and encapsulate a diode in it and monitor the diode stability. The discovery of ammonia in one commercial plastic encapsulant and the recommendation of teflon as a superior encapsulating material are noteworthy. Major points of confusion in the paper are the following: (1) The constants A and B in the Arrhenius equation do not fit the 200-V data on Fig. 6 as claimed (two 200-V curves appear but neither is described by $I = 24 \exp [+8.39 \times 10^3/T]$). (2) On p. 476 mobile ions in the plastic which move under the influence of an electric field are hypothesized to induce inversion layers and high leakage currents. But several sentences later the statement is made that baking the plastic-encapsulated diodes *under* reverse or forward bias tends to remove the high leakage currents and hence verify the hypothesis. This logic is difficult to follow or else the argument is incomplete. In a subsequent private communication, the first author states: (1) The correct Arrhenius equation is $\ln I = 24 + (-8.39 \times 10^3)/T$, which was fitted to the data on Fig. 4 (not Fig. 6 as the text states). (There are still two 200-V curves. This equation fits the 200-V curve labelled stoichiometric). (2) The word "under" (italicized above) should be changed to "without."

R67-13396 ASQC 844
Autonetics, Anaheim, Calif.

INVESTIGATION OF SURFACE FAILURE MECHANISMS IN SEMICONDUCTOR DEVICES BY ENVELOPE AMBIENT STUDIES

G. V. Brandewie, P. H. Eisenberg, and R. A. Meyer *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 493–521 refs (See N67-10101 01-34) CFSTI: HC $3.00/MF $0.65
(Contract AF 04(694)-247)
(N67-10129)

A method was developed to analyze the gas ambient of good and failed semiconductor devices by use of a mass spectrometer with a mass range of 1 to 1400 and a unit resolution at mass 700. Techniques were developed so that the device junction would not be destroyed when the package was opened. Electrical measurements were made before, during, and after removal of the ambient and after back-filling with selected ambients. Other techniques were developed using the gas chromatograph for analysis. Several examples in which device package gas ambients were an important factor regarding the failure mechanisms are described. A survey of Minuteman II transistor and integrated circuit package ambients indicated that the gases present are a result of the manufacturing processes and are not well controlled.
R.N.A.

Review: The results reported in this paper are shocking! Many papers at previous Physics of Failure symposia have demonstrated the importance of surface contamination and the ambient surrounding silicon planar devices; yet here, years later, it appears that the composition of the gases surrounding encapsulated devices are not standardized, not controlled, and not even known by the manufacturers. In retrospect, the investigation reported here seems long overdue. The appearance of outgassing contaminants is an insidious situation which, now that it is identified, should be minimized or eliminated as a source of failure. This chain of events is what Physics of Failure is about. There are some distracting errors in the paper: manufacturer A should read manufacturer X on p. 508 (there is no manufacturer A); Table 1 on p. 504 should read Table 2; k, t, p, and K, T, P are apparently used interchangeably on pp. 508 and 509 (kT might naively be assumed to be a unit of thermal energy—here it actually means leak rate x time/volume).

R67-13397 ASQC 844
Autonetics, Anaheim, Calif.

DESIGN AND PROCESS CONTRIBUTION TO INHERENT FAILURE MECHANISMS OF MICROMINIATURE ELECTRONIC COMPONENTS FOR MINUTEMAN II

A. J. Borofsky and D. C. Fleming *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 561–595 refs (See N67-10101 01-34) CFSTI: HC $3.00/MF $0.65
(Contracts AF 04(694)-247; AF 04(694)-626; AF 04(694)-402)
(N67-10131)

High-stress testing of 200,000 microminiature components used on Minuteman II, and subsequent analyses of failures, have demonstrated deficiencies in design and processing of these microminiature components. These tests and analyses were made during the course of the Component Quality Assurance and Component Evaluation Programs. A summary of these results is given. It provides criteria for establishment of designs and processes for microminiature transistors, diodes, capacitors, resistors and integrated circuits. Solutions for demonstrated deficiencies are identified and categorized in terms of design improvement, process and tool changes, inspection changes, and screens. The role of component procurement documents and component qualification procedures in the assurance of proper design and processing of high reliability microminiature components is discussed. The effectiveness of these procedures in elimination of design and process inherent failure mechanisms is shown. Author

Review: Of the 32 pages of text in this paper, 23 are composed of 10 tables listing the sources of failure found in 10 different Minuteman components from resistors to integrated circuits. Much useful information is thereby compactly presented, including a record of the corrective action associated with each failure type. These tables serve as a useful history of Minuteman experience and should be valuable as a guide for future procurements of large electronic systems.

85 DEMONSTRATION/MEASUREMENT

R67-13361 ASQC 851; 844

Philco Corp., Lansdale, Pa. Microelectronics Operation.

THIN FILM ACCELERATED LIFE TESTS Technical Report, 10 Feb. 1964–10 Feb. 1965

M. J. Walker and M. Sharp Griffiss AFB, N. Y., RADC, Jun. 1965 160 p refs

(Contract AF 30(602)-3287)

(RADC-TR-65-137; AD-619689; N65-34138)

The purpose of the program is to study, investigate, and develop test and measurement techniques for controllably accelerating the aging processes in tantalum thin film R–C networks, and to study and investigate the physics of failure associated with the R–C networks. The initial phase of the program included a review of related literature, the construction of individual tantalum thin film resistors and capacitors, accelerated testing of these structures, and failure mechanism determination. A number of failure modes were determined as a result of testing and analysis of the individual resistors and capacitors. There are indications that three basic failure mechanisms are related to all failures and are the failure rate controlling mechanisms; they are: (1) oxidation; (2) ion migration; and (3) crystallization (both field-induced and temperature induced). Some rate information was determined on the oxidation mechanism. Author

Review: This report contains a large quantity of data describing the performance of tantalum thin film resistors and capacitors. The report is workmanlike and appears thorough, even though few novel ideas are developed. The announced objective of developing meaningful accelerated tests for tantalum components is not fulfilled here. A concluding section states what should or will be done to finish the job.

R67-13384 ASQC 851; 844

General Electric Co., Philadelphia, Pa. Missiles and Space Div.

A TECHNIQUE FOR CONTROLLABLE ACCELERATION AND PREDICTION OF DEGRADATION MECHANISMS OF ELECTRONIC PARTS

M. Rocci (RADC) and T. Walsh *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 59–73 Supported in part by NASA (See N67-10101 01-34) CFSTI: HC $3.00/MF $0.65

(Contract AF 30(602)-3415)

(N67-10105)

The results of an accelerated test program on electronic parts and the use of the test data to predict the life characteristics of the parts are discussed. Examples are given to illustrate the analysis method used for combining the results of the various test phases into a stress versus expected life chart which may be used in designing long life equipment. The two general techniques used for the data analyses are described and data are given to illustrate each technique. Recommendations are also included for the design and analysis of future accelerated test programs. R.N.A.

Review: This paper is concerned with some accelerated tests run for RADC and NASA. It is typical of the kinds of analysis of accelerated testing that appear in the literature. The step-stress tests are the type which presume that all of the damage accumulated at stresses lower than that at which failure occurs is negligible. The program appears to have been well conceived and well carried out, although examples of the analysis show the usual fit of the data to the straight lines, namely, not very good. Even though the measure of degradation was selected so that its rate versus temperature has the same form as the Arrhenius equation, there is no reason to suppose that the two kinds of things are directly related. This is so because the selection of a function of the degradation rate is chosen without regard to anything except making the equation fit (and, of course, presumably simplicity). The curves in Fig. 5 are especially poor fits to the data in the sense that one *would certainly tend to draw other curves did* he not have some prior knowledge in mind. In Fig. 6 where testing is done at high stress levels and time to failure extrapolated to a use level, the median points of a distribution are implicitly presumed to lie on a straight line. While this is especially convenient for extrapolation, there is no prior reason given for such an assumption. Fig. 8 is another example of a very poor fit of a line to the data; the occurrence of almost half the failures at one time suggests that the hypothesis of Normality is most inappropriate. Any use of accelerated testing, of course, involves extrapolation. Some authors seem to be more aware (as demonstrated by their actions rather than their cautions to the reader) of the difficulties and risks associated with such extrapolation. Estimates of the uncertainty involved are always worthwhile, and it helps if the author indicates whether the points are indicating to him the shape of the line or if he is trying to see if the points can be reasonably supposed to fit the line.

R67-13387 ASQC 851; 844

Bell Telephone Labs., Inc., Laureldale, Pa.

LIFE PREDICTIONS OF DIFFUSED GERMANIUM TRANSISTORS BY MEANS OF POWER STRESS

W. C. Gibson *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 140–155 refs (See N67-10101 01-34) CFSTI: HC $3.00/MF $0.65

(N67-10108)

A study was conducted to show the feasibility of power stressing germanium devices to obtain meaningful life predictions. The approach followed to *achieve this objective* was to insure that failure modes often observed when using power stress methods were not the result of inadequate or aging equipment, to secure a safe device operating range without introducing abnormal failures, to stress device samples based on these findings and predict device life, to compare the prediction with temperature stress life predictions of this and a similar device, and to comment on "in service" results. The study showed that meaningful predicted life expectancy of germanium devices can be determined from power stress results if test sets and aging facilities do not introduce failures, and if the safe device operating region is predetermined and operation is kept within this region. Power stress results for the germanium device yielded 2 magnitudes shorter life for a given temperature than did temperature stress results even after extensive precautions were taken to eliminate abnormal failure mechanisms. R.N.A.

Review: This is a worthwhile extension of earlier work on accelerated testing of germanium transistors. The fact that current crowding can exist and seriously disrupt the electrical and thermal behavior of the transistor may help to explain some of the results that Partridge observed earlier, and helps to define a reasonable area for accelerating the testing of germanium transistors. Power stressing gives only about 1/10 the life that temperature stressing does, although both are estimated to have the same activation energy of 1.6 eV. The behavior is presumed to follow the Arrhenius equation although no attempt is made to have the curve fit the detailed distribution of the points. Without this prior emphasis one would certainly draw different lines through those points. The results of the accelerated testing are extrapolated both to low probabilities and to rated stresses and compared with inservice results. The estimated failure rate is too high. The quite reasonable explanation is that the transistors are operated at lower than their ratings. All in all this paper furthers the state-of-the-art in accelerated testing by emphasizing the need for care in choosing the accelerated conditions.

R67-13389 ASQC 851; 844

Philco Corp., Lansdale, Pa.

ACCELERATED AGING AND FAILURE MECHANISM ANALYSIS OF THIN TANTALUM FILM R–C NETWORKS

M. J. Walker, A. Mc Kelvey, G. L. Schnable, and M. Sharp *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 179–209 refs (See N67-10101 01-34) CFSTI: HC $3.00/MF $0.65 (Contract AF 30(602)-3287)
(N67-10110)

Accelerated stress testing of tantalum thin film resistor–capacitor networks was conducted to establish a means of predicting use failure rates and determine major failure modes. Physical failure mechanisms were also studied. Simultaneous tests were made at both elevated and use voltages and temperatures. Relationships between accelerated stress and actual failure rates were investigated. The resulting failure modes include resistance changes and thermal runaway for resistors, and leakage current increases and dielectric breakdown for capacitors. Interaction rate plots of tantalum resistors with various gases were made at high temperatures. The Ta_2O_5 dielectric conduction mechanism studies indicated ionic conduction. Several methods for locating defects in the Ta_2O_5 capacitor dielectric films were evaluated; best results were obtained with a copper plating method. The tantalum thin film resistors are very reliable and the failure mechanisms are understood well enough to predict resistor reliability under various stress conditions. The thin film capacitors are reasonably reliable, but are the limiting factor in R–C network reliability.
R.N.A.

Review: This is a good report on what appears to be a good piece of work. Considerable attention was given to the physical behavior of the devices, which makes the test results much more meaningful. The discussion on the Weibull distribution is not as good. There are several misprints; the graphs are not clear, and the presumption that a constant β means no change in failure mechanism does not appear well founded. For example, some non-Weibull distributions could describe only one failure mechanism; when the operating conditions are different, the fact that the two Weibull slopes are the same would not indicate that the failure mechanisms were similar. The activation energy calculation in Fig. 12 for tantalum in nitrogen and oxygen shows the usual great dispersion of points about the straight line.

R67-13390 ASQC 851; 844

Texas Instruments, Inc., Dallas.

A LIMITATION TO THE STEP STRESS TESTING CONCEPT FOR INTEGRATED CIRCUITS

W. Shurtleff and W. Workman *In* RADC Phys. of Failure in Electron., Vol. 4 Jun. 1966 p 258–278 refs (See N67-10101 01-34) CFSTI: HC $3.00/MF $0.65
(N67-10114)

Reliability information for integrated circuits is extremely difficult to obtain. Process improvements and major breakthroughs in the state of the art have pushed the reliability of integrated circuits extremely high. Reliability engineers must depend on accelerated life testing to obtain the required reliability information. There are limits to accelerated life testing which, if exceeded, preclude the possibility of obtaining useful data. Simple laboratory tests, such as those described, on a few devices can reveal the onset of these limitations and allow the maximum information to be obtained. Author

Review: The limitation discussed in the title does not affect the concept of step–stress testing per se, but puts limits on the maximum acceptable stresses which may be considered. This good paper discusses the ways in which integrated circuits are built and shows why the various limitations on testing exist. Integrated circuits are very difficult to use in accelerated tests because of their heterogeneity. The paper does not discuss the acceleration factors obtained in such tests, but presents a good discussion of the problems. As such, it can be of tremendous help to anyone who is contemplating running such tests, or who has the task of interpreting them.

R67-13398 ASQC 851; 521; 771; 844

INTEGRATED TEST PLANNING AND ANALYSIS.

M. L. Hinkle, Jr. (Raytheon Co., Wayland, Mass.).
In: Quality Control Seminar Papers. Seminar sponsored by SAE Southern New England Section and Hartford Section of American Society for Quality Control, Mar./Apr. 1965. New York, N. Y., Society of Automotive Engineers, Inc., Jul. 1965, p. 17–22. 19 refs.
(SP-273; SAE Paper-650399)

An overall philosophy of test planning is presented that should provide maximum information at the least cost within the specified time, cost, performance, reliability, and maintainability constraints of particular requirements. Among the general test planning methods discussed are factorial experiments, fractions of factorial experiments, and random balance experiment designs from these. Regression and correlation analyses are also considered; as are sequential-stress testing until failure, constant stress testing at a level above rated design, and linear discriminant analysis. Emphasis is placed on various nondestructive testing techniques and the selection of the operating characteristic curve to depict results. M.W.R.

Review: The integration of special reliability and maintainability tests into a suitable program can yield much needed information and effect economies in time and cost. The paper provides only a very general description and illustration of some of the test planning methods which are available. However, 19 references are cited as sources of details. The reader interested in pursuing these topics will do well to regard this paper as a general introduction, and look elsewhere for information on which to base implementation of the ideas.

SUBJECT INDEX

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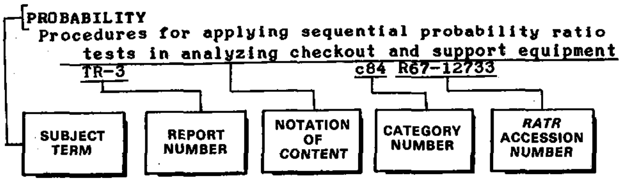

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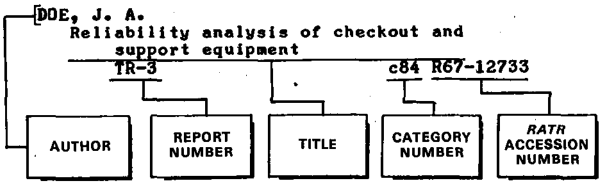

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 9

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Reliability Abstracts and Technical Reviews

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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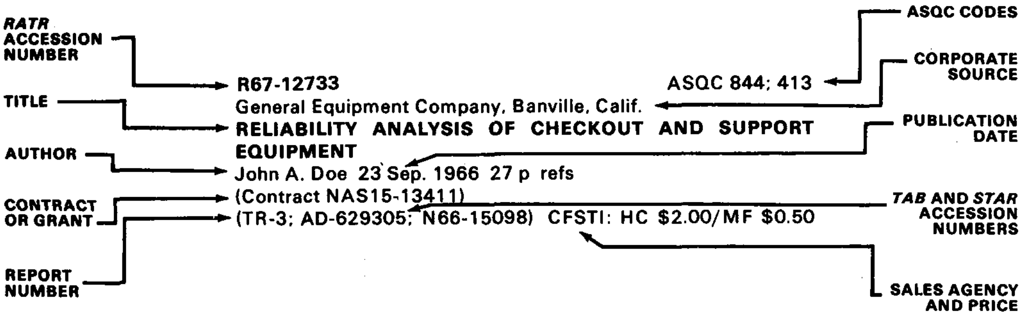
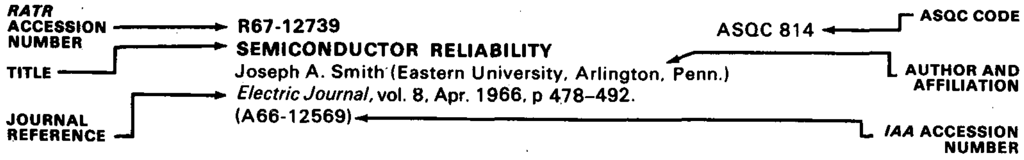
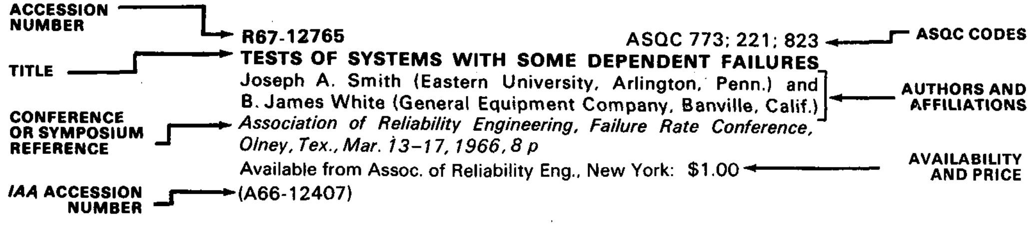


R67-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N66-15098) CFSTI: HC $2.00/MF $0.50



R67-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A66-12569)



R67-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A66-12407)

VOLUME 7 NUMBER 10

Reliability Abstracts and Technical Reviews

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80 RELIABILITY

R67-13422 ASQC 800; 820
HINTS AND KINKS.
Paul Gottfried (Booz-Allen Applied Research Inc., Bethesda, Md.).
IEEE Reliability Group Newsletter, vol. XII, Issue 2, April 1967, p. 5.

Instinctive dislike for statistical approaches to reliability that is often displayed by physicists and hardware-oriented engineers is discussed, and the usual arguments that say failure is a physical phenomenon are included. The need to treat physical events such as human mortality, automobile collisions, and behavior of molecules in a gas by statistical methods is cited. It is stressed that statistical procedures are usually selected out of necessity rather than from preference because of the inability to measure exactly at some levels, to define processes and interactions precisely, and to distinguish among individuals. Further, the impracticability of solving equations and exercising models even in the presence of adequate inputs is cited. M.W.R.

Review: This is another of the excellent short essays by this author which appear occasionally. This is on the utility of statistics as one of the tools for reliability. He suggests that deterministic methods and statistical ones complement each other rather than conflict. The discussion of the utility of statistics in various situations is good and easily understandable. He suggests that physicists have an instinctive dislike for statistical approaches in spite of their extensive exposure to these subjects during required courses in statistical mechanics and particle physics. But those kinds of statistics are generally not the kind used in reliability work and they do not produce the trauma in application that statistics often does in reliability. One of the big reasons statistics is so often deprecated is the lack of rigor with which it is used. For example, if one were to include all of the implicit assumptions the statistician makes during the course of his analysis, the results would appear more palatable because they would be observed in a different light. Too often the engineer has abdicated his reponsibilities in this matter to someone else. He cannot do this and properly fulfill his functions.

R67-13431 ASQC 800; 810; 815; 820; 844; 851
Engineering Publishers, Elizabeth, N. J.
RELIABILITY IN SPACE VEHICLES
Charles E. Roth, Jr., C. M. Ryerson, John A. Connor, W. B. Anderson, I. Doshay et al 1965 136 p refs

Based on the proceedings of the fifth annual seminar on Reliability in Space Vehicles, various aspects of contemporary reliability procedures, methods, and data are reviewed. A degradation analysis for space component selection is included, as are the interpretation of reliability K-factors for space systems, inclusion of structural reliability in a spacecraft dependability example, and management of product reliability. Synchronous orbit satellites and failure modes and mechanisms in microelectronics devices are considered, along with the future of established reliability parts specifications and the contractual implementation of NASA's NPC 250-1. M.W.R.

Review: The first paper is just an introduction to the volume. The second one ("Degradation analysis for selection of components for space applications") contains material that the author has since published elsewhere. The techniques apparently have been successful as testified by the satellites made by the author's company. They are not generally applicable because of the extreme emphasis on getting rid of potentially unreliable parts regardless of how many good ones are thrown away at the same time. Where the cost of the discarded parts becomes an important factor in the overall cost of the operation, then some modification of the procedures is necessary. The general burn-in procedure is: the appropriate parameters of each part are monitored and the part is accepted if the behavior is stabilized at a reasonable value between the limits. The trend should be away from the nearest control limit and preferably the equilibrium value should be somewhere near the center of the range and not too far from its original starting point. All others are regarded for less demanding uses or rejected. The author rightly emphasizes that this highly restrictive burn-in must be accompanied by the usual type of quality control in all phases of the product cycle. The third paper ("Interpretation of reliability K factors for space systems") is philosophic in nature and contains many quotations from the literature. The author justifies K factors on the basis of their utility and interpretation as probabilistic safety factors, especially at lower levels of sub-system complexity. There is still considerable interest in the use of these factors, but they are becoming more and more specialized so that different elements have different factors for the same nominal environment. Likewise the environments are being broken down further than just aircraft or shipboard, etc. The paper does make interesting reading, especially if it is skimmed for items of importance. The emphasis in the fourth paper ("Including structural reliability in the WSEIAC spacecraft dependability example") is on using extreme value probability functions for estimating the structural reliability of portions of the spacecraft. The paper uses a fair amount of technical notation without explanation, such as Type I and Type III extreme value distributions. Most engineers will need references in order to know what these are. This paper is a reasonable discussion of the use of such a probability function, although the method of calculating the straight line and of extrapolating it should be viewed with some caution. Calculating the best line for a series of points is more difficult when the points have high correlation; since the data in the paper are ordered by cumulative probability (rather than coming from independent trials) they are highly correlated. When extrapolating a great distance as done in the example, it is suggested that either the graphic or analytic uncertainty in the slope be projected to the intercept point. In the example of Fig. 3, it is estimated that there would be a factor of 10 uncertainty in the unreliability. Further it may be wise to make the plot on several different kinds of probability paper to see if the results are sensitive to the change, unless there is a very strong prior reason for using one of them. (The problem, of course, is that the points will have considerable scatter and may easily appear to be fit best by a curved line.) The fifth paper ("Product reliability management") contains some good ideas on the relationship between design and production. The author makes the very valid point that design and production both contribute to the reliability of equipment and that one can degrade or help it as well as the other. He also wisely questions the meaning of a term such as "inherent reliability." There is heavy emphasis on reviews and on failure-modes-and-effects-analysis. These are both good. The sixth paper ("Synchronous orbit communications satellites") describes the Syncom satellite and gives a few generalities about the Early Bird parts program. A very interesting explanation for the excellent life of the equipment in orbit is the final sentence in the paper, "This perhaps can be best explained by the absence of people handling the equipment..." The seventh paper ("What's ahead for established reliability parts specifications") is essentially out of date, having been given two years ago. The eighth paper ("Failure modes and mechanisms in microelectronic devices") is a good one on failure modes and mechanisms in specific silicon integrated devices. Copious and good use is made of illustrations of various defects in methods of construction. The use of accelerated step-stressing is appropriately emphasized as a means of generating failures. The final paper, number 9, ("Contractual implementation of NASA's 250-1") is also somewhat dated. All in all, if one does not already own the book, there is probably little point in attempting to get it. Most of the important information has appeared elsewhere by the same or other authors.

81 MANAGEMENT OF RELIABILITY FUNCTION

R67-13400 ASQC 815

RELIABILITY MANAGEMENT UNDER FIXED-PRICE CONTRACTS.

F. E. Black (General Dynamics Corp., Fort Worth Div., Fort Worth, Tex.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 99–102.

(A67-30403)

Consideration of two cardinal principles of reliability management under fixed-price contracts: management must clearly understand what it is contracting for, and it must have and exercise the means necessary to control the sources of reliability. The approach presented is one that requires a minimum of change to programs such as those which conform to the MILD-STD-785 reliability program requirements. IAA

Review: A brief overview is given of the key approaches for achieving reliability. The presentation is partly philosophical, but all quite appropriate. Explicit fixed price features do not enter into the discussion very much. Rather, the point is that when there are fixed price and fixed reliability requirements, then more attention must be given to achieving reliability.

R67-13403 ASQC 816; 351

SUPPLIER CONTROL AND RELIABILITY.

Lawrence E. Swaton (Martin Marietta Corp., Orlando, Fla.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 261–269.

(A67-30407)

Description of a comprehensive program which, if followed by a customer quality representative, can determine if a supplier is following an appropriate quality program, that the delivered product is defect-free the first time, and that product reliability is consistent. Reliability is assured by supplying adequate inputs to the supplier, correctly monitoring the outputs, and by taking positive corrective action to eliminate problems once they are discovered. IAA

Review: This paper is essentially conversation which could be of interest and possible help to customer quality representatives, particularly those with little experience. To those who have been in the game for a while, much of what is said will be obvious. From the term "reliability" in the title it should not be inferred that there is any content that will help the technically-oriented person in this field.

R67-13404 ASQC 810

A COMMERICAL RELIABILITY PROGRAM.

James L. Brown (National Cash Register Co., Quality and Reliability Engineering, Dayton, Ohio).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 287–298.

Techniques and methods employed by a commercially operating reliability program are described that permit the prediction, measurement, and control of reliability on a customer application level. Selection of the applicable reliability techniques is discussed in terms of their use in failure detection and performance prediction; and their application to the overall program and control procedures is considered. A development sequence model is presented and the reliability program relative to this model is considered to fall within the broad areas of product specification and design, inhouse testing and evaluation, and field followup procedures. Top management participation in the organization of a reliability program is stressed. M.W.R.

Review: After some unnecessary thrashing around in the first two pages concerning such notions as inherent equipment reliability, exponential models, and the bathtub curve, this paper settles down to briefly describe a sensible commercial reliability program. Apparently it is for electromechanical items. Record-keeping on tests and usage with subsequent corrective action is a strong element of the reliability program. The many illustrations attest to the effectiveness of this approach, since great reliability improvement is attained as the product goes from engineering models to regular production. Where the item is electromechanical, it is particularly risky to generalize the applicability of bathtub curves and constant failure rates for all parts. This is not at all to say that it is not important to count failures which occur during testing and usage and to normalize this count with respect to numbers of items and usage, as is done here. Rather, keep an open mind on what individual part and equipment failure distributions might be. Erroneous design approaches may thus be avoided and improved operational maintenance procedures may result. While the author has in mind a commercial product, the ideas on implementing an effective reliability program have pertinence also to the production of military and aerospace equipment.

R67-13421 ASQC 815; 837

AGING TOLERANCES AND RELIABILITY PARAMETERS FOR COMPONENTS OF COMPLEX COMMUNICATIONS ASSEMBLIES.

N. N. Solovev

Telecommunications and Radio Engineering, Part I–Telecommunications, vol. 19, May 1965, p. 51–54. 3 refs.

The association of technical specifications parameters with reliability parameters is considered in relation to the components of complex communications assemblies in a general discussion on aging tolerances. In order to achieve better component reliability, it is recommended that reliability parameters be introduced into technical specifications, an official definition of the guaranteed component life be established, and the data on components which are to be rated or guaranteed be determined. The establishment of groups of complex assemblies for which the reliability is to be calculated from the viewpoint of total failure and others based on reserve factors that allow for partial failures is suggested. M.W.R.

Review: This article fails to live up to either its title or its abstract and is probably not worth reading. It complains about the problem wherein the guarantees by manufacturers deal with deviations only at the time of issue whereas the engineer is concerned with deviations at the end of the desired life of the components. It further points out that some of the specifications do give a life, but that the component can be expected to deviate by several times the specified tolerance, during the course of that life. The author's root of all evil is informative; viz., "Such a play on words, distorting their original meaning and bordering on sheer deception, has a history with roots in the practice of foreign advertisements, which is obviously quite unsuited to the Soviet industry." The Russians appear to have the same problems with regard to advertising and users vs. suppliers that we do.

R67-13451 ASQC 810; 814; 833

QUALITY RATED COMPONENTS.

E. J. Tyberghein

Bell Laboratories Record, vol. 45, Apr. 1967, p. 110–115.

Constant surveillance of product quality and coordinated efforts by many departments are noted in a paper dealing with approaches used to implement reliability and quality assurance in telephone equipment. In addition to high reliability, emphasis is placed on ease of operation and maintenance and safety factors; and the general procedures followed by a large industrial complex are reviewed. For sampling and rating purposes, it is noted that transistors are grouped with components having similar characteristics and requirements; and standard quality levels are established for transistors and for all of the products used. From curves which depict failure distributions that might be encountered from different production lots of the same component, it is concluded that mean-time-to-failure numbers are not necessarily significant in estimating the number of troubles that are apt to be experienced in the field. It is stressed that the establishment of tests that can be used to determine long-term component reliability requires a good understanding of the failure modes as well as the operational factors. M.W.R.

Review: There are no technical details in this overview of the Bell System components reliability and quality activity. A bit of insight can be gleaned about the approaches used and the organization, but this article contains mainly light, sales-type discussion and illustrations.

82 MATHEMATICAL THEORY OF RELIABILITY

R67-13406 ASQC 825; 615; 838

ALLOCATION OF SYSTEM RELIABILITY BY DYNAMIC PROGRAMMING.

D. E. Fyffe, W. W. Hines, and N. K. Lee (Georgia Institute of Technology, Atlanta, Ga.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 311–322. 6 refs.

(A67-30409)

Discussion of the detailed allocation method of system reliability, designed to select the optimal solution in the context of the tradeoff analysis. The problem is formulated mathematically by assuming that the system under consideration consists of n functional units which are connected in series and that failure of any unit in the system may be regarded as an independent event. Associated with each of the n functional units there exist several choices of design alternatives that the system designer can employ in order to meet the allocated reliability requirement. The fact that the problem can be structured as an n-stage sequential decision problem permits a dynamic programing approach to its solution. Some numerical results are presented. IAA

Review: Some expansions are found in this paper relative to other literature items on reliability allocation by dynamic programming. Here the more typical problem of redundancy only and a single penalty is extended to include both redundant and non-redundant reliability improvement and to include two penalties. The Lagrange multiplier is used to extend the penalties. The discussion is in terms of parallel active redundancy and of cost and weight. The approach is readily applicable to substituting other forms of redundancy such as automatic or manual standby and other penalties, such as volume. It is heartening to see the academic world participating in the development of reliability analysis techniques.

R67-13408 ASQC 820; 431

RELIABILITY STATISTICS FOR REPAIRABLE DEVICES.

J. M. Lowerre (General Electric Co., Burlington, Vt.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 477–481.

(A67-30412)

Discussion of the limitations in analyzing the number of failures of a repairable device by the Poisson distribution with parameter λt or λt^{α}. Specifically considered is the nonhomogeneous Poisson whose parameter is an unidentified function of t, say m(t). Hypotheses, believed intuitive and different, are established, from which it can be proved that the distribution is the nonhomogeneous Poisson. A sketch of this proof is included. Statistics for the function m(t) are presented in three different ways. An application to observed test data is made. In conclusion, the limitations of the analysis are mentioned and some problems to be solved are presented. IAA

Review: This is a mathematical paper will be of interest to theoreticians concerned with the application of stochastic processes to reliability theory. The motivation for the work is reasonable, since there are certainly situations, notably those involving preventive maintenance, in which the assumption of a constant hazard rate is unrealistic. Whether the alternative of using a nonhomogeneous Poisson distribution is optimum in any practical sense would depend on the physical situation to which it might be applied. This, of course, implies no adverse reflections on the mathematical treatment. As the author indicates in his conclusions, certain problems remain to be solved before the approach is ready for practical application.

R67-13409 ASQC 821; 831

DEMAND INTERVAL RELIABILITY.

Ernest G. Enns (Northern Electric Co., Ltd., Research and Development Laboratories, Ottawa, Canada).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 483–493.

(A67-30413)

Consideration of demand interval reliability, defined as the probability that a system will operate satisfactorily throughout a specified time interval or intervals. The demand interval is formulated generally for a single time interval. This formulation involves calculating the distribution function for the time to system failure, assuming that a system repair was just completed. Of three examples considered, the first compares the demand interval reliability of two parallel systems with different modes of operation; the second and third example both consider a parallel two-unit system. IAA

Review: Renewal theory is applied in the determination of the probability that a system will operate satisfactorily throughout a specified time interval. The mathematics is competent, concisely presented, and illustrated with examples. Underlying assumptions are clearly indicated. The orientation of the results relative to other published work is pointed out.

R67-13410 ASQC 824; 552

ESTIMATING RELIABILITY FROM THE FIRST TWO FAILURES.

John S. White (General Motors Corp., Research Laboratories, Mathematics Dept., Warren, Mich.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 495–503.

(A67-30414)

Analysis of a standard life-testing experiment in which n similar units are cycled to failure. The data obtained from this experiment are the failure times (cycles, miles, etc.) of the individual units. Consideration is given only to life-testing experiments which are terminated at the second failure—i.e., the experiment is started with n similar units and run until two units have failed. Graphs of the confidence limits vs the corresponding failure times are plotted. It is shown that the confidence bands may be considered horizontally, to obtain lower confidence limits for the time corresponding to a given percent failure. IAA

Review: A graphical method of estimating the distribution of population failure times on the basis of the first two failures is described. Plots on Weibull probability paper are made with median ranks, so that the result is essentially a median line. More importantly for estimation purposes, it is also shown how 80%, 90%, and 95% confidence bands may be obtained. This is a succinct description of "how to do it" and will be sufficient for those with some prior knowledge of graphical estimation procedures. No attempt is made to present the mathematical derivation; the author states that it will be published elsewhere. This is a useful contribution to statistical methodology for reliability analysis—particularly so because of the small amount of data required for its implementation. For other work on the Weibull distribution by this author see R63-11015, R66-12722, R66-12841, and R67-12970.

R67-13413 ASQC 821; 846

PREDICTION TECHNIQUES INCLUDING NONOPERATING AND OPERATING TIME PERIODS TO DETERMINE OPERATIONAL READINESS.

T. R. Gagnier (Martin Marietta Corp., Martin Co., Reliability Dept., Orlando, Fla.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 523–533. Research supported by the Martin Marietta Corp.

(Contract AF 30(602)-3772)

(A67-30416)

Review of prediction techniques developed under the Storage Technology for Operational Readiness (STORE) program. These techniques incorporate the effect of storage and dormant operation on operational readiness. The major factors affecting operational readiness, such as part types, part classes, system complexity, system and test-equipment design, test-equipment failure-detection capability and frequency of periodic test are included in the prediction techniques, and their interrelationships are discussed. The use and validation of the operational-readiness model in making predictions is shown. Techniques by which better weapon-system design decisions can be made to maintain the required operational readiness at any time in the electronic-system life cycle are presented. Finally, comparisons between nonoperating survival predictions and actual field observations are presented. IAA

Review: The behavior of parts and equipment when stored or inert for long periods (say up to 5 years) is an important question on which too little is known. The programs described in this paper (STORE and RADC) should do much to alleviate this situation. The paper essentially gives some highlights of the results with emphasis on operational readiness prediction and the comparison of predictions with field observations. However, more extensive information will be found in the author's Reference 3, which, judging by its AD number, has restricted circulation. For those with a not-too-detailed interest in the topic, this paper will serve a good purpose. A striking result is the excellent agreement between field observations of reliability and prior predictions. The results pertaining to observations made after 2.9 and 4.5 years are more impressive than those related to the 5-month period, assuming that long-term effects are important. The evidence of a linear degradation trend is also interesting.

R67-13416 ASQC 824; 864

RELIABILITY SCOREBOARD—A NEW TOOL FOR RELIABILITY ASSESSMENT.

Gerald J. Plotkin (American Science and Engineering, Inc., Cambridge, Mass.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 553–562. 10 refs.

(A67-30419)

The paper describes a method of performing Reliability Assessment on incomplete and inaccurate field removal data, and obtaining valuable reliability information in spite of the data shortcomings. The Reliability Scoreboard, an unbiased display of assessment results, serves as a valuable tool for both customer and contractor by exposing serious problem areas and avoiding misdirection of reliability improvement loads. The Reliability Assessment procedure is described in detail, showing how the removal data are systematically analyzed, corrected, grouped, measured, and displayed as a series of graphs, histograms and tables along with narratives which explain significant aspects of the results. A case history and other examples illustrate how the Reliability Scoreboard has been used to make reliability improvement decisions. The Scoreboard technique, in general, solves the classic problem of communicating statistical reliability information to nonreliability-oriented management. Author (IAA)

Review: The term scoreboard refers to the manner in which field failure data for the AN/SPG-51 radar are presented for management and customer consideration, after the data have been analyzed. There are many illustrations. Computerization is implied, but what is presented seems to come from manual efforts. Someone setting up a field failure reporting system might find some ideas here. Somewhat aside from the topic of data presentation, the situation here is a fortunate one in that some field data are being obtained, that there is sufficient equipment operating to comprise a reasonable sample, and that the contractor has funds to analyze the field data. Quite often, this is not the case.

R67-13418 ASQC 824

California Univ., Berkeley. Operations Research Center.

ASYMPTOTICALLY OPTIMAL STATISTICS IN SOME MODELS WITH INCREASING FAILURE RATE AVERAGES

Kjell Doksum Nov. 1966 19 p refs

(Contract Nonr-3656(18))

(ORC-66-35; AD-645545; N67-25406) CFSTI: HC $3.00/MF $0.65

Let F and G be defined by F (t) = H (gamma t) and G (t) = H (theta t) where H is unknown and H (O) = O. For testing the equality of the means of F and G in the two-sample problem; it is shown that the Savage (The Annals of Mathematical Statistics (1956) pp 590–615) statistic maximizes the minimum power over increasing failure rate distributions asymptotically. Asymptotic uniqueness holds only in a class of rank tests. The results are extended to censored samples, the problem of estimating the ratio of the means, and the k-sample problem. Author (TAB)

Review: Although this report is directed toward important problems in reliability, e.g., the two-sample life-testing problem, tests for exponential models, etc., the discussion is quite theoretical and the reader will need a substantial background in this area of statistics for complete comprehension of the material. The practical implications of the paper are the following: Whenever one is trying to decide which one of two devices (or systems) has the longest mean life in the two-sample life-testing problem, one should use the Savage statistic because it guards best against having a large probability of making a type II error for a wide class of distributions (IFRA distributions). Modified Savage statistics can be used for censored samples, k-samples and estimation.

R67-13419 ASQC 820; 844

THE PROBLEM OF ORGANIZING THE REPAIRS OF AUTOMATIC DEVICES AND SYSTEMS BY TAKING INTO CONSIDERATION RELIABILITY INDICES.

N. F. Broido

(Izmeritelnaya Tekhnika, Jan. 1965, no. 1, p. 9–10). *Measurement Techniques,* June 1965, no. 1, p. 11–13. 4 refs.

Reliability theory is considered for defining the organization of and planning for the daily activities of an automation laboratory, which is charged with the repair and maintenance of automatic systems and devices. A formula is given for the evaluation of the faultless operation of a device over a given period of operation, and this is related to the time between inspections for the system. Such a solution, it is stated, will raise the technical and economic efficiency of automation. M.W.R.

Review: This is a short paper and is poorly written and/or poorly translated. It attempts to show that the time between inspections should take into account the known reliability of the devices being used in an automatic system. The exponential distribution is assumed for all failure times of devices and systems. It is not clear, then, why there should be any periodic inspection. There is an editorial note that "All of the conclusions arrived at in the article hold for the exponential time distribution law of the faultless operation of devices comprising an automatic system." In any event, even if the work were accurate, this elementary type of calculation would be simple to make and has doutlessly appeared many times in the American literature.

R67-13428 ASQC 821; 844; 851

Hughes Aircraft Co., Culver City, Calif. Aerospace Group.

COMPONENT RELIABILITY PREDICTION

C. M. Ryerson Jun. 1965 48 p refs

(TM-828; N65-29235)

A reexamination of the categorization of stress and strength factors so as to provide an improved rationale for prediction based on realistic mathematical models is proposed. A set of mathematical models formulated in the form of prediction equations for specific components, taking into account those environmental and operational factors which exert an influence upon the basic failure rates are discussed. The initial equations are to reflect the theoretical and intuitive considerations derived over a period of years by experienced reliability engineers. Failure rate theory, interaction factors, and factors for improved prediction are included. E.E.B.

Review: This paper is divided into three parts. The first is a theoretical discussion of failure rate vs. stress. The second discusses what a subsequent test program is supposed to include. The third deals with ways to improve the failure rate prediction. The third part is rather short, but mentions about eight good ways for improving the failure rate prediction, such as more specific identification of parts than is given in sources such as MIL Handbook 217, better knowledge about part capabilities and "stresses," and emphasizing the key parameters which are critical to reliability for each part. The second part of the paper is a good discussion on a test program, presumably one to be used with the theory developed in the first part. This second part mentions such things as proper design of experiments, the various kinds of accelerated tests and their interpretation, identification of various failure mechanisms, and the way in which parts degrade. The first part can be reviewed in either one of two ways. One could say that the author is to be commended for trying to find another approach and for so doing, and finally to point out that the success of his model can be determined by how well it works in practice. The other approach to reviewing it, however, will be followed here. This condemns the theory as unsatisfactory and misleading. The historical part of the paper reviews the Arrhenius model and one proposed by John Connor of Astro Reliability Corporation without passing judgment on their adequacy; it is good. The Erying model is then given, but immediately there is some confusion between reaction rate, rate constant, and failure rate of a part. The Erying formula, of course, deals with the rate constant for a chemical system. It is derived on the basis of an intermediate reaction which takes place at a higher energy level. In practice the Erying model is indistinguishable from the Arrhenius model because the exponential dependence on reciprocal temperature is so much stronger than the direct dependence on temperature. The constant in front does have a theoretical basis, namely, it involves the change in entropy for the intermediate reaction. In most practical Reliability situations there is absolutely no way of evaluating this entropy and it is empirically determined from the data if at all. Very often in physics and engineering a $\log_e$ rate is plotted vs. 1/kT and if the resulting curve can be considered to be a straight line (however procrustean one must be with the data) an activation energy is said to exist and the slope is it. This, of course, implies only that the Arrhenius form is applicable; the size of the activation energy (slope of the line) gives some insight into the mechanism of the reaction. It is patently pointless to include basic constants such as Planck's and Boltzmann's in a formula for the failure rate. Obviously they are multiplied by a constant which must be determined from the data, and just as obviously this latter constant has no basic physical meaning. The modification by adding various functions of stress is just as arbitrary as any other method of introducing stress. First of all, the word stress is actually an arbitrary function of some parameter describing that kind of stress, and secondly there is no a priori reason to suppose it has an exponential form. There is apparently a misprint where it is asserted that "...f_1 is applied to adjust the energy distribution..." Presumably the author meant entropy distribution. I assert that we have no comprehension at all what that means. Another factor is supposed to adjust the enthalpy (activation energy) for the presence of nonthermal stresses and I assert again we do not know what that means. The final formula for failure rate contains many arbitrary functions and many arbitrary constants. One certainly ought to be able to fit most any set of failure data without stretching his conscience too far. In summary this mathematical model is probably no better and no worse than many, except that it is quite complicated, but in any event to call it a modified Erying model or to call the correction factors Erying factors, is a poor choice of terminology at best. At worst it is trying to ride the coattails of a famous scientist with worthless ideas. The final Eq. 21 is a bastard mixture of approximations for small temperature variations only and of the basic Erying form.

R67-13436 ASQC 824; 414; 814; 822
Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

AN ANALYSIS OF THE ECONOMIC RISK OF THE EXPONENTIAL ASSUMPTION IN RELIABILITY TESTING

Stephen G. Dizek (M.S. Thesis) Dec. 1965 82 p refs
(GRE/SM/65-01; AD-628102; N66-23920) CFSTI: HC $3.00/MF $0.65

The characteristics of the exponential time to failure distribution are compared with those of Weibull life distributions with shape parameter greater than one. Computer simulation is used to determine the probability of accepting an exponential life distribution hypothesis when the distributions are Weibull. An economic model is then used to show that, for items meeting reliability specifications, the risk may increase with the shape parameter when the exponential life distribution is assumed and sampling plans based on it are used. Author (TAB)

Review: The economic risk mentioned in the title is analyzed on the basis of an arbitrary cost function, using computer simulation. The result is an academic exercise, befitting its role as a Master's thesis. Its practical significance is limited by the narrow range of alternatives to the exponential, namely the Weibull with shape parameter (β) greater than 1. Since the risk is that of rejecting increasingly more reliable items as β increases, the use of the exponential (the case $\beta = 1$) tends to be conservative and does not impose a risk which is of serious concern to the user of the items accepted (except that of added cost). The author's suggestion that goodness-of-fit tests be used to determine the appropriate life distribution whenever sufficient data are available is reasonable as far as it goes. However, in most reliability-analysis situations there are not enough data. In using the Chi-square test (which the author recommends), attention should be paid to the admonitions in the better textbooks regarding the amount of data necessary to yield a valid test. It should also be kept in mind that the Chi-square is not the only quantitative test of statistical significance and further that engineering significance is probably of greater concern. About two-thirds of the text is devoted to rather elementary statistical considerations. While generally accurate, the discussion is somewhat oversimplified and should not be relied upon as a fundamental source of information on these topics. Textbooks serve this purpose better. For example, the author assumes that failures which are "random or due to chance" necessarily occur at a constant rate and therefore the times-to-failure follow an exponential distribution. The terms "random" or "chance" do not imply a constant rate, although this misconception appears in much of the reliability literature. The Weibull, for example, is just as much a distribution of a random variable as is the exponential. It is the constant hazard rate which leads to the exponential, while the time-dependent hazard rate is allowed for in the Weibull.

R67-13442 ASQC 824

ESTIMATION OF THE PARAMETERS OF FAULT-FREE OPERATION OF NONDUPLICATED ELECTRONIC EQUIPMENT.

I. V. Korolkov

Telecommunications and Radio Engineering, Part I–Telecommunications, vol. 20, Aug. 1966, p. 67–70. 4 refs.

Formulas are evolved for the probability and average time of fault-free operation as well as for the frequency and intensity of breakdowns of nonduplicated electronic equipment having permissible short-term failures during which the equipment fulfills its functions. These formulas are considered suitable for calculating the reliability parameters of a duplicated repairable system that has an idling nonrepairable standby whose reliability differs from the main equipment. In such a system the permissible stoppage time is, therefore, the average time of operation for the standby system. At any given time, the system can be considered in three different states: (1) failure does not occur, (2) failure occurs and is repaired in a given time, and (3) failure occurs and repair is not completed in a given time. M.W.R.

Review: From the beginning, the mathematics of this paper is *incorrect. Hence, none of the formulae are valid.* To see that the development is incorrect, note first, with the states s(t) as defined, that to order $o(\Delta t)$

$$\begin{aligned} P_o(t+\Delta t) &= \Pr\{s(t+2\Delta t) = s(t+\Delta t) = 0\} \\ &= \sum_{p=0}^{2} \Pr\{s(t+2\Delta t) = s(t+\Delta t) = 0, s(t) = p\} \\ &= P_o(t)e^{-\lambda 1\Delta t}+P_1(t)e^{-\lambda\Delta t} \\ &= P_o(t)\,\lambda_1\Delta t+P_1(t)\,\lambda_1\Delta t, \end{aligned}$$

which is not the formula at the bottom of p. 67 in the paper. The formula at the bottom of p. 67 is, however, satisfied in the formulation of the same problem wherein states are defined by $s(t) = 0$ if the device is correct at t, 1 if the device is broken down at t. However, with this formulation note that if $0 < t < T_n$, then $P_2(t) = 0$ so that $P_2(t) = 0 \neq \lambda_2 P_1(t)$, *contrary to the third equation in (1) on p. 68 in the paper.* The approach, however, is interesting. Perhaps it can be supplied with correct mathematics to give useful results.

R67-13443 ASQC 824

THE USE OF THE CHANCE FAILURE LAW TO EVALUATE HAZARDS ON MISSILE AND SPACE VEHICLE TESTS, BEING A PRESENTATION OF THE CHANCE FAILURE LAW, ITS APPLICATION, AND SOME OF THE RATIONALE USED IN HAZARD EVALUATION OF MISSILE TESTS.

James R. Duffett and J. N. Thilges (TRW, Inc., TRW Systems Group, Cocoa Beach, Fla.).

Logistics Review and Military Logistics Journal, vol. 1, 1965, p. 11–20.

From determinations of mean-time-between-failures of components and knowledge of the logistics system and its failure rate or potential trouble spots, determination can be made of the required number of spare parts to optimize both military and logistics system utilizations. The proposed method is also applicable to determining failure rate of the logistics system and the portions of it that require review of handling or other procedures; as well as the absolute maximum failure rate of the logistics system itself. This method is not limited to the Chance Failure Law, but is readily extended to other variations of the Weibull distribution. Calculations of maximum probability for breakdowns at time associated with the most disastrous consequences can also be determined, such as the assessment of space vehicle failure at the most critical time just prior to lunar landing or docking. M.W.R.

Review: The main point made in this paper is that the maximum probability of failure of a ballistic vehicle during the time interval t_1 to t_2 may be approximated by $e^{-1}[(t_2-t_1)/t_2-t_0)]$ where t_0 is the start time of the system, provided t_2-t_1 is considerably smaller than the required operating time. (The expression for the exact maximum probability is also provided, but it is less easy to use.) As the authors emphasize, the use of this has the advantage that no test data are required. All is well as long as the above maximum probability is acceptably small. The approximation, as presented on p. 15 in the paper, is a reasonable consequence of the constant hazard rate, which the definition of the chance failure law on p. 13 implies. (This use of the term "chance" is misleading because failures which are random or due to chance to not necessarily occur at a constant rate.) The mathematics presented on pp. 13 and 14, while correct, does not add much to the discussion. Given that the authors were willing to assume a constant hazard rate in the first place, they have an underlying exponential distribution as a well-known result. The term "hazard" as used by the authors does not have the same connotation as "hazard rate" in the reliability literature. This could be confusing to the reader who associates a constant hazard rate with the exponential distribution. The hazard which the authors maximize is the risk of damage due to failure of a missile.

83 DESIGN

R67-13401 ASQC 837; 400; 822; 844

WORST DISTRIBUTION ANALYSIS FOR STATISTICAL CIRCUIT DESIGN.

Kenneth B. Gray, Jr. (Hughes Aircraft Co., Research Laboratories, Theoretical Studies Dept., Malibu, Calif.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 207–211. 6 refs.

(A67-30406)

Outline of a method for obtaining some of the benefits of statistical design without having an exact knowledge of the component densities. It is shown that for practical purposes the technique of worst-distribution design can be approximated by assuming that each component has a maximum variance distribution which assigns a probability of 1/2 to each end point. Statistical design relative to these distributions is used to set component tolerances so that the probability of failure is acceptably small. IAA

Review: For those who use or want to use worst-case design but are concerned about its overly-conservative aspects, this paper has some ideas. So-called worst distribution analysis lies between worst-case design and full-fledged statistical design in which all pertinent distributions are assumed known. In return for being less conservative, you must accept some risks. You must also supply some ingenuity in making assumptions regarding the class of component densities to be used. The paper does little more than introduce the concept and illustrate it with simple examples. However, it does that quite effectively. The concept deserves to be explored more fully to find out how practical and useful it will turn out to be.

R67-13405 ASQC 831; 612; 836; 837

CIRCUIT ANALYSIS BY COMPUTER.

L. J. Clark, Jr. and H. C. Jones (Westinghouse Electric Corp., Atomic, Defense and Space Group, Aerospace Div., Baltimore, Md.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 299–310. 9 refs.

(A67-30408)

Discussion of circuit analysis by computer as a means of assisting reliability and quality control engineers. Several of the programs available are delineated, and comments are made on their shortcomings and capabilities. These programs are ECAP, NET-1, PREDICT and SCEPTRE, ASAP, and BEV4. ECAP is perhaps the most widely used circuit-analysis program. It is an extremely versatile analytical tool, and its capabilities are discussed by means of several simple but realistic examples. Difficulties arise with ECAP in the determination of the transient response of certain circuits to arbitrary inputs. IAA

Review: This paper promotes the use of circuit analysis programs for performing the two reliability tasks of determining electrical operating conditions for parts and analysis of circuit parameter variations. It provides an introduction to automated circuit analysis from the user viewpoint and will be worthwhile reading only to those persons just starting in the activity. Most of the information has been previously presented in numerous other sources (c.f. articles covered by R66-12512, R66-12513, R66-12614, R67-12984, and R67-13049). It briefly describes several existing programs: ECAP, NET-1, PREDICT, SCEPTRE, ASAP, and BEV4, and then uses ECAP as an example for more in-depth discussion of application. Some very worthwhile comments are made about the practical limitations of circuit analysis programs. The basis concepts and uses of circuit parameter variation analysis are not described. Another reliability task being performed by circuit analysis programs but not described in this paper is failure mode and effects analysis. A good description of automating this task is presented in the paper covered by R66-12514. (The author in a private communication has pointed out the following typographical error in the paper: on p. 299 the eighth line from the bottom should read "we are *now* able to achieve...")

R67-13411 ASQC 830; 824; 844

ENGINEERING ASPECTS OF NONELECTRIC RELIABILITY IN DESIGN.

T. L. Bush (IIT Research Institute, Chicago, Ill.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 505–516. 9 refs.

(A67-30415)

Outline of a method of determining the reliability of a system or device by considering the system as being composed of a number of smaller elements connected in either series or parallel, depending on their relationship (in a reliability sense) within the system. By assuming no interdependence of the elements, the interface problem is avoided, thus simplifying the reliability-prediction task. The discussion briefly indicates the rudiments of a practical engineering approach to the problems of reliability prediction in nonelectronic systems. Primarily mechanical aspects of the problem are considered, since the mechanical problems often govern the prediction of hybrid system reliability. IAA

Review: This paper discusses the kinds of things that can be done but does not fully convey the difficulties in actually doing them. It gives the impression that much of the work which connects statistics with 'mechanical design for survival' was begun at the author's institution. This is not accurate, especially with regard to fatigue; for example, ASTM Committee E-9 on fatigue was concerned with probabilistic interpretations in the mid-fifties. Some of the weak points in the paper are as follows. (1) The distinction between time-independent and time-dependent failure mechanisms is not clear. Apparently it refers to whether or not the desired measure of performance is changing with time. It implicitly assumes that the conditions of operation and the environment stay reasonably constant. (2) In the discussion under stress–strength interference, the distinction between the actual situation and what has been computed is not made clear. For example, it is asserted that when only nominal values of stress and strength are computed, the probability of survival is either zero or one. Mother nature, of course, behaves as she will and not according to our computations. (3) The discussion on wear devotes most of the space to estimating a value for (mean) life which, of course, does not involve a probability. When probabilities are desired "...recourse must be made to experimental data," which puts one right back where he started. These data are rarely available, especially in sufficient quantity to make meaningful estimates of say the 1% survival point. (4) The discussion of fatigue is extended and somewhat oversimplified. Publications of the ASTM committee E-9 on fatigue give a much better and more balanced presentation. There is no discussion in this paper on the probabilistic aspects of the endurance limit. There is no hint that much work has been done on the fatigue properties of materials with respect to notched vs. unnotched specimens, surface finish, etc. The aircraft and automotive industries, of course, have done a tremendous amount of both practical fatigue testing and theorizing about it. Even so, it is not possible to predict accurately the fatigue properties during the design stage. Virtually all of the work is strictly ball-park estimates. For example, theories of cumulative damage are numerous and varied. It should be pointed out that the field of mechanical reliability is not new—mechanical engineers and designers have been concerned with both degradation and catastrophic failures in their equipment for many years, even though the statistical nature of the failures was not always taken into account (in many cases the statistical nature was irrelevant). All in all this paper serves as little more than an introduction to mechanical reliability for those not concerned about the quantitative aspects of the field.

R67-13440 ASQC 833; 552

WEIBULL PROBABILITY PAPER.

Lloyd S. Nelson (General Electric Co., Lamp Div., Cleveland, Ohio).

Evaluation Engineering, vol. 6, May/June 1967, p. 24–25. 5 refs.

The cumulative distribution function of the Weibull distribution is given in terms of age at failure, shape and minimim life parameters, and characteristic life at the 63.2 percentile; and a linear function results from a double logarithmic transformation with minor rearrangement. An example shows a plotted Weibull probability chart on specially prepared graph paper, and tells how it can be used to determine the necessary failure data. M.W.R.

Review: This paper was covered by R67-13227.

R67-13441 ASQC 833; 816
HOW IBM SELECTS COMPONENTS.
Norman E. Nitschke (IBM Corp., Systems Development Div., Kingston, N. Y.).
Evaluation Engineering, vol. 6, May/June 1966, p. 32–34, 36.

Five areas considered in the selection of components and vendors are applicability, availability, reliability, cost, and specifications. Cost and reliability interactions and tradeoffs are discussed, along with component usage and its effect on reliability. State of the art and special testing are discussed, and desirable component engineer characteristics are noted. A case history is included to show how improper component selection led to a switching application problem, and the solution which resulted in a high performance switch is included. M.W.R.

Review: An overview of the key areas involved in the selection of parts and vendors is given in this paper. The areas are basic, i.e., applicability, reliability, and cost. They are discussed here in a manner which would be equally pertinent to commercial, industrial, or military applications. This is the sort of paper which is helpful to a new components engineer and to experienced persons who want a capsule orientation to selecting components.

84 METHODS OF RELIABILITY ANALYSIS

R67-13407 ASQC 840; 730; 870
FAILURE INFORMATION SYSTEM FOR COMPANY-WIDE APPLICATION.
Clarence E. Booth, Jr. (Litton Systems, Inc., Guidance and Controls Div., Woodland Hills, Calif.).
In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 379–386.
(A67-30410)

Description of a systems approach to company-wide aspects of failure reporting. This system provides a uniform method for reporting product and test equipment failures, for recording all subsequent repair actions taken to determine the cause of failure, and for providing information necessary to determine what corrective action can be taken to prevent recurrence of the failure. The basic concept behind the mechanics of the system is that all the detail regarding each failure and subsequent repair action associated with the failure is recorded on a single document which accompanies the failed equipment or any of its elements until the cause of the failure is determined. IAA

Review: A reasonably comprehensive description of a failure-reporting system is given in this paper. The system itself is more comprehensive than many which have been reported upon in the literature. It was designed to meet a broad class of requirements, and is asserted to have accomplished this objective. The paper will be of value to those concerned with the efficient handling of failure information. There have been many papers on "how we solved failure reporting" in the literature, and yet the problem seems to be still with us. It is not known how well this particular system is actually working, nor whether the results will improve or deteriorate with time.

R67-13412 ASQC 840
LOWER COSTS THROUGH TOTAL RELIABILITY.
Richard L. Straley (Dalmo Victor Co., Belmont, Calif.).
In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 517–522.

The role of mechanical reliability in lowering costs while improving quality is stressed, as is the expansion of reliability concepts in government contracts. The servomechanism is cited as an example where a mechanical approach to system reliability is considered a must to be accomplished during the stages of critical component design, reliability prediction, and failure mode and effect analysis. Failure costs are discussed within the critical component definition, and a ranking of failure effects for various components is presented. The necessity of coordinated efforts involving the mechanical reliability engineer and electronics personnel is stressed. M.W.R.

Review: There appear to be two main parts to the paper. The first is an exhortation for Reliability to sell itself to management and to fellow engineers, largely by doing more of the engineering job and by using Dale Carnegie techniques. The remainder of the paper is devoted to showing how mechanical reliability is different from electronic reliability and describing a criticalness coefficient which is calculated from a measure of the danger in and the probability of the failure. Implicit in the discussion is the idea that conditions with the worst criticalness index are corrected first. One may wish, however, to make the changes which will produce the greatest change in criticalness for the amount of money spent. This portion of the problem should have been discussed in the paper. The criticalness index is arbitrary as most are, but it is not unreasonable. The earlier exhortations to reliability engineers are appropriate (and in fact could as well be addressed to any part of a company), namely: quit doing sloppy jobs, do a little more than is sometimes required, and go out of your way to put your best foot forward so that others think of you as cooperative rather than as antagonistic.

R67-13414 ASQC 844; 780
ENVIRONMENT ADJUSTMENT FACTORS FOR OPERATING AND NON-OPERATING FAILURE RATES.
Logan Haycraft, Jr. (Boeing Co., Aerospace Group, Space Div., Seattle, Wash.).
In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 535–542. 11 refs.
(A67-30417)

Development of a method of deriving operating and non-operating failure-frequency adjustment factors (K_e) for environmental conditions on a more realistic basis than that commonly used in the aerospace industry. The currently used factors in most cases do not adequately describe the environments to which they apply, nor do they provide different factors for different equipment types. A simple method is offered for deriving K_e factors based on clearly defined environmental conditions, as they affect a wide variety of equipment categories. IAA

Review: The current use of environmental failure frequency adjustment (K_e) factors has deficiencies; e.g., "the failure of K_e factors to describe adequately the relevant environments, and the fact that different factors are not provided for different equipment types. This paper describes a study which has made some progress toward a more realistic approach to this problem. The results consist of a matrix of equipment types and environmental conditions, with data inserted from all available sources. The adjustment of non-operating failure rates is also considered. The approach appears reasonable, and the description of it is concise and clear. Some 11 references are cited for background and additional information. No claim is made that the problem is completely solved, and indeed much remains to be done. The K_e factor approach is essentially an attempt to reduce a very complex problem to a simple tractable form. The tractability has much appeal, but it must be remembered that reasonably realistic representation of the physical facts is of equal importance. This comment implies no reflection on the present paper, as the author has been quite frank about the deficiencies and difficulties involved. The paper will serve a useful purpose for those interested in this approach.

R67-13415 ASQC 844; 716; 782; 831; 846

RELIABILITY ASSESSMENT AND DORMANT STORAGE.

Harley E. Walker (Sandia Corp., Components Reliability Div., Albuquerque, N. Mex.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 543–552. 15 refs. AEC supported research. (A67-30418)

Discussion of reliability assessment methods for dormant weapons. Weapon experience has shown that those components which will have a limited useful life can be identified; if used, they can be replaced before reliability is degraded. Effects of dormancy on other components have been minimized by system designs which allow for rather large parameters changes. Unexpected high rates of catastrophic failure in dormancy are avoided through the use of derating, redundancy, and other conservative design principles, supported by thorough reliability analyses. Experience has shown that present techniques for weapon reliability assessment achieve satisfactory results. These assessment techniques are recommended for other systems which are required to function after years of dormancy. IAA

Review: An approach to the problem of assessing the reliability of units designed for years of dormancy followed by minutes of use is discussed. Generally speaking, the elements of the approach are not unique to this specific problem, but are rather commonly used in reliability assessment (e.g., failure modes and effects analysis, reliability allocation, component analyses, and environmental effects). Their relevance to the dormancy problem is brought out, however. Also stressed is the importance of stated and implicit assumptions in reliability analyses, particularly those which establish or express the criteria used for judging the applicability of specific test data. The material is clearly presented, and 18 examples of observed failure modes are given. The discussion and the bibliography (15 items) will be useful to those concerned with assessing the reliability of systems which have had relatively long periods of dormant storage.

R67-13420 ASQC 844; 851

PHYSICS OF FAILURE AND ACCELERATED TESTING.

G. E. Best, G. R. Bretts, and H. M. Lampert (General Electric Co., Missile and Space Div., Valley Forge, Pa.).

Electro-Technology, vol. 76, Oct. 1965, p. 79, 81–92. (A66-24728)

Review of the principles and practice of accelerated testing of transistors, resistors, and capacitors, to determine the reasons for certain types of component failures. The design of accelerated tests is discussed, and factors relating to film resistors—e.g., metal-film and oxide-film microstructure and aging mechanisms and accelerated-test data on metal films and oxide films—are considered. Dielectric aging mechanisms and accelerated testing of capacitors are investigated, and surface failure mechanisms, bulk mechanisms, and accelerated testing of semiconductors are described. IAA

Review: This paper appears to be a well-prepared summary of other papers which have appeared before; see, for example, R64-11456, R65-11949, R66-12423, and R66-12869. It is well organized and directed toward readers of the magazine. The discussion of failure mechanisms and of physics of failure is generally good. Thus, on a phenomenological basis the paper is quite satisfactory. The uses of the Arrhenius model and the time-Temperature parameter (tTp) are fraught with difficulties, however, as shown by the following examples. (1) In Eq. 1 a linear function of an arbitrary function is obviously still an arbitrary function of the original variable; so two of the constants are irrelevant. (2) There is a confusion in step 4 on page 83 where the authors suggest that one make Arrhenius plots, and then go on to suggest that the function should be plotted vs. the tTp. It is easy to show that if the tTp is in fact appropriate, then the Arrhenius description is not, and the concept of activation energy is not applicable. (3) It is then further suggested that if a linear plot is obtained, presumably with the tTp, true acceleration is said to exist. This can be taken as the definition of true acceleration, but it is an awkward one. The more usual one which asserts that "the acceleration is true if the system is in essentially the same state regardless of which of the two time-stress paths it takes to get there" is a more workable definition; it is not obvious that the other follows from it. (4) A method is given for combining the tTp's when the temperature is not constant. The method is nowhere justified and is obviously incorrect since it does not hold for the special case where the temperature is constant. For example, if there is an exposure of time t_1 and then of t_2 the combination at the same temperature should be of the same form, but for t_1+t_2; however, in the authors' method the times are actually multiplied together—an obviously ridiculous state of affairs. (5) In the section on metal film resistors this statement is made: "If the reaction causing resistance change is of zero order, then a function of resistivity which is dependent on the progress of the reaction is $df(r)/dt = K_r$ ..." This equation does not really say anything since the function of r is arbitrary and it would be very easy to write an equation for any order just by modifying f(r). What this equation really says is that it is possible to find an f(r) such that the "reaction" can be written as a zero order one.

The term order, of course, refers basically to chemical concentrations and, it is difficult to see what relationship this bears to resistance. (6) The usual form of expansion for the rate constant in terms of the Gibbs free energy is made and then followed by an attempt to convert it to the form of the tTp. Ignoring the confusion between natural and common logs, the attempt is a failure since the absolute temperature appears as multiplying the arbitrary function of resistance. (7) In evaluating the fit of the curves which are plotted against the tTp, it should be noted that this parameter is proportional to $[15 + \log_{10} t/\text{hr}]$. Most of the data will lie between $t = 10$ hr and 1000 hr, so that $[15 + \log_{10} t/\text{hr}]$ will be around 17. A deviation of a point from the line of only 3% corresponds to a factor of 3 in the time; therefore, small deviations are not to be regarded lightly. This is the case for many of the points in Fig. 6. (8) The discussion on dielectric aging mechanisms perhaps contains a misprint—the equation which is purported to be linear is not. In any event it has been customary for years to assume that the life of a dielectric follows the simple Arrhenius relationship. The authors provide about 60 references many of which will be quite valuable to anyone wishing further information in the field. Some should be read with care since the main errors mentioned here appear elsewhere in the literature and are still being perpetrated. In fact, that is the main reason for taking so much space to discuss some of the difficulties of this report—because these same ones continue to appear in the literature. In summary, on the level of phenomena this report is very good. On the level of mechanisms there are too many inconsistencies at least in the early part of the paper.

R67-13423 ASQC 844; 775

Rome Air Development Center, Griffiss AFB, N. Y. Reliability Branch.

SEMICONDUCTOR RELIABILITY—THE CORRELATION OF EXCESS NOISE WITH DELETERIOUS SURFACE PHENOMENA Final Report

Edgar A. Doyle, Jr., Jack S. Smith, and Gerald G. Sweet Dec. 1965 83 p refs

(RADC-TR-65-379; AD-627891; N66-21464) CFSTI: HC $3.00/MF $0.65

The properties of 1/f (excess) noise present in semiconductor p–n junctions under normal operating conditions, including noise voltage, frequency dependence, noise frequency exponent alpha, and the noise voltage-reverse leakage current proportionality constant K', are described. Variations in these excess noise parameters, when the semiconductor surface is subjected to various external ambients, have been demonstrated and indicate that excess noise in semiconductor devices can be associated with the surface in general and, more specifically, with surface inversion layer or channel formation. Techniques employed in excess noise measurements and for detecting semiconductor surface inversion are described. The applicability of gross excess noise voltage, noise frequency exponent alpha, and the noise proportionality constant (K') measurements for use as a reliability screening technique is discussed. Author (TAB)

Review: This report is a summary of an extensive and detailed investigation of the noise parameters of various grown junction n–p–n transistors. For some years now noise parameters have been regarded as potentially useful non-destructive tests for electron devices (see R64-11371, R64-11374, R64-11460, and R67-13204). The noise measurements required to separate good units from bad units, however, have always eluded isolation; but in general researchers were not discouraged. This report suggests that the correlations between noise and failure are not so simple as initially thought. The conclusions of the investigation, which is probably more thorough than those previously published, are that no noise parameter can be unambiguously related to failure potential, even though relatively large differences in the measured noise parameters exist. This statement is by no means the final word. Understanding of excess noise is increasing (see, for example, C. T. Sah and F. H. Hielscher, "Evidence of the Surface Origin of the 1/f Noise," Phys. Rev. Letters, vol. 17, pp. 956–958, 31 Oct 66).

R67-13424 ASQC 844; 851

Sylvania Electric Products, Inc., Woburn, Mass.

RELIABILITY ANALYSIS OF X-BAND TUNNEL DIODES Final Report

Charles Davis and Arthur Lueck Griffiss AFB, N. Y., RADC, Dec. 1965 74 p refs

(Contract AF 30(602)-3487)

(RADC-TR-65-291; AD-625956; N66-20817) CFSTI: HC $3.00/MF $0.65

The report presents an account of a microwave tunnel diode improvement program, and the results obtained from reliability tests performed on devices fabricated by the improved processes. A new solid structure tunnel diode was developed during this contract which exhibits superior reliability characteristics to any previously tested tunnel diode. The process and fabrication details for this device along with reliability data are included in the report. Author (TAB)

Review: The chief contribution of this report is a description of a mechanically more rugged tunnel diode structure (called SSTD for Solid Structure Tunnel Diode) and the demonstration of its improved performance under various mechanical and thermal cycling tests. The steps in the manufacture of the SSTD are given and the reasons for its superiority over tunnel diodes manufactured by the standard process are obvious. Unfortunately the report is written more in the tone of a status report to the contract monitor than as a final contract report destined for wider distribution. It is not a self-contained report; the authors assume that the reader is already familiar with the program, its problems, and its previous accomplishments. For example: (1) The operation and function of the apparatus in Fig. 3 are not explained; the data plotted in Fig. 4, describing yields of the operation performed by the apparatus of Fig. 3, have little meaning for the reader without additional background information. (2) The terms J_p, I_p, C_v, etc., quite common and meaningful symbols to the tunnel diode worker, are not defined in this document; no scale is given on the I_p/C_v axis of Fig. 9. (3) The information to be transmitted by Fig. 17 (which covers 5 pages) is not clear, partly due to illegible printing but also partly due to lack of captions and labels. Section 3.0 (background) lacks coherence; the report in general seems to be inefficient in that too much paper is taken to convey the message. Many illustrations are poorly labeled or not labeled at all.

R67-13425 ASQC 844

ITT Federal Labs., Palo Alto, Calif. Shockley Labs.

RELIABILITY PHYSICS STUDIES ON TRANSISTORS Quarterly Status Report No. 1

W. Schroen Griffiss AFB, N. Y., RADC, Aug. 1965 63 p refs

(Contract AF 30(602)-3605)

(RADC-TR-65-141; AD-621075; N66-10870)

The report deals with failure mechanisms in silicon semiconductors. Investigations were made of surface breakdown phenomena in oxide protected silicon devices. The surface breakdown voltage of a diode can be altered by external illumination or by carriers moving in surface channels. The fact that a small photocurrent controls an avalanche current which is several orders of magnitude larger has been studied in three respects: The effect of the illumination itself, both with and without an additional gate around the diode under consideration, the effect of an adjacent diode located at a certain distance from the diode under study, with and without gate, and the effect of surface ion drift, again with and without gate. Further investigations are made of the second breakdown phenomenon in silicon power transistors. Diode structures have been used to observe the appearance of hot spots. Plasma breakdown in relatively large areas has been observed. The high temperature associated with the plasma was able to seriously damage the aluminum evaporated for contacting the diodes. TAB

Review: This contract technical report continues the Shockley Laboratory investigations of failure mechanisms in silicon devices. Previous notable work has included studies of second breakdown in silicon transistors (see R64-11461) and the measurements of oxide potential (and surface ion motion) by the Kelvin probe technique (see R67-13119). Both these investigations are extended in this report but the chief topic is a model describing the degrading influence of light upon the breakdown voltage of a p–n junction. The phenomenon is interesting to avant garde circuit designers in that a relatively modest input of light energy can cause a junction to switch from a low-current mode to an avalanche, high-current mode. The model developed to explain the observation is consistent with the reported observations. It is, however, sufficiently new that independent confirmation seems particularly important. The concept of acceptor trapping levels being charged by channel current is a fundamental contribution and should be further examined. It is surprising that no more discussion or confirmation of this model is available by now, other than the Shockley publications. The original presentation is at least two years old (see R65-12338); apparently no research group other than the author's has attempted to investigate the detailed consequences of this trapping model. It was not until mid-1966 that the author published this work in the open professional literature [1].

Reference: [1] W. Schroen, R. D. Woodruff, and D. Farrington, "Influence of non-equilibrium carriers on the surface breakdown of diodes and MOS structures," IEEE Transactions on Electronic Devices, Vol. ED-13, July 1966, pp. 570–577.

R67-13426 ASQC 844; 775

Quan-Tech Labs., Inc., Whippany, N. J.

STUDY OF THE RELATIONSHIP OF NOISE AND COMPONENT RELIABILITY Final Report, 1 Feb.–15 Dec. 1965

15 Dec. 1965 60 p

(Contract NAS5-9550)

(NASA-CR-83896; N67-25959) CFSTI: HC $3.00/MF $0.65

The purpose of the study program was to determine which type of noise or noise measurement is the most effective screening tool for detecting defective transistors and to establish a "cull line" or screening level for this measurement. The resulting data from the tests showed a very strong correlation between failure and noise measurement with a 30 milliampere collector current. This correlation however began to degrade at the end of 72 hours of operation at maximum dissipation and a 100°C ambient. The failure rate as a function of time showed that beyond the 72 hour period, a constant failure rate occurred. The failures during this constant rate showed no correlation with any measured parameter and it appears that the manufacturer's rating of the device is in excess of the proper limit. Of the 500 transistors aged, 10% failed a 100 nanoampere maximum Icbo specification. 50% of these failures occurred in units exhibiting high noise, that is in the top 20% of the above test. Only 10% of these failures occurred in units exhibiting noise in the lower 52% of the noise test. In the normalized data, assuming the units tested were typical of their group, of the 3000 transistors screened 53% of the failures occurred in the top 29% of the noise test. However, at 72 hours of ageing 100% of the failures were contained in the top 29%. Author

Reveiw: The subject of this investigation is identical to that of [1], but the conclusion differs. The authors here conclude that 1/f noise (which dominates the low frequency noise voltage measurements) is an effective screen for weeding out early failures in silicon planar n–p–n transistors. This conclusion is based on a relatively small sample and less intensive testing than that of [1]. However, failures unrelated to noise were observed and a significant number of noisy transistors did not fail. This is substantially the same picture as developed in [1]. The differing conclusions may merely reflect the different orientations of the investigators. The conclusion in this report is that some recognizable correlation between noise voltage and failure does exist and should be exploited; the conclusion in [1] is that this correlation is not high enough to be of practical value yet. One disturbing feature of this report is that the observation of a constant failure rate after 72 hours at maximum dissipation must be attributed to the manufacturer's over-rating of the tested transistor. The implication is that since failures after 72 hours are not correlated with noise measurements, burn-out due to over-stress is predominating the failure rate. The alternative explanation—that for most of the normal life of these transistors noise is in fact unrelated to failure—must be at least considered. The chief source of 1/f noise in planar silicon devices is now thought to be interface states. The relationship between interface density and device failure rate is not yet clear but upon further study may lead to effective device screens based on noise measurements.

Reference: [1] Doyle, Edgar A., Jr., Smith, Jack S., and Sweet, Gerald G., *Semiconductor Reliability–The Correlation of Excess Noise with Deleterious Surface Phenomena,* RADC Technical Report RADC-TR-65-379, Dec 65 (AD-627 891)

R67-13427 ASQC 844; 775; 851

Systems Research Labs., Inc., Dayton, Ohio.

INVESTIGATION OF RF RADIATION AS A SECONDARY PHENOMENON FOR USE IN CHECKOUT

James W. Ballard and Eugene F. Horn Wright-Patterson AFB, Ohio, AF Aero Propulsion Lab., Jun. 1965 101 p refs

(Contract AF 33(615)-1489)

(AFAPL-TR-65-46; AD-619899; N66-11459)

The emission of radio-frequency (rf) radiation was studied over a range of frequencies from .15 to 400 megacycles per second (Mc/sec) for small gaps of .5 to 10 mils. The electrodes were .050-inch in diameter with polished plane ends which formed the gap. Most of the work reported was done in air at atmospheric pressure with nickel electrodes although argon gas and gold, aluminum, and copper electrodes were employed. Considerable attention was given to shielding, and the effect of receiver and generator circuitry. The effect of antennas and cables were also studied in relation to rf radiation emission and reception. Radiation from malfunctioning systems is attributed to a brush type discharge across very small discontinuities within the electrical parts. These discontinuities in a number of cases were found to be essentially contact, i.e., less than a few thousand angstroms. The mechanism causing breakdown was found to be the avalanche type with the involvement of secondary electronic emission. TAB

Review: This report will be useful mostly to those who are doing research in this field. It is more a basic study of a few kinds of electrical discharges than of the emanations from faulty components. The only faulty components actually used were made faulty artificially and the faults were apparently big enough so that larger than usual voltages had to be applied to the component in order to induce the discharge. The authors may well be right that the brush discharge is responsible for the RF radiation from faulty components. Obviously, however, they have not shown it for typical faulty components, largely because they were unable to find any. The subject of RF emissions from faulty components for use in check-out is an important one. Discussions about it have not appeared in the unclassified literature as much as they probably should in view of its potential importance. For while it may be true that you cannot inspect reliability into a product, you can certainly inspect unreliability out of it. It is in this direction that the large advances in reliability will come in the future.

R67-13429 ASQC 844

Naval Research Lab., Washington, D. C.

SOME FACTORS INFLUENCING THE LIFE AND PERFORMANCE RELIABILITY OF HIGH-PRECISION POTENTIOMETERS

V. G. Fitzsimmons and J. B. Romans 12 May 1965 22 p refs (NRL-6287; AD-616893; N65-30824) CFSTI: $3.00

Linear precision potentiometers, which had been subjected to life testing, were studied to determine the relation between lubrication, wear, potentiometer life, operating characteristics, and electrical noise generation. Oil or grease had been used as the contact arm and winding lubricant. Wear was concentrated on contact arms and was most severe where oil had been used. Potentiometers made with precious metal windings showed the least wear. Both oil and grease had been used for lubricating the potentiometer ball bearings. Half the bearings were rough in operation and two were locked because of wear and fetting corrosion products. Contact arm wear scar size showed no correlation with change in total resistance or torque required to operate the potentiometers. Noise levels of all potentiometers rose during the life tests, but those with contact arms having the greatest wear at the end of the tests produced the least noise. Noise increase is related to loss of contact arm lubricant by evaporation, creep, or migration. Recommendations are made for reducing noise, and preventing oil creep and migration. R.N.A.

Review: This is a good report in many ways. It is, of course, not possible to discern the quality of the experimental program from reading the report. But from the care and detail which is apparent in the report, one suspects that the same quality went into the program itself. The direct results are of narrow interest, but the general problems encountered will be stumbled against in many programs. For example, conducting these tests was difficult because of insufficient information on construction of the parts. Some variables did not correlate with others and there was a prior expectation of a good correlation. It was also found that the statistical aspects of the problem were not tested for this report. All in all, anyone who is considering a program of mechanical component analysis would do well to read the report and to see what the problems were and how they were handled.

R67-13433 ASQC 844; 851

PHYSICS OF FAILURE IN COMPONENT PART RELIABILITY TESTING.

G. E. Best, G. R. Bretts, H. M. Lampert, and T. M. Walsh

In: Proceedings of the Spring Seminar on Concepts and Case Studies of Reliability Test Demonstrations, Apr. 28, 1965. Seminar sponsored by Reliability Chapter, Boston Section, Institute of Electrical and Electronic Engineers and Electronic Systems Div., Air Force Systems Command, Bedford, Mass. Newton, Mass., IEEE, Inc., 1965, p. 13–23. 2 refs.

Available from IEEE, Inc., Newton, Mass.: $4.00.

Test and measurement techniques are described for controllable acceleration of electronic part aging, as well as for physics of failure studies of the components used. To meet reliability requirements of satellites operating for three years, resistors, capacitors, diodes, and transistors were subjected to constant levels of electrical and thermal stresses for periods of between 700 and 14,000 hr; and all but the capacitors were subjected to temperature step-stress at constant power levels. Metal film resistors exhibited greater stability than oxide film resistors at 200°C and 50% of rated power during 11,000 hr testing; and phase precipitation and oxidation processes were identified during stress testing of the metal film resistors. Glass dielectric capacitors were stressed at five times rated voltage at 50°C for 12,000 hr without significant parameter change; and mathematical models were developed to describe the relationship between ionic distributions at equilibrium, leakage current, and life versus temperature for these capacitors. M.W.R.

Review: The first part of the paper is similar to other papers produced by these authors. See, for example, R64-11456, R65-11949, R66-12423, and R66-12869. The comments in those reviews apply as well to this one, namely, the detailed analysis, especially with the time-temperature parameter is not too good, but the discussion of failure behavior is worthwhile. The second part of the paper deals with tests on assemblies of components. Some observed failure rates are given and compared with quoted failure rates. On the practical level the tests and the analysis seem to be well carried out.

R67-13437 ASQC 844; 770; 851

Rome Air Development Center, Griffiss AFB, N. Y. Research and Technology Div.

RELIABILITY IN MICROELECTRONICS

Joseph B. Brauer Oct. 1966 14 p refs Presented at the IEEE Microelectronics Symp., St. Louis, 18–20 Jul. 1966 (RADC-SP-66-3; AD-644195; N67-18912) CFSTI: HC $3.00/MF$0.65

This paper reviews the current and anticipated future reliability requirements for microelectronic devices and compares these to the present reliability levels. The "quality problem" as it affects reliability is discussed in some detail. Data is derived from various equipment development programs and investigations of integrated circuit quality and reliability. In recognition of the fact that the product (microelectronic devices) does not yet meet the "promise," some of the problems and interim solutions are discussed in detail. The effectiveness of various acceptance and screening procedures for integrated circuits is evaluated. Author

Review: An important message of this paper is "...most if not all of our (microelectronic) reliability problem is, in fact, a quality assurance problem." In spite of some sour statistics on the contemporary product being delivered, the author is clearly an optimist. The goal of Maintenance-Free Lifetime (MFL) is lofty enough to always elude complete attainment, but the purpose of this paper is to point out the next steps in that direction. Two basic questions are raised and answered: (1) "How do we get there?"—evidently by 100% screening similar to the procedure given in Fig. 12 (the author emphasizes the omission of shock and centrifuge screens); (2) "How can we stay there?"—by QUPID (Qualification Procedures for Integrated Devices), a current Philco program which apparently is attempting to specify those screening procedures that are necessary in order to attain various failure rates. Little information is given about the details of QUPID. The author's style is colorful, and his reliability vernacular is original.

R67-13438 ASQC 844

National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.

INVESTIGATIONS OF MONOLITHIC INTEGRATED CIRCUIT FAILURES

Kenneth W. Woodis 21 Nov. 1966 45 p

(NASA-TM-X-53548; N67-14908) CFSTI: HC $3.00/MF $0.65

The results of failure analyses performed on a group of monolithic integrated circuits obtained from industry are presented. The devices tested were defective and had been rejected. The most prevalent failure modes and/or causes of rejection of monolithic integrated circuitry were determined, and the capability of performing failure analysis of these devices was developed. The experiment showed the greatest causes of failure to be (1) bonding and (2) open or shorted aluminum interconnects. Other failure causes found were: too thin a layer of silicon step-up or step-down, poor adherence of aluminum to the silicon, failure to remove all surface contaminants, chipped dice, poor mask alignment, and defects in both the silicon material and the mask. It was determined that proper failure analysis could reveal over 90% of the failures encountered. Author

Review: The results of this small sampling of rejects from commercial integrated circuit production lines speak reasonably well for the industrial procedures used to separate good units from bad units. Almost all units were verified to be rejects; only a small percentage of apparently good units were found in these admittedly small samplings. It is not possible to know what abnormal screens or criteria were used by industry prior to submitting these reject samples for analysis. Clearly the possibility exists that a manufacturer could perceive the advisability of submitting only rejects when asked to furnish rejects. Submitting a large number of good units as rejects is a response most commercial suppliers would take some precautions to avoid. Hence the sampling here may very well not be representative of what actually ends up in the typical reject bin. This subject is not discussed in the report. The analyses show that poor workmanship exists but that quality control is catching at least some of it. It is also important to know how much is slipping through—how many units are passed that should be rejected? The information presented here in general confirms the findings of previous similar investigations (see papers published by Autonetics personnel in Physics of Failure Volume 4, and reports of work done on the MIT Apollo program).

R67-13439 ASQC 844

National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.

DEGRADATION OF TRANSISTOR PERFORMANCE DUE TO PASSAGE OF SMALL-COULOMB HIGH-VOLTAGE SURGES

Norman M. Garrahan Sep. 1966 13 p

(NASA-TM-X-55572; X-711-66-449; N66-39528) CFSTI: HC $3.00/MF $0.65

In order to determine the effects of high-voltage-pulse transients on transistor life and beta stability, a few selected transistors were subjected to a series of randomly applied high-voltage pulses across the base-emitter junction. It was found that successive high-voltage pulses caused a gradual beta degradation and drop in junction resistance, with a need for increased base-current drive for a measurable non-zero beta. As the amplitude of the pulses was increased, a point was reached where the transistor open-circuited. This report describes a brief empirical qualitative check made on a few selected transistors to help arrive at a quick solution to production failures of transistors in potting molds. Author

Review: This extremely brief note discloses preliminary information on the degradation of n–p–n transistors which have been subjected to a series of discharge pulses from a 25 pf capacitor. These pulses were placed across the emitter-base junction in both the forward and reverse directions; the peak voltage during discharge was varied from 400 to 1500 volts. This information is probably of interest only in special applications (such as environments with high static electricity); a rough threshold of safe operation seems to be suggested. Criteria for preferring one transistor over another have not been developed; thermal resistance is probably highly correlated with degradation susceptibility.

R67-13444 ASQC 844

ELECTRICAL FAILURE IN SOLIDS.

Joseph E. Eichberger (Stromberg-Carlson Corp., Rochester, N. Y.).

Electro-Technology, vol. 77, May 1966, p. 77, 79–86. 5 refs. (A66-29669)

Discussion of the modes of electrical failure in solids and a consideration of the phenomena which cause such failures. All failures are caused by either excess energy storage or excess internal disordering. Zener breakdown in a crystalline structure occurs when a voltage-induced field is sufficient to cause an electron to move from a valence band to a conduction band. Electrical breakdown can also be caused by increasing ionization. For breakdown to occur, the impressed field must be such that the energy gain exceeds energy loss for electrons of all energies. Gas-discharge breakdown is initiated by an electron avalanche in the gas. Failures caused by the generation of heat in a conductor or semiconductor are considered. Entropy failure mechanisms and diffusion processes which result in the degradation of the conducting material are analyzed. IAA

Review: The scope of the materials physics described in this paper is broad; the discussion is basic and general. To be truly first-rate, review papers of this type must grasp the basic principles of the subject and present them in a coherent development so as to emphasize the unity that is often obscured in the random, scattered original publications. Good review papers and text books invariably replace original publications as cited references. This paper starts out in its introduction as though it might be in this category, but shortly afterwards seems to lose sight of the goal. What results is a collection of excerpts of topics in material physics whose primary unity is that they all describe phenomena that can cause irreversible changes in the physical properties of solids. It is difficult to identify a useful role that this paper will fulfill. Readers not already familiar with the subjects will not be able to follow the discussion; those that are will find as many problems raised as are answered. Hence, its usefulness as a reference paper is limited. The unifying exposition of failure in solids that is hinted at in the introduction is not delivered.

R67-13445 ASQC 844

AN INVESTIGATION INTO THE RELIABILITY OF PLANAR TRANSISTORS.

M. R. P. Young and D. R. Mason (Texas Instruments Ltd., Bedford, England).

Microelectronics and Reliability, vol. 4, Sep. 1965, p. 245–266. 10 refs. Sponsored by the Dept. of the Navy.

Testing history and results are presented for the high temperature aging of several lots of n–p–n planar transistors, and it is concluded that degradation transistor failure results from an adsorption mechanism at the semiconductor-oxide interface. For thermally generated failure mechanisms, it is found that Arrhenius acceleration curves can be drawn which appear to predict the future behavior of planar transistors with sufficient accuracy. Obtained failures are explained by the formation of depletion–inversion layers on the transistor base, and the consequent increase and then decrease in gain accompanied with an increase in leakage current. While the adsorption model for leakage current degradation is preferred, a postulated chemical reaction model predicted the correct form of the life curve but was less accurate in predicting how the leakage current of failures increased with life. M.W.R.

Review: The authors have attempted to deduce the chemistry and physics of a surface phenomenon from life test data of n–p–n planar transistors. Their investigation appears very competent; their account of it in this paper convinces the reader of their scientific ingenuity and persistence. A major basic surface interaction is postulated under the title of the adsorption model. The fundamental problem investigated here is the exchange of charge carriers between surface states (due to unidentified absorbed species) and the underlying silicon. This work is now three years old. In the intervening years the influence of space charges in oxide due to ionic contaminants has become well publicized and could probably provide a better explanation of the surface effects observed here. The fundamental charge exchange problem remains, however, and might well still prove to be of significance, once ionic contaminants (or their effects) are removed. Not inconceivably the source of oxide space charge (which does not "communicate"; i.e., exchange carriers, with the underlying silicon) and those interface or surface states postulated in the authors' adsorption model could be identical. In considering various hypotheses the authors have occasion to review briefly work already in the literature. The nomenclature of the original papers is not changed and often is not adequately defined. The result is a stringing together of various independent works to form a rather disjointed narrative in places.

R67-13446 ASQC 844; 814

LOOKING AT INTEGRATED CIRCUIT COSTS AND FAILURES.

Robert A. Bernay (Thompson Ramo Wooldridge, Inc., TRW Systems Group, Washington, D. C.).

Electronic Industries, vol. 24, Dec. 1965, p. 76, 77, 79, 80. (A66-15496)

Review of the refinements made that improve the yields, costs, and reliability of monolithic integrated circuits (ICs) of the silicon planar variety. The cost factors and the failure mechanisms are comprehensively reviewed. It is shown that the increased silicon IC complexity per package is actually reducing costs and improving reliability. In general, it is concluded that the higher the complexity, the greater the value. The value of the flat pack is noted. It is shown that the greatest single cause of failures is poor connections—the gold wires that connect the aluminum interconnection pattern on the die to the external leads on the package. It is maintained that the greater the complexity of the die (i.e., the more functions per package), the fewer the total number of bonds, and it is therefore concluded that reliability per function improves with increasing internal package complexity. Two additional failure mechanisms are considered: open aluminum interconnections, and leaky packages. IAA

Review: This paper is a clear, simple statement of the advantages in reduced cost and failure rate/component that are anticipated for complex integrated circuits over the simpler off-the-shelf integrated circuits of today. These very same advantages have now been demonstrated by simple integrated circuits over discrete component circuits. There seems to be no reason to doubt their extension as discussed here. The sub-heading of the paper suggests that the reader might be surprised to learn that complex integrated circuits will reduce system costs and increase reliability. The vast contemporary effort on Large Scale Integration (LSI) techniques says that a significant group of people have been convinced of this fact for some time. The author also gives good arguments and illustrations for preferring the flatpack over the TO-5 package.

R67-13447 ASQC 844; 716; 782; 846

HOW LONG-TERM STORAGE AFFECTS RELIABILITY.

Rocco F. Ficchi (Radio Corporation of America, Defense Electronic Products, Communications Systems Div., Camden, N. J.).

Electronic Industries, vol. 25, Mar. 1966, p. 42–48, 50. (A66-23755)

Summary of information available on the behavior of electronic parts and equipment when stored or inert for long periods. A numeric is developed which indicates what the failure rate should be for such materials, the nature of existing information in this area is discussed, and long term storage tests conducted by the Radio Corporation of America, The Martin Company, and The New York Naval Shipyard Materials Laboratory are described. A nomograph is given of data accumulated from testing of parts after up to three years storage, and data resulting from storage tests on transistors are tabulated. IAA

Review: Little is known about the behavior of parts and equipments after they have been stored or inert for a relatively long time. Yet such information is essential to the assessment of the reliability of much present-day defense and aerospace equipment. This state-of-the-art survey serves the dual purpose of summarizing the available information (as of early 1966) on this topic, and of pointing the way toward a suitable program of investigation. Judging by the current literature (which is meager on this topic), the summary is quite complete. The suggestions are reasonable and will be valuable to those interested in pursuing work in this area.

85 DEMONSTRATION/MEASUREMENT

R67-13402 ASQC 851; 775

TESTING THE RELIABILITY OF ELECTRIC CONTACTS II: ONE YEAR'S PRACTICAL EXPERIENCE.

R. F. Snowball and J. W. Lawrence (Burndy Corp., Electronic Products Lab., Norwalk, Conn.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill.; May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 213–219. 7 refs.

Field performance of a Contact Resistance (CR) Meter, which measures the resistance at the interface of two conducting members of an electric contact, indicates its usefulness in measuring long-term device reliability. Many dry reed capsules, relays, switches, and connectors exhibit a correlation between reliability and the electrical resistance of the contact interface; except in cases where excessive wear occurs. As compared to the predictive ability of MIL-SPEC tests, the CR Meter gives better correlation with performance. A comparison of standard tests versus initial CR as failure predictors is tabulated, as is a comparison of pulsed and nonpulsed contacts. Results are given for an analysis of the relationship between initial and final CR, and it is concluded that the CR Meter provides a valuable means for nondestructive assessment by an initial measurement. M.W.R.

Review: This paper will be of interest to those concerned with the specification/measurement of long-term reliability for connectors, relays, and switches. A non-destructive method for accomplishing this through the medium of indirect measurement of contact resistance is discussed. A key consideration, since it justifies the use of the method, is the relationship between contact resistance and performance. The authors cite work in progress which has yielded positive results toward verifying this correlation. The accomplishment of this would establish contact resistance as the important parameter in assessing the reliability of these components.

R67-13417 ASQC 851; 751; 844

MICROELECTRONICS VISUAL INSPECTION—FACT OR FICTION?

H. D. Ludwig (Westinghouse Electric Corp., Molecular Electronics Div., Baltimore, Md.).

In: American Society for Quality Control, Annual Technical Conference, 21st, Chicago, Ill., May 31–June 2, 1967, Transactions. Milwaukee, American Society for Quality Control, Inc., 1967, p. 629–635.

Emphasis is placed on the necessity of revising visual inspection procedures in the microelectronics industry to improve overall operation efficiency from both quality and quantity viewpoints, improve reliability of the shipped product, and decrease the need for quality and engineering support because of interpretation problems. Controls considered are a quality audit program, inspection training and certification program, a project called Review and Control Escapes (RACE), and in-process controls. The investigation, evaluation, and correction action phases are delineated for the audit program; and personnel moves, visual standard review, and handling and processing improvement are discussed under corrective action. Lot acceptance, real problem identification, and special studies are treated in terms of an improvement program to evolve into an objective visual inspection method that will reject initial failures, detect potential failures, and accept a final reliable product. M.W.R.

Review: Visual inspection of microcircuits are grudgingly performed by manufacturers, are insisted upon by large-volume customers, and constitute a source of irritation and mistrust to both. Little discussion of these problems appears in the literature, perhaps because of their subjective nature. It is these very problems that are the subject of this paper. Among the fundamental problems of visual inspection are those of (1) deciding what criteria should be used to distinguish rejects from accepts, and (2) once having decided upon a particular criterion, having it uniformly enforced. Training and motivation of inspectors are vital to establishing a useful visual inspection station. These problems are treated fairly by the author; the human side of the problem is effectively presented. After cataloguing the slow progress required for upgrading the visual inspection process, the author drops his bomb; "one hundred percent visual inspection is detrimental to the product cost, a deterrant (sic) to the quality control of true problems, and a threat to reliability if not properly defined and administered." Fewer rather than more visual inspections from the present norm is the author's preference. All these conclusions do not follow from the text presented—the "true" problems whose quality control is being compromised by visual inspection are not enumerated or in any way identified; it is unlikely that any reader not already of these opinions will be converted to them by arguments presented here. The conclusions are a statement of opinion on an important phase of reliability. Having the statement made is a service itself–particularly about this too-little-discussed topic. The spelling in the paper mildly refutes the conclusion–good visual inspection would eliminate misspellings such as "than" (for "then"), "consistant," "learing" (for "learning"), "deterrant," and "unsubstanciated."

R67-13430 ASQC 851; 782; 833

Grumman Aircraft Engineering Corp., Bethpage, N. Y. Research Dept.

PRESELECTING AND PRECONDITIONING OFF-THE-SHELF TRANSISTORS AND MICROCIRCUITS FOR RADIATION RELIABILITY

P. Grinoch and M. Rossi Jul. 1966 28 p refs
(RM-332; AD-485860; N66-37112)

Semipermanent and permanent radiation effects in silicon planar passivated transistors and monolithic silicon integrated circuits were evaluated by their induced damage to lattices and surfaces. Results showed that lattice damage became consequential after device exposure to either 10^{12} fast neutrons/cm^2, 10^7 R of 1-MeV gamma or X-radiation, 10^{14} electrons/cm^2, or 10^{11} protons/cm^2. Similarly, surface damage became significant after exposure to either 10^5 of gamma or X-radiation, 10^{13} electrons/cm^2, or 10^{12} protons/cm^2. Radiation vulnerability was intensified by the damage susceptibility of parameters such as β and I_{CBO}, so that the mean time-to-failure of a given transistor type in a given radiation field was characterized by an order-of-magnitude uncertainty. A sample circuit was designed with degenerative feedback from more radiation resistant device types, such as Zener diodes, Esaki diodes, and ferrite core devices, that tolerated β degradation by a factor of 12. G.G.

Review: The question raised here is: given the contemporary manufacturing techniques of silicon planar technology, how can the system designer improve the radiation resistance of circuits built with off-the-shelf components? The answer suggested is to employ various screens which consist of irradiating and annealing steps from which the most radiation-resistant units can be selected. No attempt is made to understand more fully the physics of device degradation or to suggest alterations in device manufacture. The discussion is aimed at helping a circuit designer do the best he can with what is available now. The paper attempts to show how to make the best of a bad situation, for the circuit with off-the-shelf components is likely to be rather limited in radiation tolerance. The preselection technique recommended here enables the designer to use only the most resistant units and to improve mission-time-to-failure by a factor of 2 to 5 over circuits built with unsorted off-the-shelf components. The discussion is qualitative throughout and offers a clear, readable summary of what is known about irradiation effects. The primary device considered is the planar silicon transistor. The extension to silicon integrated circuits is considered briefly in the conclusion. This report, an interim contract report, summarizes the problems very well and defines a reasonable stance for the system builder to assume.

R67-13432 ASQC 851

WHAT IS A RELIABILITY DEMONSTRATION TEST?

G. Garfinkel (International Business Machines Corp., Systems Manufacturing Div., Hopewell Junction, N. Y.).
In: Proceedings of the Spring Seminar on Concepts and Case Studies of Reliability Test Demonstrations, Apr. 28, 1965. Seminar sponsored by Reliability Chapter, Boston Section, Institute of Electrical and Electronic Engineers and Electronic Systems Div., Air Force Systems Command, Bedford, Mass. Newton, Mass., IEEE, Inc., 1965, p. 1–11. 1 ref.
Available from IEEE, Inc., Newton, Mass.: $4.00.

The exponential reliability function is considered as the most common statistical form for the determination of a reliability demonstration test; and statistically-designed demonstration tests are discussed in terms of reliability indexes, which are numbers that describe equipment life characteristics during a normal operation period. Typically, a demonstration test should consider a null hypothesis in terms of MTBF and the producer's risk as well as an alternate hypothesis that takes into account the consumer's risk. In other words, the reliability demonstration test is defined as a statistical test to demonstrate a null hypothesis with an applied or specified level at which an alternate hypothesis is accepted in place of the null hypothesis. Typical fixed-time and sequential statistical plans are discussed within this definition. M.W.R.

Review: This paper presents the usual kind of information about reliability demonstration tests where the constant hazard rate is assumed. It is generally a good and accurate, though brief, presentation. There are two philosophic questions which, as is also customary in these elementary discourses, are not treated. (1) The operating characteristic (OC) curve has the true MTBF as one of its axes. The producer's risk, which is one point on the OC curve, involves the paradox that the producer must make the equipment with a longer MTBF than required, if he is to have a good chance of passing the test. But then if he knows what that longer MTBF is, why is this prior information not used? If he does not know what it is, is it not meaningless to discuss the producer's risk? (2) The segregation in the bathtub curve of causes for failure such as random in the central flat portion and due to defective parts, workmanship defects, etc. in the initial portion is quite artificial. If the uncertainty in time of a failure is important, it is a random occurrence regardless of whether the probability distribution is Gaussian, exponential, or something else. The causes of failure in the separate regions of the bathtub curve are generally concerned with the grossness rather than the kind of defect. The discussion of sequential plans is weak since no example is given; the beginner will have a hard time figuring out what the technical language means. The author probably did not mean, "They duplicate the operating characteristics of a fixed-time plan..." The sequential test will have different properties from the fixed-time single-sample plan. Sequential tests are more difficult to analyze and are generally done in a different way from single-sample tests. The discussion of truncation of sequential tests is inadequate. A sequential test can be truncated in any manner desired although the calculation of probabilities may be difficult. Aroian has done quite a bit of work with truncation of sequential tests and has shown how they can be truncated without changing any of the previously-calculated probabilities. This is possible because the probabilities are ordinarily calculated by approximations which are overly generous. The tests can be truncated, at least in certain ways, and still stay inside of these probabilities. Other important considerations in designing demonstration tests besides those mentioned in the text are contractual ones and the obstinancy of the customer.

R67-13434 ASQC 851

RELIABILITY TEST OF A COMPUTER.

Donald D. Bishop (Air Force Systems Command, Electronic Systems Div., Bedford, Mass.).
In: Proceedings of the Spring Seminar on Concepts and Case Studies of Reliability Test Demonstrations, Apr. 28, 1965. Seminar sponsored by Reliability Chapter, Boston Section, Institute of Electrical and Electronic Engineers and Electronic Systems Div., Air Force Systems Command, Bedford, Mass. Newton, Mass., IEEE, Inc., 1965, p. 55–64.
Available from IEEE, Inc., Newton, Mass.: $4.00.

Contractor preparation and guidance, time factors, and failure classification are discussed in terms of a computer reliability test. The distinction between test and demonstration is emphasized; and it is recommended that the contractor successfully test each item and function before demonstrating performance. Adequate documentation of failure and other data is also stressed, along with the establishment of useable failure categories. M.W.R.

Review: This paper is a recapitulation with commentary of the reliability tests and problems on a particular large-scale computer system. The unmanned contractor was not prepared for reliability demonstration and the schedules slipped appreciably (in fact, slippage slipped on slippage). The author is rather frank in discussing the contractor's problems and his lack of preparation for the reliability testing and demonstration. Apparently the system project officer contributed extensively to the test plans and procedures, more so than one would expect in equipment designed and built by a contractor. In several places the author emphasizes that the contractor was not only unprepared to demonstrate the reliability, he was barely prepared to verify it to himself. There are good and helpful hints in this article, both to system project officers and to contractors—it will be especially important to contractors because it does give an Air Force point of view. There are one and a half pages of recommendations which are good solid reading.

R67-13435 ASQC 851

DEMONSTRATING RELIABILITY—THEORY VERSUS PRACTICE.

Roy B. Carpenter, Jr. (North American Aviation, Inc., Space and Information Systems Div., Downey, Calif.).
In: Proceedings of the Spring Seminar on Concepts and Case Studies of Reliability Test Demonstrations, Apr. 28, 1965. Seminar sponsored by Reliability Chapter, Boston Section, Institute of Electrical and Electronic Engineers and Electronic Systems Div., Air Force Systems Command, Bedford, Mass. Newton, Mass., IEEE, Inc., 1965, p. 83–99. 12 refs.
Available from IEEE, Inc., Newton, Mass.: $4.00.

Theoretical and practical aspects of demonstrating reliability are discussed, and the growing disparity between methods and requirements of space mission assurance is analyzed. It is emphasized that demands placed on the mission planner cannot be met by purely statistical tools, and an approach to reliability determination is presented that is based on the derivation of a Test Emphasis Index, which is a relative measure of data required to provide reliability assurance on a given component of a system in relation to other system components. A method is suggested for determining optimum distribution of testing funds and for reducing overall time devoted to reliability procedures and a control medium and synthesis of confidence levels is included in the proposed reliability index. Test by statistical design is considered as theory as opposed to practice via assurance synthesis and overstress testing. M.W.R.

Review: This paper is more valuable for the problems it raises than for the solutions it offers. The complaints about long testing time, constant hazard rate assumption, etc., are valid, certainly. The fault most assuredly does not lie with statisticians and probably not with engineers, but with the problems—they are too complicated for the state-of-the-art. There is some good criticism of present-day practices such as calculating estimates of failure rate to many decimal places when the data are good to only one or two at best. The applicability of the constant hazard rate assumption is a matter of continuing controversy. Obviously it does not apply in a wear-out region—by definition—since the term wear-out is used to describe the region wherein the hazard rate is continuallly increasing. Even though the author is somewhat disenchanted with the constant hazard rate, he uses formulas and concepts which imply it. The use of MTBF as the criterion for reliability obviously presumes a one-parameter distribution, of which the most common is the exponential, based on a constant hazard rate. Testing at stresses higher than operating stresses is a good idea and the use of prior information for assisting in the estimation of reliability is most worthwhile. The problems arise not in being unwilling to bend mathematical rigor, but in honestly knowing what you have as a result. After all, the purpose of mathematical rigor is to be sure you do not wind up saying, "This is both A and not A at the same time." That is a contradiction in Aristotelian logic and the phrase is meaningless, but it can be said in one devious way or another if due attention is not paid to rigor. (The author has one interesting graph wherein the reliability goes above one. This same graph is actually rather misleading since it shows a constantly increasing hazard rate giving a reliability always above that for a constant hazard rate. Obviously there is more to this than meets the eye, since if they started out with the same hazard rate, the increasing one would always be worse. Furthermore the author puts wear-out away down near zero reliability and, of course, in the increasing hazard rate curve, the whole curve is in the wear-out region.)

R67-13448 ASQC 851; 815; 824; 844

SPECIFYING SEMICONDUCTOR RELIABILITY.

Lawrence Jones (Westinghouse Electric Corp., Atomic, Defense and Space Group, Semiconductor Div., Youngwood, Pa.). *Electro-Technology,* vol. 77, May 1966, p. 48–53.
(A66-29667)

Discussion of the factors affecting reliability in semiconductors and an outline of a reliability control program. It is generally assumed that failures for electronic components follow an exponential distribution; because of this distribution, the important quantity in reliability demonstration is the number of unit-hours of test. Alternative distributions are considered such as the Weibull, the log normal, and the gamma. A table is presented in which the sample sizes for a 1000-hr test are given for demonstrating failure rates with 90% confidence. Accelerated testing techniques are predicted on exposing the devices to be tested to conditions in excess of their ratings—smaller sample sizes and test periods can be used. Reliability control programs are discussed in terms of quality assurance tests, in-line patrol inspection, failure analysis, and quality surveys. IAA

Review: This paper is a good summary of contemporary semiconductor reliability. It is well-written, clear and accurate; it is brief but includes all the important facets of the subject—from the statistics to the human interaction aspects. The author has succeeded admirably in fitting all the various diverse activities that have been pursued under the name of reliability into an organized coherent reliability program. From this paper the reader can acquire some insight into the conflicting interests of vendor and vendee (see the paper by Ludwig, Transactions Twenty-First Annual Technical Conference, ASQC, 1967, p. 629–635) and an appreciation of the intangible factors in achieving high reliability. The introduction to the mathematics of reliability models is aimed at the novice. It is not completely self-contained in that the mathematical form of the models is not given but it illustrates vividly the fundamental problems that arise in assessing semiconductor reliability by conventional failure statistics. The various steps that have been taken beyond device testing are described from a general, overall viewpoint with the idea of identifying the contributions and limitations of each step. The author, obviously associated with a manufacturer, displays good understanding of the user's viewpoint.

R67-13449 ASQC 851; 814

TRANSISTORS—RELIABILITY, LIFE AND THE RELEVANCE OF CIRCUIT DESIGN.

J. M. Groocock (Standard Telephones and Cables Transistors, Ltd., Footscray, Kent, England).
(Institution of Electronic and Radio Engineers, and Institution of Electrical Engineers, Symposium on Engineering for Reliability in the Design of Semiconductor Equipment, Hatfield College of Technology, Hatfield, Herts., England, May 13, 14, 1965, Paper.) *Radio and Electronic Engineer,* vol. 31, Apr. 1966, p. 234–240. 5 refs.
(A66-29675)

The paper describes the design features of the high reliable silicon planar transistors and a brief description of the "accelerated life test" is given. These tests have to be carried out with high precision. The problem is discussed from the circuit designer's and the manufacturer's point of view and suggestions are made for obtaining reliable performance and a low rate of failure from the transistors. Author (IAA)

Review: The relevance of circuit design to reliability is not actually considered in this paper. Instead it is a discussion of reliability via device testing which is written for the circuit designer. One of the more emphasized points is that reliability costs money. A fundamental problem then facing the designer is to decide how much reliability is worth in dollars (pounds, in this case) for a particular circuit. The purpose of the paper is to offer guidance on this problem by outlining what screens, accelerated tests, and over-stress methods have been employed, what they cost, and what they guarantee. The discussion is largely qualitative. The information presented is more in the nature of advice than firm rules or formulae.

R67-13450 ASQC 851; 844

FINDING THE RELIABLE TRANSISTOR—THE MECHANICAL AND THERMAL TESTING OF SILICON PLANAR DEVICES.

J. M. Groocock (Standard Telephones and Cables, Ltd., Components Group, Footscray, Kent, England).

British Communications and Electronics, vol. 12, July 1965, 429–433.

(A65-26871)

Development of a rigorous screening procedure capable of eliminating "rogue" transistors. It had been found that test procedures involving centrifuge, drop, and tumbling treatments may not be rigorous enough; hence, a series of thermal and mechanical tests was introduced. It was found that, for an unimproved transistor, moderately stringent mechanical tests could eliminate a small proportion of weaker devices which were probably rogues. Ultrasonic testing gave a large and continuing proportion of failures. Tests involving both thermal and mechanical stresses when repeated continuously gave a continuing series of rejects and were much more stringent than the same mechanical tests performed alone. None of the test sequences gave a product which would withstand without failure a thermomechanical test. Process changes were effective in improving reliability. Test sequences which had produced many failures in the unimproved devices gave no failures with the improved type. It is considered that the main virtue of the test procedures was in showing clearly the improvements produced by process changes. IAA

Review: This paper is of relatively minor significance. The problem to have been solved was the development of screens to eliminate potential bond failures from silicon planar transistors bonded with aluminum wires. The effective screens are not developed; the problem is circumvented by an improved manufacturing process, no details of which are given. An interesting finding is that ultrasonic vibration proved more taxing than either the centrifuge, drop or tumble tests. Also mixed mechanical and thermal screens seemed more effective than either alone. In a subsequent private communication the author indicates that the points he makes are: 1. Screening cannot salvage a bad product; 2. Performance in screening tests is an effective criterion to distinguish between good and not-so-good manufacturing methods.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 10

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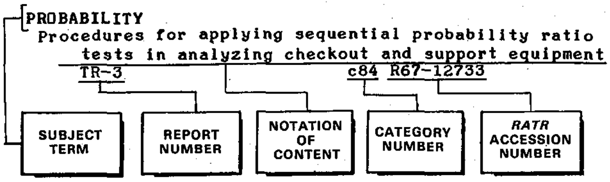

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PERSONAL AUTHOR INDEX

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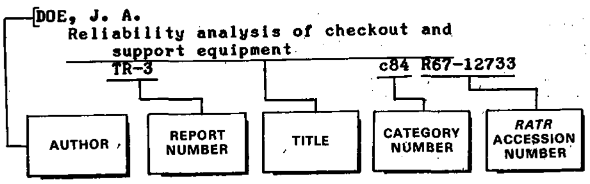

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 10

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NASA-Langley, 1967

NOVEMBER 1967

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R67-13452—R67-13499

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

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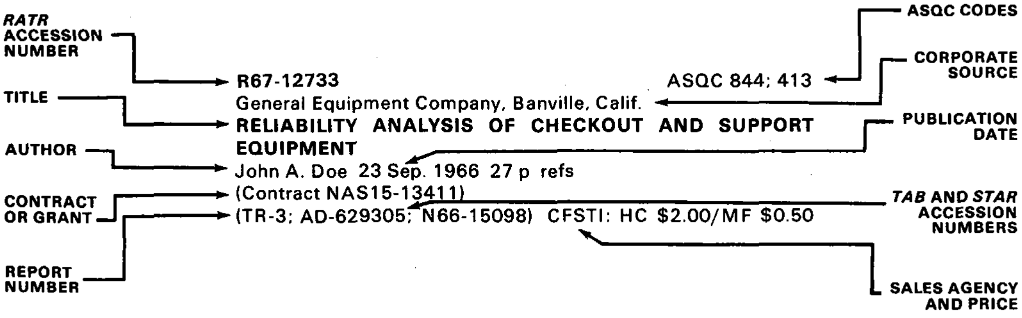
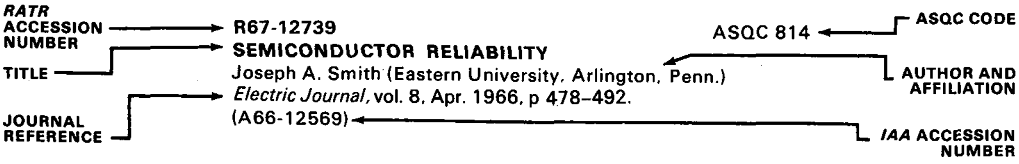
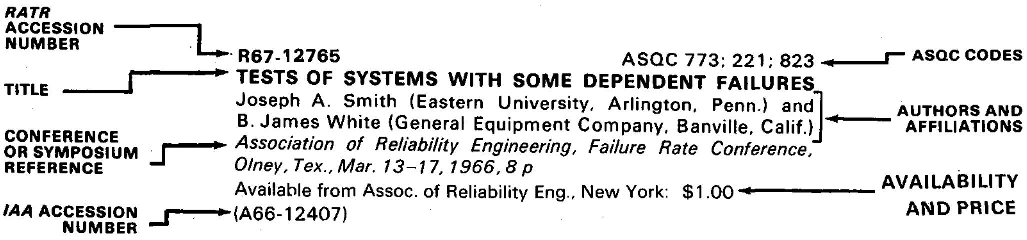


R67-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N66-15098) CFSTI: HC $2.00/MF $0.50



R67-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A66-12569)



R67-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A66-12407)

VOLUME 7 NUMBER 11

Reliability Abstracts and Technical Reviews

A Monthly Publication
of the National Aeronautics and Space Administration

November 1967

80 RELIABILITY

R67-13459 ASQC 800
RELIABILITY.
FOA Orienterar OM, 1966, p. 30–44.

An overview of reliability procedures and the physics of failure approach at the Swedish Military Electronics Laboratory is presented. Reliability is discussed in terms of the complexity of a modern weapon system that requires very high reliability of both its countless components and its overall functioning, and effect of system requirements on reliability requirements is considered. Reliability engineering methods employed in the development of new equipment are reported, including the components program, fixing the reliability goal, prediction of environmental stress and reliability, variability and maintenance analyses, and design review. Pilot series and system tests are discussed, as well as type testing, reliability testing, quality control, and technical and statistical failure analyses. Organization and resources are described for the physics of failure, which is concerned with component failure analysis in conjunction with type testing, continued development of failure analysis methods, and collection and distribution of information on reliability methods and failure mechanisms. M.W.R.

Review: This is a rather general discussion on the subject of reliability appearing in a publication describing the activities of The Swedish Military Electronics Laboratory (FTL). The first part of the paper is an expository presentation of some of the fundamental concepts of reliability engineering. This is followed by a description of the FTL program in reliability. The most important features of a reasonable reliability program appear to be included, and are described briefly. The FTL work in physics of failure is discussed in a separate article in the same publication. For those with an interest in reliability work in other countries, these papers will be worth reading; otherwise they contribute nothing.

R67-13466 ASQC 800; 810; 836; 844
Westinghouse Electric Corp., Sunnyvale, Calif.
RELIABILITY AND QUALITY CONTROL
L. D. Connell *In* Stanford Univ. Proc. of the Intern. Symp. on Magnet Technol. 1965 p 281–286 refs CFSTI: $3.00
(N66-16851)

An integrated approach must be followed to obtain reliability and quality control as well as to reduce economic waste throughout all phases of the manufacturing process. Causes of unreliability and the basic problems are considered. Reliability is discussed in terms of relationships, disciplines, and goals; the need for inherent reliability in design procedures is emphasized; and a design review reliability check list is presented. Product verification, quality of manufactured products, procurement, and defect analysis are reviewed. Both analytical and control techniques are considered necessary to achieve reliability in the manufacture of heavy electrical equipment. M.W.R.

Review: This paper is the kind addressed to both management and lay audiences and as such can be of value; at this level the paper is satisfactory. Examples of difficulties at a more detailed level are the following. (1) The *inherent* reliability of a design is not a well-defined term and can be misleading; a better word perhaps is *reference* reliability. (2) The author says, "Is this problem of unreliability due to degraded standards of manufacturing in industry?" and proceeds to answer no, asserting that "...much better equipment is now in use than in previous years." Three paragraphs later he says, "Other causes of unreliability include: (a) tendency to work components close to maximum capacity, (b) poor engineering practices, (c) lack of systems planning... (f) inadequate personnel training." These two paragraphs appear highly contradictory or else the equipment in use in previous years must have really been terrible. Much of the difficulty in analyzing this concept, of course, lies in the definition of the word 'better.' (3) The author makes a distinction between reliability and quality control which is not too clear and which pertains to a limited number of companies. Other companies interpret the words differently. (4) The reason for product reliability being less than one is called the result of various deficiencies. However, if a design is intentionally made a certain way with a knowledge that there will be some field failures, it is awkward to call it a design *deficiency*. There is a good emphasis on describing a reliability program as a discipline and there is a well-placed emphasis on the design review as part of this discipline. The actual effectiveness of the review depends on how well each person carries out his function. If the reviewers are usually engaged in other tasks for which they have prime responsibility, the design reviews may suffer due to lack of adequate preparation and interest. All in all, this is a general survey paper which is not intended to and does not relate anything new.

R67-13471 ASQC 800
Joint Publications Research Service, Washington, D. C.
ON BASIC TRENDS IN RELIABILITY THEORY
N. G. Bruyevich and V. P. Grabovetskiy *In its* Cybernetics in the Service of Communism, vol. II 18 May 1965 p 1–14A refs
(JPRS-30128; TT-63-31010; N65-23780)

The use of calculations for maintaining the precision and reliability in various complex instrument and machine devices and circuits is discussed. Statistical data is used for testing. Means of increasing reliability and durability are described; and the problem of reserving parts for machines is treated. L.S.

Review: As the title suggests, this is a general survey of the state of reliability theory. It ranges quite widely and thus discusses the kinds of things that can and need to be done rather than giving any details of the applications. It is of interest out of curiosity about Russian progress and perhaps to reliability specialists who want a complete idea of what is going on. The "foreign" references are limited to the Annual Symposia on Reliability and IEEE Transactions on Reliability (which probably proves something).

81 MANAGEMENT OF RELIABILITY FUNCTION

R67-13455 ASQC 817; 814; 851

RISK/COST TRADEOFFS FOR OPTIMIZING RELIABILITY DEMONSTRATION REQUIREMENTS.

Myron A. Wilson (General Electric Co., Reentry Systems Dept., Philadelphia, Pa.).

In: Proceedings of the 1965 Aircraft and Missile Division Conference, Cocoa Beach, Fla., Nov. 8–10, 1965. Sponsored by Cape Canaveral Section of the American Society for Quality Control. p 60–72. 7 refs.

Two criteria discussed for optimizing reliability demonstration requirements are: (1) minimum expected total mission cost as the sum of test cost and loss due to mission failure and (2) highest demonstrated reliability at preselected test cost. Test time necessary to demonstrate a given reliability is determined by the reliability, the required demonstration level, the required confidence level, and chance; and growth of demonstrated reliability as a function of test time under the influence of these four factors is examined. The demonstration requirement, which minimizes the expected value of total mission cost, is found by a tradeoff procedure in which the variables are the cost of testing and of mission failure. It is also shown that the growth curve and tradeoff curve can be used to select the expected value of reliability, which can be demonstrated at a chosen confidence level for the available funds. M.W.R.

Review: Decision theory is applied in this paper to planning optimum reliability demonstration tests, assuming exponential behavior. The presentation is non-theoretical, and a hypothetical example is included. More discussion of actual applications to real-world test planning would be desirable. The context of the paper is that of space vehicles, where real-world applications of reliability demonstration tests based on statistical notions of accumulating test time and failures have not generally been economically feasible unless some time-compression approach is used. Such acceleration techniques introduce additional assumptions which further cloud the meaning of the tests. A difficult feature of applying these techniques is assigning a cost (not necessarily monetary) to the consequences of mission unreliability. Very little has appeared in the reliability literature on the topic covered in this paper. Other references are Chapter 3 in the handbook covered by R67-13051 and Chapter 4 of the report covered by R66-12480.

R67-13456 ASQC 814; 863

RELIABILITY PREDICTIONS AND SYSTEM SUPPORT COSTS.

James E. Lott (Martin Marietta Corp., Martin Co., Logistics Engineering Dept., Orlando, Fla.).

(Institute of Electrical and Electronics Engineers, Aerospace and Electronic Systems Convention, Washington, D. C., Oct. 3–5, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems, vol. AES-3, May 1967, p. 382–389. (A67-31256)

A study is presented of the relationship between reliability predictions and system support costs. A case study of predicted reliability, predicted maintenance factors, and actual spares consumption of 53 component boards (printed circuit cards) used in a major item of ground-support equipment for a tactical missile system is reported. This case study illustrates how a system can be undersupported or oversupported, depending on the data used to determine the quantity of spares required. Factors for undersupport and oversupport are computed for the type of hardware included in the case study. These factors may be related to dollar costs. The problems associated with undersupporting or oversupporting a weapon system are briefly discussed. IAA

Review: System support costs treated in this paper are confined to spares. The paper presents some data for component boards used in a missile ground support equipment covering (a) spares actually supplied as recommended by spares personnel, (b) spares actually consumed, and (c) reliability predictions. Consumption of spares was generally less than spares supplied. This paper then raises the question "What if the number of spares had been based on the reliability prediction?" It presents some numbers which indicate that there would have been serious under-supply. No mention is made of the predicted versus actual reliability. The remainder of the paper is devoted to calling for improvements in the accuracy of reliability and spares predictions. Although the author could be accused of drawing rather broad general conclusions based on limited data, he is probably correct in concluding that numbers of spares based on the recommendations of a spare parts specialist usually result in overstocking and that using operational reliability predictions without suitable adjustments would result in under-stocking. The paper notes that the spares consumption data indicated a 600-hour burn-in, but that the reliability prediction which is cited here does not cite burn-in. This of course would result in more serious understocking during burn-in if the reliability prediction were used for planning spares stocking. Quite often reliability predictions are mute on the burn-in point, and this is an appropriate general criticism of reliability prediction. Also noted in the paper is the point that more spares are consumed than an accurate operational reliability prediction would indicate because of such factors as secondary failures, incorrect initial diagnosis, shelf-life, etc. The author apparently does not feel that such factors would cause a large difference between operational failure rates and spares consumption. It may well be that this difference is quite significant. All in all this paper has a worthwhile message, reporting limited but useful spares data and calling attention to inaccuracies in spares and reliability predictions.

R67-13457 ASQC 815

CUSTOMER REQUIREMENTS AND RELIABILITY SPECIFICATIONS.

Henry R. Thoman (Naval Air Systems Command, Avionics Div., Washington, D. C.).

AIAA, Annual Meeting, 3rd, Boston, Nov. 29–Dec. 2, 1966. 7 p.

(AIAA Paper-66-858) AIAA: $0.75 members; $1.50 nonmembers

A listing of current government documents pertaining to reliability and maintainability specifications and standards of military electronic equipment is presented. The development and use of these documents is traced in order to indicate the present stand of reliability practices by government agencies. Efforts to standardize and generalize reliability specifications within the government and in collaboration with industry are mentioned. Test programs, reliability predictions, and documentation trends are discussed. The emphasis of this paper is on avionics. Reliability of airframes and aircraft engines is also briefly covered. K.W.

Review: The brief discussion of the historical features of government reliability activity which comprises this paper is interesting and easy reading. Sensible views are expressed. Progress which has been made in the government–industry reliability area is to a large degree due to the tenacity of government workers such as the author, who continue to insist on reliability programs and associated tests. Listings of government reliability and related specifications are given in the paper; they may be of reference value to some readers.

R67-13458 ASQC 815

WHAT ESTABLISHED RELIABILITY SPEC MIL-R-39008 OFFERS RESISTOR BUYERS.

W. D. Hauser and L. S. Moshier, Jr. (Speer Carbon Co., Speer Electronics, Niagara Falls, N. Y.).

Electronic Procurement, vol. 6, Feb. 1966, p. 23–25.

The use of the term high reliability is clarified and shown to differ from the new so-called "established reliability" specification in the case of carbon composition resistors. The concept of established reliability was introduced to aid in determining whether the high costs of component testing were justified in every application. An accompanying chart compares specifications of the old MIL-R-11 with those of the new MIL-R-39008. Such factors as resistance tolerance; life failure rate level; shock, vibration, and high frequency, and load life are compared. The cost and time involved in reliability testing to compile the necessary data for qualification are discussed. S.P.

Review: A table in which the principal reliability features of the new Established Reliability (ER) Specification MIL-R-39008 are compared to those of the quite older specification MIL-R-11 is the essence of this article. It depicts nicely the differences and additional requirements. Thus the fixed carbon composition resistor has joined those electronic piece parts covered by ER specifications. The article also notes that there are few producers qualified to MIL-R-39008, which is not uncommon for ER specifications. Much life testing is required to qualify to ER specifications, which of course increases costs, perhaps to several times more than without these tests. This sort of cost increase means few buyers, and few buyers means few manufacturers attempting to qualify. Thus, a great need exists at the piece-part level for alternatives to massive life testing as a means of assuing high reliability. In a private communication the author has made the following comments. This specification was revised subsequent to this article and the A revision is now in effect. While the requirements of the current specification aim to achieve the same reliability status of the old, and in fact does, certain requirements have been changed to facilitate testing and documentation. Selling prices of MIL-R-39008A units are now generally competitive with MIL-R-11 resistors.

R67-13469 ASQC 813

Hughes Aircraft Co., El Segundo, Calif. Space Systems Div.

RELIABILITY FOR THE AUSTERE PROGRAM

Alvin L. Hall and Mitchell F. Krause Nov. 1965 10 p Presented at the ASQC Aircraft and Missile Div. Conf., Cocoa Beach, Fla., 8–10 Nov. 1965

(N67-85553)

A reliability effort is discussed that was introduced to meet program goals and schedules as well as to reduce excessive costs that were occurring because of high failure rates in an aerospace industrial complex. The approaches used are considered useable with austere programs to minimize unprogrammed failures early in the design and procurement phases. Also included is a manageable method for controlling the effect on schedule and cost of failures that do occur in spite of this early preventive approach. It is noted that so-called austere programs have a tendency to make purchases for the lowest possible costs, which eventually leads to high costs and inefficiency. To preclude this from happening, the reliability program must resolve critical problem areas; and the most fruitful approach is considered to be the assessment of parts derating, for which design problems will not exist if derating is 50% or better. Manufacturing process assessment must be approached more realistically, with in-process inspection points in critical areas; acceptance test procedures and data must be reviewed, and particular attention given to the documentation of these and other data. M.W.R.

Review: Some sensible guidelines are given in this paper for the low-budget reliability program. The approach leans heavily on follow-up of failures for corrective action which is compatible with what others are saying. Note that the term austere which appears in the title and in the paper is not the name or acronym of some mysterious project, but rather refers to skimpy budgets in general.

R67-13470 ASQC 810; 836

Hughes Aircraft Co., Culver City, Calif.

A CASE HISTORY OF A SPACE PROGRAM FAILURE REVIEW BOARD OPERATION

Irving Quart Nov. 1965 10 p Presented at the ASQC Aircraft and Missile Div. Conf., Cocoa Beach, Fla., 8–10 Nov. 1965

(N67-85554)

Failure reporting procedures and their interface with an established Failure Review Board of an industrial complex are discussed. The reporting form consists of efforts by five sections, designated as originator, verification, rework and retest, engineering, and reliability. Reporting procedures as well as corrective action procedures insure adequate review on a routine basis; and it is the Failure Review Board that expedites and documents decisions that will improve overall quality. The basic philosophy of the board is based on these questions. What is the problem? What caused it? How can the cause be eliminated? What are the critical design areas in which a nominal degree of reliability improvement will provide a major increase in system probability of mission success? M.W.R.

Review: This paper deals with some management aspects of a reliability program, i.e., how should a group be set up and run so that it contributes effectively to the overall program? The group in this paper appears to be set up well; but, of course, there is no way of knowing how it is actually working in practice from a description presented at a technical conference. Some very practical considerations have been understood, such as keeping the problems before the board sufficiently challenging that board members will wish to attend. In fact, this would seem to be one of the major considerations because people who are qualified enough to sit on the board are usually also qualified enough to have much personal authority in deciding where they shall spend their time. Outside projects, of course, are among the first to suffer unless they present a personal interest and challenge. The review of failures is an important part of any reliability program and the success of such reviews probably depends on having them checked out at the appropriate level. A failure review board is certainly a necessary level in this system.

R67-13484 ASQC 815; 782; 833
National Aeronautics and Space Administration. Electronics Research Center, Cambridge, Mass.
THE REQUIREMENTS PLACED ON ELECTRON TUBES FOR SPACE APPLICATIONS
W. H. Kohl, C. M. Veronda, and R. W. Wilmarth Washington, NASA, Jan. 1967 12 p refs Presented at the 8th Natl. Conf. on Tube Techniques, New York, 20–22 Sep. 1966
(NASA-TN-D-3733; N67-28751) CFSTI: HC $3.00/MF $0.65

Basic concepts of reliability, the weight and size penalties imposed by space missions, and the environmental parameters of temperature, vibration, shock, radiation, and particle bombardment are discussed. The special requirements imposed by the absence of a gravitational field and by the sensitivity of magnetometers to stray magnetic fields are also reviewed. The need for further reduction of the weight penalty for microwave tubes, particularly in cooling systems, is pointed out. The introduction of more efficient heaters and cathodes is thought to be a partial solution of the problem. K.W.

Review: Those who are concerned with the production of highly reliable microwave tubes for space applications, as well as design and development engineers on the equipment using them, should be familiar with the material presented in this report. In keeping with its role as a technical note, it is not an extensive treatise on the subject, but rather a summary of the most essential considerations. These range from reliability fundamentals through constraints on size and weight to the effects of specific environments. The report itself will meet the needs of those who want a bird's-eye view of the subject. The reasonably extensive list of references will help those who wish to delve deeper.

R67-13487 ASQC 815
BURGHARD—QUALITY AND RELIABILITY ASSURANCE FROM COMMON NATIONAL STANDARDS.
J. M. Groocock (Standard Telephones & Cables Ltd., Footscray, Kent, England).
Electronic Components, vol. 6, Oct. 1965, p. 931–936. 2 refs.

An analysis is presented of proposals made by the British Committee on Common Standards for Electronic Parts, and a statistical approach is suggested to be of benefit to the manufacturer attempting to meet the quality and reliability assurance requirements proposed. Pattern specifications, and electrical characteristics and their testing are described along with the mechanical and environmental tests, life tests, and inspection levels. Reliability assurance from the transistor and resistor life tests is treated, and some lot acceptance life test data and reliability level data are tabulated for both groups of equipment. It is emphasized that the specifications discussed are only tentative. M.W.R.

Review: This review of a committee report on quality and reliability standards for electronic parts is not of direct interest to U.S. reliability engineers since it is British. But the kinds of things they are trying to attain and the critical analysis thereof are of interest to those in this country engaged in the same kinds of tasks. Parts of these requirements are obviously an attempt to use standardization and realism to achieve the maximum assurance for the least expenditure rather than an attempt to get the maximum assurance regardless of cost. This is an excellent base upon which to begin. It is important that we at least take steps to do as well as we reasonably can now, even if the result does not accomplish everything that everyone would like. It is worthwhile, if feasible, to build into the system a reasonably easy way to improve and expand it.

82 MATHEMATICAL THEORY OF RELIABILITY

R67-13452 ASQC 823; 431; 851
Aeronautical Research Council (Gt. Brit.)
ON SOME TESTS DESIGNED TO DEMONSTRATE STATISTICALLY THE REQUIRED MEAN LIFE
Z. A. Lomnicki London, HMSO, 1967 5 p refs Supersedes ARC-25953
(ARC-R&M-3443; ARC-25953; N67-26130) CFSTI: HC $3.00/MF $0.65

Two Life Tests recently suggested by various Government Agencies are described in sections 1 and 4 respectively and the consequences of their application are discussed. It is shown that to satisfy them with some reasonable probability the manufacturer has to produce equipment of much higher standard than initially stipulated. Although the tests are meant to be designed so that the probability β of accepting an inferior equipment would be appropriately small, it is shown that the second test does not satisfy this condition leading to the acceptance of inferior equipment with much greater probability (section 7). Author

Review: It is well known that in order to have his equipment accepted with reasonable probability under certain reliability demonstration tests, a manufacturer must design for an MTBF much higher than that specified. Quite naturally, this problem has attracted the attention of those who design plans for the demonstration of minimum life. Of the tests described in this paper, the first was presented in the paper covered by R63-11035. The other, which is a form of sequential test, was proposed in a British paper cited by the author. However, it is shown that the second test can lead to the acceptance of inferior equipment with probability greater than that specified, and is therefore unsatisfactory from the consumer's point of view. Although many firms and Government Agencies have found this test attractive, it should not be used. This paper is a brief mathematical discussion which provides some insight on the consequences of applying the two tests. It does not contribute any help on the producer's risk problem, however. As remarked in R63-11035, tests which take a priori information into account would make it less difficult to prove high MTBF. Some theoretical work on the problems of applying a priori knowledge to sampling plans could prove fruitful.

R67-13453 ASQC 823; 431; 838

Aeronautical Research Council (Gt. Brit.).

RENEWAL PROCESSES ARISING IN THE STUDY OF MULTIPLEX SYSTEMS

Z. A. Lomnicki 1967 30 p refs

(ARC-R&M-3444; N67-30048) HMSO: 10s 6d

The object of this report is to discuss the improvement of reliability of systems when redundancy is introduced in the form of so-called 'multiplexing' so that a given task is performed not by one suitably chosen set of components (referred to as a 'lane') but a number of separate lanes operating independently in parallel. Under the assumption that the failure of individual lanes can be described by a Poissonian Process it is shown that the Renewal Process representing the failure mechanism of a system composed of m lanes exhibits, for comparatively small time intervals, a dramatic improvement of reliability (from a small probability p for one lane to a much smaller probability p^m for the system) whilst for the large time intervals the improvement is less than proportional to m. Thus the multiplexing appears to achieve its maximum advantage only when after a comparatively short period of operation, all the lanes are inspected and brought to their initial state by repair or replacement; without these precautions multiplexing is still useful but the law of diminishing returns operates then: by increasing the number of lanes, less and less is added to the asymptotic reliability of the system. The discussion of the general case of m lanes is followed by a more detailed analysis of duplex and triplex systems and, in the closing section, a modified method of multiplexing (the 'majority vote') is described. Author

Review: A mathematical description of the underlying renewal process for a system of m separate lanes operating independently in parallel, i.e. a multiplex system is given. Limited results are obtained for the general case (m lanes), while more detailed attention is given to duplex (m=2) and triplex (m=3) systems. The majority vote method is also considered. This competent mathematical treatment is a contribution to the theory of redundancy as a means of improving the reliability of systems. The results will be of interest to the theoretician studying these problems rather than to the engineer although they provide a useful, general warning to designers that the beneficial results of multiplexing have a limited value: the advantages become very small if the system is meant to operate for a longer time without its components being inspected, repaired or replaced.

R67-13460 ASQC 823; 822

Cornell Univ., Ithaca, N. Y.

FACTORS AND PROCEDURES FOR APPLYING MIL-STD-105D SAMPLING PLANS TO LIFE AND RELIABILITY TESTING

Henry P. Goode Washington, Office of the Assistant Secy. of Defense, 21 May 1965 48 p refs Sponsored by ONR (TR-7)

A procedure for adapting MIL-STD-105D to acceptance sampling inspection is presented, and conversion factors are given for three alternative criteria for lot evaluation: mean life, hazard rate, and reliable life. Sample inspection is by attributes, with testing truncated at the end of some preassigned period of time; and the Weibull distribution is the underlying statistical model, with the exponential distribution as a special case. Probability of lot acceptance under the procedure presented depends only on the sample failure before the end of test truncation time; and number of items failing rather than life at failure is of interest. Tables of factors are included for use with this attribute acceptance procedure, and means for the mathematical determination of the specific relationships are evolved. M.W.R.

Review: Methods and conversion factors are provided to enable the use of MIL-STD-105D sampling plans for life testing based on the Weibull distribution with shape parameter assumed known. This work is essentially an adaptation of procedures and tables previously published by the author and associates (for which references are cited in the report). The discussion is straightforward and the examples will serve to clarify the use of MIL-STD-105D in life and reliability testing under the three different criteria considered. In addition to the technical reports in this series, the author and associates have published a number of papers on life testing based on the Weibull distribution. See, for example, R61-10046, R62-10202, R62-10208, R63-10756, R63-10995, R63-11016, R64-11446, and R65-12051. For tutorial purposes, some good examples are given in the paper covered by R67-13173.

R67-13461 ASQC 824; 541; 831

PROBIT ANALYSIS AS A TECHNIQUE FOR ESTIMATING THE RELIABILITY OF A SIMPLE SYSTEM.

R. R. Prairie (Sandia Corporation, Albuquerque, N. Mex.). *Technometrics,* vol. 9, May 1967, p. 197–203. 3 refs. Sponsored by Atomic Energy Commission

A modification of a probit analysis yields point and interval estimates of the relation between reliability and stress for a simple system that contains several identical but independent components. Information concerning the failure distribution of the individual components is assumed, and the probability of system failure is related to component failure. Detailed mathematical formulations are included. M.W.R.

Review: A concise mathematical description of a method of estimating the relation between reliability and stress for a simple system is given. Standard probit analysis is modified to allow for the appropriate introduction of a function H which relates the probability of system failure to that of component failure. Those familiar with probit analysis will find the development straightforward. Those who are not may wish to consult the author's Reference 3 for a detailed discussion. Alternatively, a good concise description may be found in *Biometrika Tables for Statisticians, Volume I,* Cambridge University Press, 1956, pp. 4–9. From the standpoint of practical application, the author's example will be useful and the underlying assumptions are clearly stated. As usual, these impose limitations. For example, application to systems more complex than those considered is likely to be hampered by lack of tractability of the function H mentioned above.

R67-13462 ASQC 823; 824

PROPORTIONAL SAMPLING IN LIFE LENGTH STUDIES.

Saul Blumenthal (New York University, N. Y.).

Technometrics, vol. 9, May 1967, p. 205–218. 6 refs.

(Grant NSF GP-4933)

Electron tube life is measured by the life of tube service in a system or lift length proportional sampling. A variety of distributions and the corresponding mean life estimates are examined by this sampling procedure which is straight-forward life-biased rather than random sampling. Improvement in variance due to waiting for failure rather than basing an estimate on present age is examined, along with the conditions under which it pays to replace the present tube with a new one and wait for a new tube to fail. Estimation of mean life from total life for large T (age) is investigated, small values of T are considered, and bias introduced by large sample theory are studied. Gamma and Weibull distributions are discussed, and conditions are found under which sampling schemes other than life-proportional are desirable. M.W.R.

Review: When the lives of items which have been in service for some time are measured, the sampling is life-biased rather than random. The appropriate procedures for estimating mean life from the resulting data are considered in this paper. It is a rather comprehensive statistical treatment of the problem, supported by appropriate references, with one illustrative example presented in reasonable detail. As such, it will be of interest and value to the statistician concerned with the analysis of life-biased data.

R67-13463 ASQC 824

RELIABILITY ESTIMATION OF THE TRUNCATED EXPONENTIAL MODEL.

M. S. Holla (Defence Science Laboratory, Delhi, India).
Technometrics, vol. 9, May 1967, p. 332–336. 17 refs.

A minimum variance unbiased (MVU) estimate of the truncated exponential life test model with a known truncation point from above is obtained on the basis of both a full and a censored model. Techniques employed are based on both one and two parameter cases, and a complete statistic for the probability density function is provided by the Tukey–Smith theorem which states that "if a family of distributions admits a set of sufficient statistics, then the family obtained by the truncation to a fixed set or fixed selection admits the same set of statistics. Derivations for the MVU estimate are detailed, and a numerical example is included. M.W.R.

Review: A concise mathematical presentation of a minimum variance unbiased estimator for the reliability function of a truncated exponential model is given. The basis of the derivation is the published work of other authors for which the references are cited. The result is applicable in situations in which life or reliability testing is truncated at some *known* point of time. The estimator has desirable statistical properties and should be used when this additional information (known truncation point) is available.

R67-13465 ASQC 824

ESTIMATION OF PARAMETERS OF LIFE DISTRIBUTIONS.

H. Leon Harter (Aerospace Research Laboratories, Applied Mathematics Research Laboratory, Wright-Patterson AFB, Ohio).
Research Review, vol. VI, Apr. 1967, p. 9–11. 32 refs.

A general discussion and 32 references deal with the estimation of parameters of life distributions and the numerous statistical techniques that have been used in their determination. Point and interval estimates of scale parameters, maximum likelihood estimators, and functional relationships between populations are noted in this summary which refers to the general content of each of the references. M.W.R.

Review: This paper is essentially a bibliography of the work done by and under the supervision of the author. This work is important because very often one wishes to concern himself with only the first half or fewer of the failures and to derive a formula from which he can extrapolate to even lower probabilities. There are two reasons for ignoring the upper half or more of the failures: (1) they are relatively unimportant in determining high reliability and (2) the more of them are used, the more sensitive are the results of the extrapolation to the exact form of the distribution which has been assumed. It is about time for someone to collect the papers on parameter-estimation for life distributions and write a book. The author's papers are published in high-quality technical journals and he has a good reputation in this field. In a subsequent private communication the author has indicated that he is working on a book entitled "Order Statistics and their Use in Testing and Estimation," which he plans to publish through the U.S. Government Printing Office.

R67-13467 ASQC 824

PROBLEMS IN SENSITIVITY TESTING OF ONE SHOT ELECTRO-EXPLOSIVE DEVICES.

Herbert D. Peckham (Holex, Inc., Hollister; Gavilan College, Gilroy, Calif.).
(1965 Aerospace Technical Conference and Exhibit, Houstin, Tex., Jun. 21–24, 1965, Paper.) IEEE Transactions on Aerospace, vol. AS-3, June 1965, Supplement, p. 628–633. 12 refs.
(A65-31145)

Analysis of techniques used to estimate the reliability of "one shot" electroexplosive devices. Current practices which can produce suspect data are discussed, and remedial action which will lead to accurate and dependable methods of reliability estimation are suggested. Author (IAA)

Review: This paper gives voice to two complaints usually found in opposite quarters. (1) Engineers are using statistical techniques outside the range for which they were designed and are, in fact as well as in theory, misleading themselves. (2) There are no satisfactory statistical tools to use to solve the problem of very high reliability for one-shot items. The author is certainly correct in both points. He has some tentative suggestions for decreasing the cost of sensitivity testing for the electro-explosive devices, but even so it is doubtful if they will be useful where 99.99% reliability is required. As a matter of practical fact, when the allowed proportion of defectives is less than 10^{-4}, the distribution on the tails is going to be too uncertain always because of the extreme sensitivity to minor manufacturing problems. One will almost have to consider the actual distribution as being made up of two tractable distributions; the first will be the usual continuous distribution and the second is a fraction defective defined by having a quality below some pre-established point. The problem is transferred then to estimating this very low fraction defective which, of course, is an equally difficult problem. The paper will probably be of more use to applied statisticians and to engineers doing theoretical research to show them what the problems are than in being a help to engineers (the latter perhaps should read it, but they could find out what they need to know from an abstract).

R67-13473 ASQC 820

Joint Publications Research Service, Washington, D. C.

SOME PROBLEMS OF RELIABILITY AND REPAIRABILITY OF MACHINES

V. P. Popov *In its* Cybernetics in the Serv. of Communism, Vol. II 18 May 1965 p 75–95 refs
(JPRS-30128; TT-63-31010; N65-23780)

Machine breakdown is classified according to certain general categories, and a procedure is given for calculating the wear resistance of certain machines. A general discussion on calculating reliability and repairability of machines is included, and the change in reliability before and after repair is illustrated. Many equations based on normal and exponential times to failure are presented. M.W.R.

Review: This is a survey article, the main content of which is quite general. There are some equations giving the exponential and Gaussian forms for times to failure; these are combined and analyzed in some detail but to little avail. The economic aspects of unreliability are pointed out and the sad state of present affairs is lamented. The relationships between reliability and repair are mentioned. There are other odds and ends of details in accordance with the title, "Some problems..." The article turns out to be a heterogeneous assortment of brief essays by the author. They will be of little use except to the idly curious and to the reliability specialist who does not want to miss anything that is going on in the field of reliability regardless of whether it represents an advance in the state-of-the-art or not.

R67-13476 ASQC 820

Joint Publications Research Service, Washington, D. C.

DEPENDENCE OF RELIABILITY ON COMPLETENESS OF CONTROL OF RESERVE

Yu. G. Yepishin *In its* Cybernetics in the Serv. of Communism, Vol. II 18 May 1965 p 155–181 refs

(JPRS-30128; TT-63-31010; N65-23780)

Reliability characteristics of a duplicated or redundant system with incomplete control of the reserve device are determined, and a variety of formulas is derived for system operation with and without spares or reserves in working order. Following consideration of some extremal problems by an integral method, dependence of these reliability characteristics on the completeness of control is determined for systems with multiple reserves. Stability of these reliability characteristics for redundant systems is discussed with respect to various breakdowns and repair times. M.W.R.

Review: This paper is difficult to read because the translated terminology is not sufficiently descriptive and the equations are difficult to decipher due to the poor reproduction. Between these two circumstances it is extremely tedious to understand exactly what is going on. For example, the meaning of "completeness of control of the reserve" is not easily figured out although it has to do with the detection of failures. It is difficult to know if this problem has been treated in the American literature, but very likely it has, since various aspects of Queueing Theory have been extensively treated in Operations Research if not in Reliability. Only the most hardy, highly-motivated, and strong-eyed will get through this article.

R67-13477 ASQC 820; 872

Joint Publications Research Service, Washington, D. C.

ON A PROBLEM IN RESERVE THEORY WITH SWITCHING

V. A. Ivnitskiy *In its* Cybernetics in the Serv. of Communism, Vol. II 18 May 1965 p 189–196 ref

(JPRS-30128; TT-63-31010; N65-23780)

Recurrent expressions are obtained for finding corrections to the formulas of fixed probabilities in work by Mar'yanovich which are introduced under the assumption that the switching time is equal to zero. The formulas for finding the first corrections are written out in clear form. In the failure and repair time problem treated, there are n identical devices in the basic combination and m such devices in cold reserve (i.e. which do not go out of order). The time of correct operation is distributed by an exponential law with the parameter λ, the time of restoration of the broken down device. The time of switching control is also distributed with the exponential law with parameter ν. L.S.

Review: This is a very short paper which treats a special case. Failure and repair times of elements are distributed exponentially, and a device may be considered to be in one of four states—in operation, in repair, in adjustment (when a failed element is replaced, it must be adjusted before the system can operate), and in reserve. The distinction between being in-repair and in-reserve is not clear. The reproduction is poor, the subscripts are small and almost impossible to decipher. It will be difficult for anyone to work his way through the paper unless he has the solved problem in front of him in which case, of course, there is little point in the effort.

R67-13479 ASQC 820; 431

Joint Publications Research Service, Washington, D. C.

SOME PROBLEMS IN RELIABILITY THEORY AS APPLIED TO COMPLEX SYSTEMS

I. N. Kovalenko *In its* Cybernetics in the Serv. of Communism, Vol. II 18 May 1965 p 244–258 refs

(JPRS-30128; TT-63-31010; N65-23780)

Problems associated with component reliability and the necessity of studying operation of elements in a complex system as a queueing system are discussed. The queueing system is approached from the standpoint of models of breakdowns and repair of elements. A mathematical diagram of processes of mass servicing is applied to problems of reliability of complex systems. Various characteristics of servicing are interpreted as the mathematical expectancy of the functionals of the Markov process; the actual finding of these mathematical expectancies is realized by using recurrent ratios. The recurrent procedure of determining the basic characteristics of reliability is discussed and supplemented by the procedure for evaluating the number of iterations required for ensurance of the given accuracy of the result. S.P.

Review: This is a mathematical paper addressed to the problem of determining the reliability of a complex system in terms of the reliability characteristics of its elements. The elements are visualized as constituting a queueing system. The paper discusses the mathematical diagram of processes of mass servicing as applied to this problem. Theorists may well get some useful ideas from a reading of the text. However, those who wish to follow the details closely will encounter difficulty in reading much of the mathematics, due to the poor quality of reproduction. Those who understand the topic and the approach well enough to guess accurately at the parts which are not clear do not need to read the paper.

R67-13480 ASQC 824

Joint Publications Research Service, Washington, D. C.

EVALUATION OF RELIABILITY OF A SYSTEM BY THE RESULTS OF TESTING OF ITS COMPONENTS

R. A. Mirnyy and A. D. Solovyev *In its* Cybernetics in the Serv. of Communism, Vol. II 18 May 1965 p 270–277 refs

(JPRS-30128; TT-63-31010; N65-23780)

Components of a system are tested to determine overall system reliability; and numerous equations are evolved for making these calculations which, for the most part, are not

dependent upon time. The variable used is the number of failures that occur in a given period, and no failure distribution is assumed in making the evaluation of system reliability.
M.W.R.

Review: This paper treats an interesting problem although, as the author points out, in the general circumstance it is intractable. Thus the analysis is limited to several special cases, virtually all of which do not have time as a variable. The number of failures in a given time is the variable and the reliability of the system in the same time is to be evaluated. Thus no distribution of failures need be assumed. As is usually the case with these translations from the Russian and with many of the STAR reproductions in general, the resolution of the printing type is abominable and the small letters often cannot be resolved. The parts that could be checked easily appear quite adequate mathematically, but it would be a difficult paper for the average reliability engineer to get anything from (because of having to guess at what some of the letters are in the equations) unless he was very familiar with what the results would likely be.

R67-13481 ASQC 820

Joint Publications Research Service, Washington, D. C.

MATHEMATICAL PROBLEMS OF EVALUATION OF RELIABILITY OF DIGITAL COMPUTERS

O. V. Shcherbakov *In its* Cybernetics in the Serv. of Communism, Vol. II 18 May 1965 p 278–289 refs
(JPRS-30128; TT-63-31010; N65-23780)

Formulas for determining the reliability of complexes of digital computers are given that consider the exponential distribution of periods of trouble-free operation as well as the time required for repairs. The mathematical investigation of reliability is discussed in terms of three basic problems, that is the flow of breakdown occurrences, the process of servicing, and the numerical characteristics of the determinations themselves. Various formulas are derived and their uses are explained. M.W.R.

Review: This paper is a surface treatment of problems ranging from the opening or shorting of components inside of a computer to the Queueing Theory problems of repair of a complex of computers. This paper is not recommended since it is too superficial and in some cases too loose. For example, the probabilities of either an open or a short are handled as independent events rather than as mutually exclusive events, from which it is clear that the definitions of the events themselves need to be examined more closely. It is further assumed that all failures are statistically independent in a computer which means that there can be no secondary failures. No degradation of parts is considered. One interesting bit of information is that the average-time-between-failures for computers of the URAL-1 type is 20 to 30 hours. It is claimed that theoretical and experimental investigations both show that the exponential law applies to digital computers and their complexes, a result not entirely in accord with our present views.

R67-13482 ASQC 824

Joint Publications Research Service, Washington, D. C.

EVALUATION OF DEVIATIONS OF FLOW OF BREAKDOWNS IN A MULTIPLE USE APPARATUS FROM POISSON FLOW

In its Cybernetics in the Serv. of Communism, Vol. II 18 May 1965 p 290–315 refs
(JPRS-30128; TT-63-31010; N65-23780)

Exact and approximation methods are considered for evaluating the reliability of an apparatus with replacement of elements that have been damaged. Closeness of the flow of breakdowns in systems of multiple use to Poisson flow in the general case is found to be dependent on the relationship between the number of elements in the system (n) and the average number of breakdowns (a) in the selected time interval. For sudden breakdowns, the ratios of the initial danger of breakdown to its fixed value and to the value of the initial stability characteristics may be significant. In practice, the flow of breakdowns may be considered Poisson for an apparatus with elements having gradual breakdowns when (n) is greater than 10, and for sudden breakdowns for any (n) and (a) when the initial instability is less than 0.05. For other cases, a correction must be added to the Poisson approximation. Results obtained are applicable for both the flow of breakdowns as well as for the evaluation of the closeness of the Poisson flow to the sum of any independent elementary flows of homogeneous events with limited after effects.
M.W.R.

Review: In analyzing the reliability of an apparatus with replaceable elements, it is commonly assumed that the number of breakdowns in a given time interval follows the Poisson law. Cases in which this assumption is not valid are cited, and an analysis procedure for such cases is developed. It consists of first estimating the possible deviation from the Poisson of the distribution of breakdowns, and then, when necessary, taking the deviation into account in estimating the reliability. The paper is a rather detailed mathematical treatment of the problem, which is difficult to follow closely because of poor quality of reproduction. Thus the mathematics was not checked in detail, but appears to be competent. The approach is reasonable, but only those with a strong interest in the specific problem are likely to want to suffer through the poor reproduction.

R67-13483 ASQC 824

Rocketdyne, Canoga Park, Calif.

CONSISTENCY OF MAXIMUM LIKELIHOOD ESTIMATORS IN SOME RELIABILITY GROWTH MODELS

Bernard Sherman Wright-Patterson AFB, Ohio, ARL, May 1966 33 p refs
(Contract AF 33(615)-2818)
(ARL-66-0084; AD-641146; N67-84266)

Properties of maximum likelihood estimators of parameters in some sample reliability growth models are investigated. In one model the underlying process is a Markov chain and the estimator of the single unknown parameter is proved consistent. In another model it is shown that no estimators can be consistent. Related estimation problems in sequences of geometric distributions are discussed. Author (TAB)

Review: The statistical consistency and asymptotic Normality of the maximum likelihood estimators of the parameters of certain reliability growth models are studied in great detail in this report. The results will be of interest to many reliability personnel but the tedious proofs will probably not be. The detailed mathematics was not all checked but appears to be good. For other results in this area see R67-13091, R67-13101, and R67-13103.

R67-13485 ASQC 821; 431

Measurement Analysis Corp., Los Angeles, Calif.

PROBABILITY FUNCTIONS FOR RANDOM RESPONSES: PREDICTION OF PEAKS, FATIGUE DAMAGE, AND CATASTROPHIC FAILURES

Julius S. Bendat Washington, NASA, Apr. 1964 61 p refs
(Contract NAS5-4590)
(NASA-CR-33; N64-17990) CFSTI: $3.00

This report reviews a number of theoretical matters in random process theory which can be applied to physical problems such as predicting peaks, structural fatigue damage, and catastrophic structural failures. The presentation emphasizes the basic assumptions which are involved, and discusses how to properly interpret the theoretical results. Various engineering examples are given as illustrations.
Author

Review: This report presents many results concerned with zero crossings, peaks, fatigue damage, envelopes, etc. of random stationary processes. Unfortunately, the proofs are all non-rigorous and the reader has to be aware of the *implicit* assumptions made in the proofs. For a recent mathematical development of many of the aforementioned topics, one can consult [1].

Reference: [1] Cramér, Harald and Leadbetter, M. R., 1967, *Stationary and Related Stochastic Processes,* Wiley and Sons

R67-13496 ASQC 824

HOW SURE ARE YOU?

S. L. Friedman (Hycon Mfg. Co., Monrovia, Calif.).
Reprinted from EDN Magazine, Jul. 1967. 2 p

Standard approaches to reliability analysis are those based on existing failure rate data and testing of the prototype as a unit. Brief mention is made of the first, and some details are presented for the second and more direct approach. The latter requires answers to the following questions that are interdependent relationships: (1) What mean time between failure (MTBF) is needed? (2) What confidence level (CL) is expected? (3) How many failures are allowed? (4) How long should the test be run? Failure probability determination is based on the parameters of CL, MTBF, total test time, and number of failures allowed. As an example, a chart is included that permits a customer to purchase a system from a vendor, specifying that it be tested to demonstrate an MBTF of at least 200 hours with a CL of 95%. M.W.R.

Review: This is one of those quick once-over articles to eliminate the pain from reliability statistics. It is satisfactory for learning the language, but should not be used for any critical calculations because of its shortcomings such as the following. (1) Formulas 1–3 for reliability assume statistical independence of the failure events and assume constant individual hazard (failure) rates throughout time. Unfortunately these assumptions are implicit, not explicit. (2) The paper asserts that the confidence level for the system is derived from the confidence level of the components. Unfortunately this is not a tractable problem in statistics. While attempts have been made to solve it, there has been no wholly successful approach. (3) Equation 9 has an integral sign where it should have a summation sign. The author is correct in asserting that his equations 9 and 10 are obviously awkward to fool around with. They are, however, equivalent to a very simple Chi-Square formula which eliminates all fooling around. (4) The confidence level referred to is that for the upper one-sided confidence limit for failure rate. (There can be a lower confidence limit also, but it is rarely used.) (5) When the number of failures is a random number, the association of a confidence level with MTBF is difficult because the random variable is discrete. (6) The author's assertion is in error that if $r = r_1$ failures are decided upon as a test criterion and too many failures occur $(r > r_1)$ then one just picks an $r_2 \geq r$ criterion and continues testing. This has become a multiple sampling problem and the statistics are definitely not the same as for a single-sampling problem. (7) Only consumer's risk is considered. There is no mention of the rest of the OC curve or of producer's risk. The confidence level term as used here is accurate only when the number of failures is that given by the curve. When no more than a fixed number of failures are permitted and less than that occur, the use of the term confidence level is ambiguous.

83 DESIGN

R67-13464 ASQC 830; 824

DESIGNING EFFICIENT STRUCTURES.

Robert F. Crawford (Martin Marietta Corp., Martin Co., Baltimore, Md.).
Space Aeronautics, vol. 46, Nov. 1966, p. 67–73.
(A67-14423)

Discussion of design techniques for advanced flight structures for military and aerospace missions. It is pointed out that, to meet the more severe as well as less predictable demands on advanced flight structures, new design methods provide statistical assessment of environmental loads, forecases of the response of high-performance materials, and rational design criteria for attaining higher reliability levels.
IAA

Review: A general-interest type of article is presented here. It is in the nature of an overview, but still has technical content. A few fundamental equations are shown, and the presentation is mainly discussion. Most of the material in the article is in the language of the structural engineer, blended to some extent with traditional reliability analysis. The reader will have to dig much further than the material which is presented in the paper in order to get a good feel for the various facets which are cited. An annotated bibliography at the end of the article will help some. For example, the single paragraph which treats reliability allocation using literal optimization techniques (search, algorithms, etc.) does so with a simple example and a few remarks about more general problems. This really serves to open the door to the myriad of literal optimization techniques which could be applied to different reliability allocation problems. Coverage of probability treatment of loads and strengths in the first figure and on page 71 suggests two remarks. One is that a most appropriate point is made in the article concerning the inability to define accurately the probabilities in the region of interest. Another is that the coverage in the article implies that the probability of failure is directly the overlap area of the load and strength curves, which is not so.

R67-13474 ASQC 838

Joint Publications Research Service, Washington, D. C.

ON RESERVING WITHOUT REPAIR

A. D. Solovyev *In its* Cybernetics in the Serv. of Communism, Vol. II 18 May 1965 p 96–145
(JPRS-30128; TT-63-31010; N65-23780)

System redundancy is considered in detail for the cases in which repair of existing parts is not a possibility, and mathematical procedures and approximate formulas are derived for use in determining system reliability. So-called loaded reserves are discussed in this light, and a probability diagram for use in different types of redundancy is studied. In considering unloaded reserves, it is assumed that the reserve element is in the non-operating state and does not breakdown. Attention is also given to so-called lightened reserves or redundancy whereby the reserve element operates at a low capacity before it is called into actual operation. The unreliability of certain switches is discussed, as are problems related to system redundancy. M.W.R.

Review: As the title indicates, the author considers redundancy without the possibility of repair of any failed units. All failure events are considered statistically independent and this assumption is made in passing rather than explicitly at the beginning. From some of the comments it would be easy to infer that the failure events need not be always statistically independent, but this is wrong. The criterion for goodness is generally the mean time to system failure, that is, to the failure of the last redundant element. For many systems, especially those where the mission time is less than the mean failure time of an element, failure rate is a much more appropriate measure of the goodness of a redundant system than is mean-time-to-failure. In the first part of the analysis reserve elements are considered to be either good or bad. In the second part, bad is divided into open or short, and series-parallel and parallel-series combinations are considered (although no hammock networks are analyzed). Up to this point switching has been ignored and in the third part the author considers several cases in which switching is not perfect. There is a proof that redundancy is best at the lowest levels of the system, but one has to be aware of the criteria for best in any such proof, because in the overall system sense redundancy is not always best at the lowest level. The reproduction in the STAR document is not the best. Some of the formulas are difficult to read, especially subscripts. This paper will have limited use since the results generally appear in the American literature. Theorists who are anxious to know who has been doing what will be the only ones concerned with this paper.

R67-13475 ASQC 838

Joint Publications Research Service, Washington, D. C.

RELIABILITY OF RESERVED GROUPS TAKING SPARE BLOCKS INTO ACCOUNT

V. P. Grabovetskiy *In its* Cybernetics in the Serv. of Communism, Vol.II 18 May 1965 p 146–154 ref
(JPRS-30128; TT-63-31010; N65-23780)

Expressions are given for determining the reliability of radioelectronic equipment with both parallel redundancy and spare parts and for which repair time is a random variable. An exponential distribution is assumed for both time to repair and to failure. A problem is solved in which a reserve group consisting of two equally reliable blocks are in operation and there are n spare blocks; and details are given for blocks that are in hot reserve and in cold reserve. It is assumed that the blocks which are in cold reserve and the spare blocks do not break down, and determination is made of the number of spare blocks required to insure a given level of reliability of the reserved group. M.W.R.

Review: The problem considered here is a restricted one. The author's description of the system wherein there is parallel redundancy plus spares is somewhat difficult to figure out. The exponential law is presumed for time-to-fail and time-to-repair of an element. The problem is treated essentially as a Markov chain and the mean-time-to-failure is the criterion for goodness. As in most of these translations, many of the equations, especially the subscripts, are difficult to read because of the poor quality of reproduction. The translation is not the best which makes it difficult to decipher just what the author is doing; generally speaking, it is not worth the effort since results of this type appear in the American literature.

R67-13478 ASQC 838

Joint Publications Research Service, Washington, D. C.

RELIABILITY OF A SYSTEM WITH REPAIR

A. D. Solovyev *In its* Cybernetics in the Serv. of Communism, Vol.II 18 May 1965 p 237–243 refs
(JPRS-30128; TT-63-31010; N65-23780)

The problem of finding the average idle time of a system during breakdown and repair is considered. It is assumed that at the initial point in time all instruments are in a state of good repair and simultaneously put into operation. Each device in the process of its operation, independent of other devices, goes through repair many times. Further consideration is given to system operation when only one of the devices operates. S.P.

Review: This short paper considers the special case of a redundant system with repair of failed elements; the system is in steady state. The problem is to find the average time of operation without making any assumption about the distribution of times. The mathematics was not entirely checked but appears to be adequate.

R67-13492 ASQC 836

GUIDELINES FOR THE DESIGN REVIEW OF CIRCUITS.

Jay Engleman
Electronic Industries, May 1966, p. 88–90.

Design review guidelines are discussed for electronic equipment in general, and procedures are outlined for various devices. These include amplifiers, circuitry, servomechanisms, power supplies, capacitors, resistors, transistors and diodes, transformers, inductors, and miscellaneous equipment. General duties of personnel involved in design review are listed in terms of meeting equipment purposes and military specifications, making suggestions for corrective action for manufacturers, and overall communication between government and contractor. M.W.R.

Review: The kind of design review referred to in the paper is one where a contractor, independent of the manufacturer, is assigned a separate contract for the analysis of a design. (This is not the kind of in-house design review that is everywhere advocated for high-reliability projects.) The paper generally does not deal with the disagreeable side of this kind of activity. Many manufacturers do not appreciate second guessing and certainly some reviewers fail to realize that there is rarely *the* optimum system. Rather, there are many ways of doing something depending of the value criteria of the person doing the deciding. One defect of the article is that it is easy to infer that there is *a* most reliable material or construction type for a part; whereas there might be many, depending upon the tradeoffs. The check list is presumably not intended to be complete, but is indicative of the kinds of things that need to be considered. This paper can be helpful to reliability engineers if it is read with a critical, questioning attitude.

R67-13493 ASQC 838
George Washington Univ., Washington, D. C. School of Engineering and Applied Science.

REDUNDANCY TECHNIQUES TO IMPROVE THE RELIABILITY OF TWO LEVEL AND THREE LEVEL LOGIC CIRCUITS

Kasivisvanathan Vairavan (M.S. Thesis) Jun. 1965 76 p refs
(Grant NsG-645)
(NASA-CR-69428; N66-15585) CFSTI: HC $3.00/MF $0.75

An investigation was made of some of the important redundancy techniques, and several additional concepts are applications of some briefly indicated. It is shown that hardware redundancy is effective when permanent failures occur; but may not be as effective where noise interference is present. When there is temporary circuit failure, hardware redundancy may not be necessary; a simple repetition of information may be sufficient. Where there is a noise interference, it is likely that all redundant systems are affected. When a permanent circuit failure occurs, information redundancy is useless. When errors are committed, they are repeated, and in such a case hardware redundancy appears to be the only solution. If the system is to be protected against permanent and temporary failures as well as noise, both hardware and information redundancies may be used. C.T.C.

Review: This thesis is of some mild interest to a worker in the field of logic circuits who wants a refresher in the use of the familiar techniques of majority organs and dual redundancy. The paper takes a look at the application of these techniques to three-valued logic, which does not appear elsewhere. A minor criticism is the author's use of the term "three-level logic" to describe this—a term which should be reserved for and-or-and, or or-and-or configurations. The disadvantage of using it here is that it may turn away a prospective reader. The applications of three-valued logic, at present, are miniscule; and this makes that part of the thesis, although intriguing, of doubtful value. Since this is the major new work and since the source papers for the rest are quite readily available, the only other value of this thesis is the author's summary of the state of the present theory in a digestible form. This he has succeeded in doing, but not to the extent that would yield an important paper. The list of references is far too short to be useful. As with all papers which depend upon their investigation of three-valued logic for their significance, this paper will have to wait on a more general adoption of such circuits to come into its own.

R67-13498 ASQC 833; 844

CARL TURNER OF RCA EXPLORES SELECTION OF SECOND-BREAKDOWN-RESISTANT TRANSISTORS.

Carl Turner (RCA, New York, N. Y.).
EEE, vol. 15, Jul. 1967, p. 82–95. 4 refs.

Second breakdown in semiconductor devices is treated from the user's point of view, and a thorough description is given of a universal safe-area rating system for the prevention of second breakdown. Nondestructive methods, test setups, and equipment for the detection of second breakdown are discussed. Stressed is the system of potential safety ratings for transistors, which enables the user to design the circuit with the transistor in a safe area of operation. Two examples are included of the forward-bias safe-area system: the first involves the analysis of a typical power inverter under initial turn-on conditions, the second involves a direct-coupled audio power amplifier operating at low frequency into an inductive speaker load. K.W.

Review: In contrast to the majority of the papers describing second breakdown, this paper is concerned less with the physical mechanism responsible for the effect that with methods for identifying the key parameters and minimizing the undesirable consequences. It is written more for the user and circuit designer than for the researcher. The paper is well written and conveys a lot of information in an organized way. Its primary value is an explanation of the safe-area rating system with illustrative examples. Some such accounting of the second breakdown limitations of a circuit must be made; this paper describes a workable system. The title may be somewhat misleading—the transistors are not free of second breakdown; they are used in circuits in such a way as to stay below the second breakdown thresholds. Parts of the paper describing the nondestructive determination of second breakdown thresholds have appeared elsewhere in more detail [1].

Reference: [1] P. Schiff and R. L. Wilson, "Detection Techniques for Nondestructive Second-Breakdown Testing" IEEE Trans. on Electron Devices, Vol. ED-13, Nov 1966, pp. 770–776.

R67-13499 ASQC 830; 833

TWENTY WAYS TO WRECK A RELAY.

Reprinted from EDN Magazine, Nov. 9, 1966. 9 p.

Pitfalls in the design of relay circuits are depicted in incorrect and correct relay circuit designs. Factors such as pulse stretching, voltage dropping resistors, interactions in latches, lamps across unsuppressed relay coils, dc power supply requirements, noise caused by transient suppression, operating time, contact load, grounding, and overoperation which may lead to trouble, are discussed. L.S.

Review: This article is useful for those with little true understanding of circuits which use relays. The title refers not to the wrecking of the relay itself so much as to the inadequacy of the circuit containing the relay. Not all of the exhortations are expressed as well as they might have been. For example, one is told to avoid grounding the relay case if possible. Obviously, as stated later, safety may require grounding the relay case and, of course, one should then consult the manufacturer. The point is, rather than as stated, not to assume that the relay case can be grounded unless such is specifically stated. In any of these examples be sure that you understand the reason why the system will not work as drawn and why it should be constructed as suggested. It is most wise in any of this type of presentation to be sure you understand the reasons rather than blindly copying what someone tells you. This text can be of value to design engineers. When they are properly applied, relays can be among the most reliable components and can compete favorably with solid state devices, in both price and performance.

84 METHODS OF RELIABILITY ANALYSIS

R67-13454 ASQC 844; 612; 837
Battelle Memorial Inst., Columbus, Ohio.

REVIEW, APPLICATION, AND EVALUATION OF COMPUTER METHODS FOR CIRCUIT RELIABILITY ANALYSIS Final Report

L. H. Stember, Jr., B. C. Spradlin, C. G. Kopp, D. C. Jones, R. N. Pesut et al 21 May 1965 223 p refs
(Contract N164-10516)
(AD-648652; N67-84712)

A step-by-step procedure is detailed for the Extended Reliability Analysis (EXTRA) computer technique for reliability analysis of avionic circuits. Equipment review and circuit selection are considered, including classification of circuits and matching methods used with circuits. The moment method, worst case method, and empirical modeling are compared with drift failure analysis methods, and the EXTRA technique is used to analyze both a computer and a power supply. For the computer analysis, a drift failure analysis is described and test points, combined drift and catastrophic reliability prediction, and results with EXTRA are given. The power supply is described, along with the performance of the drift analysis method. The EXTRA technique is evaluated in terms of limitations, time and cost of conducting drift failure analysis, and implications for widespread applications. Main difference between EXTRA and conventional methods is that the drift analysis approach in the former requires a design model, which relates the part data on the component part parameters to the circuit performance characteristics. M.W.R.

Review: Most of the contents of this report are applications-oriented material for computerized drift failure analysis of electronic circuits. The presentation is readable. It leans toward what is suited for real-world applications where the objective is a searching for means of improving the reliability of the circuit design. Methods covered are worst-case and moments. Although these methods are not new, the report explains them and shows material on their application to many different circuits. Also, a computer program listing is given in FORTRAN; the problem has a combined ability to conduct a worst case and/or moment method analysis. It would seem that the Monte Carlo method should also have been included, as this technique has a place in a collection of practical, computerized techniques for drift failure analysis. (In a private communication the first author has pointed out that this method was dropped by the sponsor.) Appendix F of the report presents information on the costs of doing drift analyses and on the effectiveness. This should be of general interest. A limited amount of material is devoted early in the report and in Appendix E to the combination of drift and catastrophic analyses for reliability prediction purposes. Here one must be very cautious in how such prediction values are used and interpreted. The state of the art here is just not well developed, and the literal accuracy of these numbers is suspect. There are some unanswered questions. For instance, the material in Appendix E of the report discusses how a circuit may have multiple performance characteristics, and indicates that the probabilistic distributions of these multiple characteristics may be dependent. It is shown in functional notation how this dependence can be approached. However, the report does not indicate how the measures of this dependence are obtained. Further, in acknowledging that drift failures can be dependent, the door is opened to acknowledging that the catastrophic failures can be dependent. The catastrophic failure rates (assuming conventional approaches) are also functions of the part values and environments just as the circuit performance characteristics are functions of them, and consideration of their probabilistic variability may affect the typical independence assumption made for catastrophic failures. Another consideration is that there are different kinds of catastrophic failure modes, i.e., open or short, and the circuit performance characteristics may react differently to different modes. Additional questions along these lines exist. The above remarks are not meant to be critical of this report in that it does not provide answers, but rather the remarks are critical of the state of the art. The point is that when a reliability prediction starts going into deep detail, there are unanswered questions concerned with structuring the problem and with solution techniques.

R67-13472 ASQC 841; 851
Joint Publications Research Service, Washington, D. C.

PROCEDURE FOR OBTAINING EXPERIMENTAL DATA ON RELIABILITY OF TECHNICAL DEVICE

G. V. Druzhinin *In its* Cybernetics in the Serv. of Communism, Vol. II 18 May 1965 p 36–65 refs
(JPRS-30128; TT-63-31010; N65-23780)

The article is an attempt to consolidate and systematize existing knowledge on reliability measurements. Tests and methods are discussed for obtaining, processing, and evaluating operational data of systems and devices. Improper functioning, damaging loads, and the simulation of these conditions in laboratory tests are considered. Accelerated wear tests, irreversible processes in technical devices, step–stress tests, degradation, and catastrophic breakdown are discussed. The mathematical and statistical aspects of the random process of wear are briefly given in addition to graphic representations of failure incidence. K.W.

Review: This is a survey paper which is split into three parts—field data, reliability tests, and computer simulation. The subjects are treated in generalities, not in specific detail. The first part deals in a rather general way with the problems in getting good field data and the conclusions are pretty much those arrived at in this country. The usual suggestions for improving reporting forms are included. The second part deals with tests run for the express purpose of finding the reliability. It mentions such things as accelerated testing, random sequences of loading, proof testing, and step–stress testing. The third part dealing with simulation points out the difficulties in reliability tests and suggests the substitution of simulation as being cheaper and quicker. Degradation as well as catastrophic failure are considered. The bathtub curve for hazard rate and stochastic processes are discussed. There is an extensive bibliography, largely, of course, of Russian material. Those wishing to read this paper will fall into two classes. The first includes reliability specialists who want to be sure they know everything that other people are talking about and wish to be sure that they have a broad view of the field. The others will be those with idle curiosity about what the Russians are saying and doing.

R67-13486 ASQC 844; 773; 775

EVALUATING COMPONENTS WITH A NON-LINEARITY TESTER.

Kaj S. Willadsen (Radiometer A/S, Copenhagen, Denmark). *Evaluation Engineering*, vol. 6, Jul./Aug. 1967, p. 30–32, 60. 7 refs.

A nondestructive method to provide information on the reliability of passive electronic components is presented that is based on measuring the nonlinearity of nominally linear electronic equipment such as resistors and capacitors. This nonlinearity is determined by selective measurement of the third harmonic voltage generated in the component by a pure sinusoidal current; and the nonlinearity is defined as the ratio between this third harmonic voltage and the fundamental voltage. Since the nonlinearity of some components can be as small as 120 db, only measuring equipment with a residual nonlinearity of less than 140 db can be used; and the established nonlinearity is then taken as a measure of component reliability. Acceptance testing results are discussed in terms of this nonlinearity method. M.W.R.

Review: This paper is a very brief description of the use of nonlinearity in the voltage–current curve for quality and reliability testing. The amount of third harmonic voltage generated in response to a purely sinusoidal current is used as a measure of the nonlinearity. Absolute limits are not used but rather anything substantially above the median (of a sample) is regarded as being less reliable. There is the statement that an ideal batch will have a pure Gaussian distribution; this is a definition of ideal rather than a further property of ideal. It is easy to infer from the example that a deviation from a Gaussian distribution is a suspect cause for rejection. This, of course, is not the same as the original criterion. It is not shown in this paper that the presence of large amounts of third harmonic voltage is associated with short life, but references are given to papers wherein these large third harmonic voltages are associated with engineering defects of the components. This technique is certainly worthy of further exploration to see just where it can be applied as a screening tool.

R67-13488 ASQC 844

THE HOWS AND WHYS OF METAL FAILURES.

Materials Protection, vol. 5, Jan. 1966, p. 43–47. 51 refs.

Summaries are presented for ten papers presented at a conference dealing with the initiation of metal failures. A current review of temper embrittlement and a degradation from hydrogen embrittlement are included, along with a paper on hydrogen content-stress relationships in $H_2S–CO_2–CH_4–H_2O$. How to conduct a failure analysis is discussed, as is the prediction of full-scale fracture with a laboratorty test. The use and limitations of fracture mechanics, fracture in a tensile specimen, fractures in corrosive media, fracture of large, high-strength pressure vessels, and the physical meaning of notch toughness are also considered. A list of articles dealing with metal failures is included. M.W.R.

Review: This is a good collection of articles which are more suitable for quick review by an engineer to whet his interest and increase his awareness than they are for reference purposes. They cover a fairly wide range of topics on metal failures and all appear to be competently written. The selected list of articles on metal failures are largely from the publications *Corrosion* and *Materials Protection* rather than being comprehensive for the field as a whole. This is a good place to point out that strength has many facets. There are many ways in which a part can fail and the usual description of a material as high-strength or very high-strength refers to only one of these ways, namely tensile strength. Very often the properties which make high tensile strength cause the material to be much more susceptible to other kinds of failure, such as impact, fatigue or notch sensitivity. In the past many of these were not as important as they are now. This paper can help engineers to realize how narrow their horizons may be.

R67-13489 ASQC 844

TOP TEN MILITARY CORROSION PROBLEMS.

Materials Protection, vol. 5, Jan. 1966, p. 19.

Topcoats for inorganic zinc primers, better cleaning equipment for aircraft, corrosion performance data recording procedures, nondestructive testing program needs, and new hand tools for surface preparation are included among the top ten corrosion problems of the Department of Defense. Mention is made of the 1966 corrosion show, to which industrial participants were invited. M.W.R.

Review: Corrosion is one of the important failure mechanisms for both electronic and mechanical parts. This kind of listing of problems is worthwhile for several reasons, e.g., (1) it brings to the attention of design engineers and manufacturers the fact that severe and unsolved corrosion problems exist, and (2) it provides a focus for those wishing to do research on specific problems. These ten listed problems deal exclusively with mechanical parts. The use of newer, more exotic materials, especially those with nominally higher strengths (aluminum, titanium and steel) tends to make the susceptibility to corrosive damage much greater.

R67-13490 ASQC 844

Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena.

FAILURE RATE COMPUTATIONS BASED ON MARINER MARS 1964 SPACECRAFT DATA

Frank H. Wright 15 Jan. 1967 16 p
(NASA-CR-81192; JPL-TR-32-1036; N67-15684) CFSTI: HC $3.00/MF $0.65

This report describes the analysis of spacecraft parts-hours, and failure data from the *Mariner Mars* 1964 program. It contains failure rates for transistors, resistors, capacitors, diodes, transformers, relays, and coils, using the JPL Problem/Failure Reporting system. Failure data origins, ground rules, and definitions are also given. Author

Review: Failure rates for a variety of components based on data from the Mariner Mars 1964 program are presented. Information on data origins, ground rules and definitions used is also given. Thus the report should serve a useful purpose for reliability predictions and risk/cost allocations for future space systems. The report is very concise, occupying less than 8 full pages; no words are wasted. The author has also indicated areas which were not covered in the reported work, but which should receive attention in future analyses. These features enhance the report's usefulness.

R67-13491 ASQC 844

DIAGNOSIS OF AUTOMATA FAILURES: A CALCULUS AND A METHOD.

J. Paul Roth (IBM)

IBM Journal, vol. 10, Jul. 1966, p. 278–291. 10 refs.

A notation and calculus for representing the behavior of failing acyclic automata are presented, and a D-algorithm is developed that permits the determination of tests to calculate internal and external failure patterns in circuits. The D-algorithm is considered along with truth-table, complements, pruning, and tracing methods for failure determination; and examples are included to explain the calculus of D-cubes, which is used to describe failure phenomena in circuits. For the latter, construction of the D-cube, intersections of cubes, primitive D-cubes of a failure and a logical block, D-intersection, and short circuit detection are detailed. A manual procedure for executing the D-algorithm is included, along with D-algorithm programming via the Iverson notation. A section is devoted to a proof of the method for the acyclic case, with the automaton constructed from AND's, NAND's, OR's, and NOR's. It is shown that if a test of failure exists, the D-algorithm will find such a test. M.W.R.

Review: The paper is in two parts—a short review of the existing methods for devising the tests for failure in noncyclic automata (logic circuits without feedback), and the much more lengthy presentation of a new method. It is intended both for the reader who wishes to apply this powerful method, and for the more mathematically-minded reader who wants to check and verify this work, and possibly to use it as a basis for further development of methods for the testing of reliability and failure in automata. The author presents his new method "the calculus of D-cubes" with extraordinary clarity. His review of present methods is tutorial and useful. For some readers the lemma-and-proof mathematical approach will flaw the presentation, but the good explanations and use of examples will more than make up for this for such readers. Where the author uses new, unusual or obscure terms, he defines them—a quality which should endear him to the person who is not well-read in this field. The author describes a manual procedure by means of an example and then does the same for the programming procedure. The report is free of any significant errors, and the bibliography is good. The last section, which is a mathematical proof, will be of particular interest to those who are carrying on mathematical research in this area. This is a splendid piece of work, well-written, and high significant.

R67-13494 ASQC 844
THE STRESS CORROSION THREAT.
John A. King
Space/Aeronautics, vol. 46, Oct. 1966, p. 61–67. 8 refs.
(A67-14602)

Discussion of the uncertainties underlying the basic mechanisms of stress corrosion in titanium. The following ways of hedging against it are reviewed: surface treatment, reduction of design stress, environmental control, and especially alloy modification. The primary concern of designers regarding stress corrosion is the cooperative effect of two characteristics which distinguish the phenomenon from other causes of material failure: (1) materials which are stress-corrodable in a specific environment tend to fail under tensile stress which is often below nominal design loading, and (2) the corrosion function takes place in relatively mild environments, often with little evidence. IAA

Review: This is an overview of the stress-corrosion threat, most specifically with regard to exposure to hot salt, but not limited thereto. It surveys the problems rather than attempting to give answers. The difficulties of even knowing the mechanisms by which stress-corrsion operates are illustrated by the brief summaries of several theories. The stress-corrosion of titanium will be an extremely important failure mechanism in aerospace applications and it behooves designers to be aware of the problems. This paper seems to treat the subject fairly and at a level that is accessible to the ordinary design engineer (one does not have to be a super-metallurgist to understand the points being made). Even some technical managers will find this article of benefit.

R67-13495 ASQC 844; 782
RELAY RELIABILITY AND LIFE.
R. R. Fowler (Automatic Elec. Co., Chicago, Ill.).
Reprinted from EDN Magazine, Nov. 9, 1966. 3 p

Relay failures are defined and classified according to mechanical, electrical and magnetic, and environmental causes. A long listing of factors that are known to affect both lifetime and contact performance of a relay is included. M.W.R.

Review: This very short paper is largely a listing of the factors which will affect contact reliability and relay life. It will be of most value to someone who is already familiar with problems of relays. It will be of little help to the novice because of its brevity. The text does explain very briefly some of the general areas on the list. The designer of course does not have to consider everything in every application. In fact if he has to consider all of these things in any particular application he is likely to be treading on dangerous ground. (This observation is certainly not limited to relays alone, but anytime one is pushing all of the limits of any device he is in for reliability trouble.)

R67-13497 ASQC 844; 775
NON-DESTRUCTIVE SCREENING TEST FOR COMPONENTS.
Glenn W. Carter (Dale Electronics, Inc., Advanced Engineering, Columbus, Neb.).
Electronic Industries, Mar. 1966, p. 74–76, 166, 167.

The GARD concept (Graphic Analyzation of Resistance Defects), a nondestructive screening test that requires about 5 seconds, is considered applicable to all types of resistive components as well as to the resistive portions of integrated circuits. The dynamic resistance change of a resistor is continuously monitored during temperature cycling in order to find failure modes related to heating, mechanical stress, and dielectric properties. To generate the temperature rise in the resistive system, I^2R heating is used; and this requires a greater voltage than the resistor is usually subjected to. Because of this overload of voltage as well as current and power, the variation in temperature and the resultant resistance variation is greatly exaggerated under GARD test conditions. This enables easy detection of defects with a high degree of accuracy. The GARD test concept is considered to be applicable in testing other equipment; and to offer the possibility of a practical, economical, and highly reliable nondestructive testing procedure. M.W.R.

Review: This article is very similar to that covered by R66-12393. The principle is that high electrical stresses are applied and the behavior under transient thermal conditions is observed. During the short period of high stress, short-term electrical or mechanical faults are recorded and indicate relative reliability. In addition, the resistance vs. temperature characteristic is recorded and can be used for sorting if desired. This kind of test is most appropriate and is worthwhile extending to other components if possible.

85 DEMONSTRATION/MEASUREMENT

R67-13468 ASQC 851; 844
UNIJUNCTION DEVICE GETS HIGH MARKS IN STRINGENT TESTS OF RELIABILITY.
T. Peter Sylvan (General Electric Co., Semiconductor Products Dept., Syracuse, N. Y.).
Electronics, vol. 38, June 14, 1965, p. 98–104.
(A65-26445)

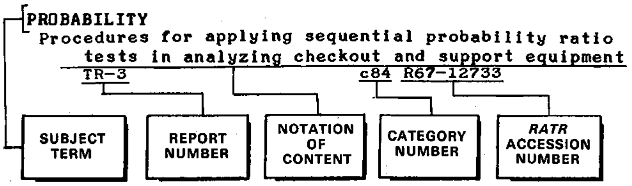
Discussion of reliability data obtained during operations with silicon bary-type unijunction transistors. Quality assurance and life testing procedures for these devices are reviewed, and catastrophic and degradational failure modes are discussed. The study of extensive life tests, field returns, acceleration factors, and failure mechanisms indicates that commercial unijunction transistors in properly designed circuits will exhibit failure rates of less than 0.01% per thousand hours if extreme stability of characteristics is not required. IAA

Review: This is a nominally useful paper and contains a great deal of information on the life and failure modes of the unijunction transistor. It is easy, however, to get the feeling that this is as much a sales document as an honest effort to report the reliability problems and successes of the unijunction transistor. The life data came from life tests rather than from field tests and that does make a difference. It is probably essential to be extremely careful in circuit design to make sure that there are no transients or other odd-ball conditions which can adversely affect the unijunction transistor.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 11

Typical Subject Index Listing



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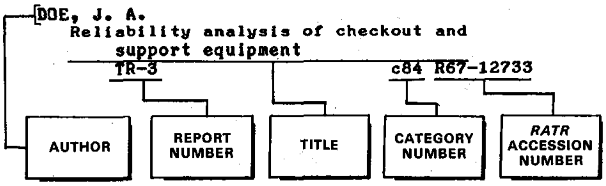
Typical Personal Author Index Listing



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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 11

List of Report Numbers

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NASA-Langley, 1967

Reliability Abstracts and Technical Reviews

DECEMBER 1967

Volume 7
Number 12

R67-13500—R67-13546

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

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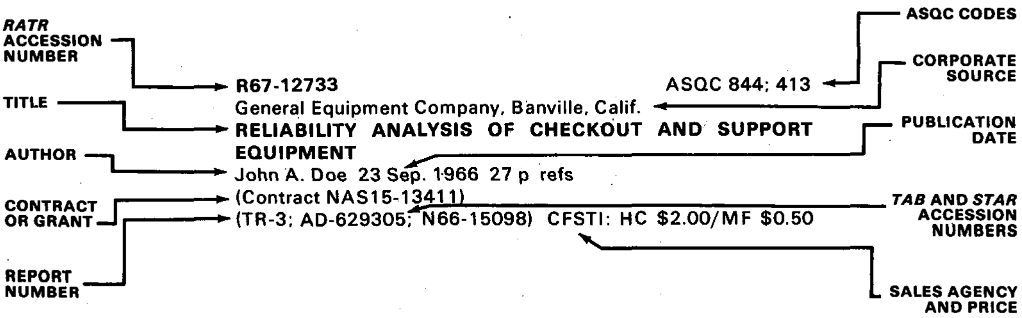
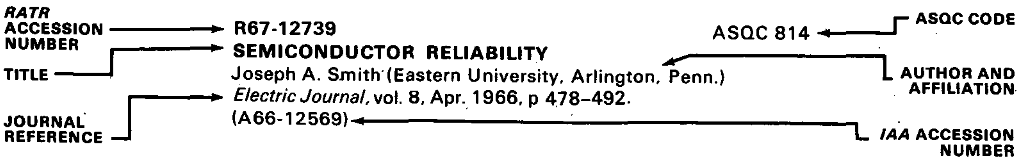
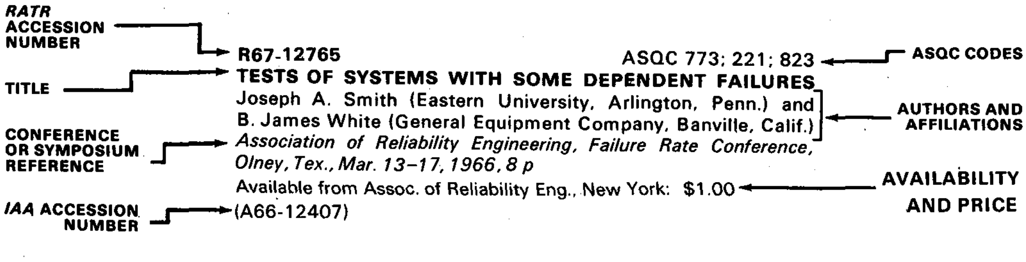


R67-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N66-15098) CFSTI: HC $2.00/MF $0.50



R67-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A66-12569)



R67-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A66-12407)

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Reliability Abstracts and Technical Reviews

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December 1967

80 RELIABILITY

R67-13524 ASQC 802
Royal Radar Establishment, Malvern (England).
ELECTRONIC RELIABILITY—CALCULATION AND DESIGN
Geoffrey W. A. Dummer and Norman B. Griffin Oxford (New York), Pergamon, 1966 252 p

Reliability theory, design, and measurement are considered in relation to electronic equipment and complete systems. Probability theory, frequency distributions, confidence limits, variance ratios, and other aspects of basic reliability are detailed. The exponential law of reliability, system prediction from failure rates, and life testing are among the topics discussed in a chapter on calculating equipment and system reliability. Safety and derating factors are reviewed in terms of various types of redundancy, weight and reliability factors, and derating of various types of equipment. A chapter on reliability in construction considers design, performance, encapsulation and connections, and other construction problems. Environmental effects on the reliability of various materials, equipment, and systems are noted; and the various types of microelectronics are detailed. Failure rates for electronic components are described and tabulated for numerous types of devices and items. M.W.R.

Review: The preface indicates that this book was written to meet the need for "a practical textbook which will introduce the subject to the student in a form which is easily assimilated, and at the same time provide a reference to the various aspects contributing towards increased reliability of both equipments and complete systems." This purpose is only partially accomplished. Of the seven chapters in the book, the last four which deal with constructional features found to maximize reliability, with effects of environment, with the newer aspects of microelectronics, and with failure rates for electronic components contain useful information based on the wide experience of the authors. However, the first two chapters which deal with basic reliability mathematics theory and with the calculation of equipment and system reliability will be of little real help to the student and could in fact be misleading; Chapter 3 on safety and derating factors also contains deficiencies. The problems are due to omissions, editorial and typographical errors, and too little attention to detail. There has been an effort to cover too much ground in too short a space. Specific comments are listed here to help the student and other users evaluate the book. Chapters 1 and 2 (Mathematical theory and calculation): The omissions, editorial mistakes, and undue restriction to exponential and Normal distributions render them virtually worthless to the student. For example, in the section on the Poisson distribution, the Poisson distribution formula is never given and barely mentioned. Many of the examples are treated as if the results were not going to be dependent on a distribution and only when table entry is about to be made is the distribution mentioned. The beginner will be especially thrown by many of the mistakes, and the advanced reader does not need much of the material. It is rarely mentioned where statistical independence is important. No clear distinction is made between a circuit diagram and a logic diagram for analyzing reliability. No good discussion is given of the difference between failure rate $(-dR/dt)$ and hazard rate $(-1/R\ dR/dt)$. (The form often used for exponentials is disconcerting to Americans, who are not used to it.) No discussion is made of the distinction between engineering and statistical confidence. Many blanket statements are made which are at best a matter of degree and sometimes a matter of controversy. Confidence limits are always shown to be two-sided whereas very often they are one-sided. The Chi-square distribution is only half-heartedly given. The authors introduce terms without having defined them earlier and act as if they had already defined or used them. One can easily get the impression that all equipment failures follow the exponential distribution which is not so. There is an unfortunate tendency to equate the words "randomly" and "chance" with obeying-a-Poisson-distribution; obviously any variable which has a probability distribution is a random or chance variable. Nothing is discussed about failure modes and effects; in fact, the statement is made that ". . . only the primary failure matters." Very often too many significant figures are given for either the reliability or the hazard rate; this implies an accuracy much greater than is actually there. The formula 2.11 is asserted to be general but holds only for the exponential case. The nonoperating hazard rates are assumed to be zero which is obviously not so. The formulas for the number of failures to be expected from a Poisson process and for estimating the mean do not take into account the statistical difference between (1) having the time-to-a-given-number-of-failures as the random variable and (2) having the number-of-failures for the random variable and a fixed amount of time. There is confusion where the symbol *m* is used to stand for MTBF and for the average number of failures in a given period, both in close proximity. Chapter 3 (Safety and derating factors): There is negligible emphasis on the most important topic of derating. viz., what is held constant while one derates other factors? For example, if the weight is fixed and capacitors are derated, larger ones will be needed. What will have its weight reduced, and will that lower the reliability more than the gain for the capacitors? It is not pointed out that blind derating may decrease the reliability, especially with electrical contacts on such elements as switches and relays. Electrolytic capacitors are another case where derating should be done carefully; resistors which are run very cool instead of warm may be more susceptible to moisture damage. The MTBF is used as a figure-of-merit. For systems which do not have a constant hazard, more useful figures-of-merit are the early hazard rate or mean hazard rate over the mission. The arrhenius law is grossly misquoted. A fifth-power law is virtually asserted to hold for all dielectrics and this is obviously not true. Very little is said about degradation; virtually all failures are presumed to be catastrophic. In all the failure rate discussions there is virtually no definition of a failure even in the tables. The discussion on connectors is much too abbreviated, especially in view of the tremendous controversy in the past few years surrounding proper reliability testing for connectors.

Chapter 4 (Reliability in construction): There are cases where hermetic sealing is a disadvantage, especially where there are electrical contacts and vapors may be given off by other things in the enclosure. Printed circuit boards are not fundamentally more reliable than conventional wiring, but they can be made more reliable if one is careful. For example, if the boards are allowed to bend, the thin conductors may break much more readily than conventional wiring. Processes and components are often described as if there is only one way of handling them, whereas, in fact, there may be many; the one asserted to be most common may be most common only in one particular application. In summary, the good material in this book is in the last four chapters. For the material covered in the first three chapters the reader would do well to look to other sources.

R67-13532 ASQC 800

BROWN CONFIRMS MINUTEMAN II HAS COMPONENT WOES.

Electronic News, August 7, 1967, p. 35.

A high rate of component replacement is reported for the Minuteman II missile, with this result of a lower alert rate than for Minuteman I missiles. Subsystem problems have been traced to random workmanship errors, except for the substandard capacitors that aborted silo test firings. While the Minuteman II guidance and control system is requiring more than the predicted maintenance, this news release reports improvement in maintainability occurs as "the system matures." M.W.R.

Review: This is the kind of article that does not appear in technical journals but only in the press. It shows that the reliability programs reported for Minuteman II were not as effective in the overall system as people had expected. There are some lessons to be learned from this, not the least of which is to remember that our simple-minded, limited conceptual models of the world are not the world itself. It would be refreshing indeed to read an article in a technical journal such as the IEEE Transactions on Reliability addressed to the topic: "Why Our Predictions of Very High Reliability Were in Error—Our Components Are Causing All the Failures in the Minuteman II Missiles."

R67-13535 ASQC 800

SOVIET COMPUTER RELIABILITY—AN APPRAISAL.

Stuart G. Hibben (Library of Congress, Aerospace Technology Div., Washington, D. C.).

Datamation, vol. 13, August 1967, p. 22–25. 11 refs.

Early history of Soviet computers is reviewed; and details are presented for experiences with the Ural-2, M-20, and Dnepr computers. Available reliability data are analyzed in light of fragmentary reports in the Soviet literature. While there are a number of quality control problems that limit the reliability of Soviet computers, the most pressing deficiency appears to be in the lack of qualified operating and maintenance personnel. It is assumed that the Soviet space computers do not suffer from the same kind of failure rates or lack of personnel that industrial machines do. M.W.R.

Review: Even though the information in this paper is of no direct benefit to design engineers, it can improve their morale somewhat by indicating that others are worse off than they are, especially when the "others" constitute a major competitor. While reading the article you can get an uneasy feeling that many of the complaints made by the Soviets are quite similar to those made here. For example, one Soviet writer deplores thumping a piece of electronic equipment to make it work. This is a time-honored practice (when was the last time you hit a piece of equipment that was not working?) and will likely continue in all parts of the world. Poor production methods and attitudes are condemned fairly often in Soviet writing; apparently some of the manufacturers do not care about their outgoing quality or about making spare parts available since these are not part of their actual incentives. It shows the importance in establishing any kind of incentive program, including those in the field of reliability, of being sure that the incentives will actually give the worker/contractor the desire to do what is best. This is a serious problem in multiple-incentive contracting where reliability is one of the factors. It seems that good help is hard to get in Russia; it is also hard to get in the United States and has been for the last several hundred years. This is probably a curse of civilization. The subject matter and the author's treatment of it both combine to make this an interesting article to read.

81 MANAGEMENT THEORY OF FUNCTION

R67-13502 ASQC 813

ASSURING QUALITY AND RELIABILITY FOR MARINER 4.

Richard A. Welnick and Frank H. Wright (California Institute of Technology, Jet Propulsion Laboratory, Pasadena, Calif.).

Astronautics and Aeronautics, vol. 3, Aug. 1965, p. 50–53. (A65-30146)

Discussion of the Mariner 4 quality-assurance and reliability programs. Proven techniques were applied to monitor and control the quality and reliability of the Mariner test and flight spacecraft. Some of the areas described are: quality systems and procedures, in-process inspection, spacecraft-equipment certification, environmental testing, and reliability prediction and failure-modes analysis. It is noted that these programs are intended to supply information for such future space projects as Surveyor and Voyager. IAA

Review: This is a very brief summary of the kinds of quality and reliability activities that were undertaken. In order for it to be any more than just a group of words strung together a person would have to have some reasonable knowledge of similar systems. There is no comparison made of the activities on this project to those on other projects which were failures; so there is no way of knowing whether the success of the Mariner is because of, in spite of, or irrelevant to those procedures. In most cases the effectiveness of a reliability effort depends more on how conscientiously each individual carries out his assignment than on the paper organization.

R67-13514 ASQC 815; 844

RELIABILITY OF ELECTROMECHANICAL SWITCHING DEVICES—AN ENGINEER'S VIEWS.

N. E. Hyde (Standard Telephones and Cables, Ltd., Sidcur, England).

Microelectronics and Reliability, vol. 6, May 1967, p. 81–94.

Efforts to obtain highly reliable components in electromechanical switching devices are discussed from an engineer's viewpoint, and the use of one standard specification and one sampling plan is stressed for all the components that go into one piece of equipment. With regard to electrical contacts, the standard 10 mV contact test is considered best for all electrical contact determinations. Equipment failure probability is related to the number of components in a system; and standard format specifications are tabulated for acceleration, air density, climate, shock, temperature, and vibration. The latest DEF specifications for switches, relays, and connectors are shown, and sampling plans for these three components are compared in accordance with their individual specifications and DEF 131 and 131-A. Reliability is discussed in terms of Army, Navy, and industry requirements, and management and the overall manufacturing process. Attention is also given to circuit reliability, contact resistance, connector rating, and failure criteria. M.W.R.

Review: An odd and intermingled collection of sub-topics comprise this paper. They include switching device specifications and testing, the general reliability problem, and the misuse of statistics in reliability. The opinions which are expressed concerning switching device testing and the summary tables concerning British specifications might be of interest to those concerned with details of these topics. The material on the reliability problem in Great Britain is suitable for non-technical audiences. That reliability problems abound is not news to a technical audience. Misuse of statistics in reliability engineering is essentially identified with statisticians in this paper. Such misuse has unfortunately occurred too often. However, engineers without adequate background in statistics but nevertheless attempting to use explicit statistics in reliability analysis have probably done more to contribute to this misuse than have statisticians without some engineering background. Explicit statistical notions have generally been properly and beneficially applied to many technical topics, such as communications theory or information theory. It seems that it is mainly in reliability that misuse occurs, but fortunately this condition is improving. Overall, this would have been a much better paper had it been restricted to topics directly concerned with switching devices.

82 MATHEMATICAL THEORY OF RELIABILITY

R67-13503 ASQC 820; 844

BEHAVIOR AND VARIABILITY OF SOLID PROPELLANTS AND CRITERIA FOR FAILURE AND FOR REJECTION.

John N. Majerus, Herman P. Briar, and James H. Wiegand (Aerojet-General Corp., Sacramento, Calif.).

Journal of Spacecraft and Rockets, vol. 2, Nov.–Dec. 1965, p. 833–845. 62 refs.

(A66-12734)

Consideration of the general effects of parameter variability for solid propellants and examination of ballistic variability. The effect of solid propellant modulus variability on structural analysis and the effect of nonlinear behavior are also considered, with an examination of failure variability from single loadings as well as from multiple loadings, which lead to cumulative damage effects. The practical and interim solution of the problem through the statistical treatment of empirical correlating parameters is illustrated in terms of full motor prediction. It is concluded that the ballistic and mechanical properties of solid propellants must be treated as statistically distributed parameters. Estimation of these parameters is essential to design and failure analysis with the failure properties of the propellant being reflected in a range of failure behavior of motors on cycling, storage and firing. To reduce the uncertainties of a grain analysis, the observed nonlinear mechanical behavior must be characterized. Present nonlinear theories involve a number of unknown time-dependent functionals, and only for incompressible materials can the unknown material parameters be readily characterized; even so, a large number of relaxation and creep tests are necessary to evaluate the unknowns. A more generalized, but approximate, nonlinear theory can be generated by characterizing the relaxation response of a statistically significant number of uniaxial and biaxial stress tests under hydrostatic pressure in which dilatation is measured. It appears that a nonlinear theory is necessary for complete calculation of the effects of pressurization on firing, but it may not be necessary for the cases of thermal cycling or slump. IAA

Review: This paper deals intensively with the subjects in the title and a large portion is concerned with inadequacies of present models for failure and with the effects of randomness in physical properties. It is particularly encouraging that the statistical problems are treated well and realistically. The challenges of fatigue, especially cumulative damage, are well brought out and the tremendous amount of scatter in the results is not minimized. There are 62 references for checking the authors' analyses and for sources of further detail. Those who are concerned with solid propellants will find this article of benefit.

R67-13507 ASQC 821; 431

THE PROBABILITY OF AN EXCESSIVE NONFUNCTIONING INTERVAL.

A. Von Ellenrieder and A. Levine (University of Buenos Aires, Argentina).

Operations Research, vol. 14, Sep.–Oct. 1966, p. 835–840. 7 refs.

A component is considered as a zero–one variable related to time such as fail–operate, in repair–available, busy–unoccupied; and determination is made of the probability that this stochastic variable does not continuously maintain one of these values for more than a specified period. A common-type of Markov process is assumed in the derivation of this excessive nonfunctioning interval. In effect, a component with a functioning and a nonfunctioning state is considered; and, if a failed component can be quickly replaced or repaired, it may not result in system failure. The probability for system failure is derived in detail as the first passage of a derived stochastic process. M.W.R.

Review: This paper gives a very interesting approach to the general idea that in some situations the operation of a device will be perfectly acceptable if it works correctly "most of the time." This idea is, of course, made specific in the paper. The assumption that the basic two-state (operational or not operationl) process is a certain Markov process is somewhat restrictive but tractable. Further, the results obtained involve a triple integral of an infinite series. It would have been useful to know good approximations for the required probabilities.

R67-13508 ASQC 821; 431

SOME STOCHASTIC PROPERTIES OF A COMPOUND-RENEWAL DAMAGE MODEL

Richard C. Morey (Institute for Defense Analyses, Arlington, Va.).
Operations Research, vol. 14, Sep.-Oct. 1966, p. 902–098. 11 refs

Broad nonparametric classes of compound-renewal processes and stochastic properties are investigated as a model of cumulative wear damage, and it is assumed that a component will function until its cumulative wear exceeds some critical threshold, generally a random variable. A monotone failure rate is assumed, as is the closely related concept of a Polya-frequency density. The first passage of time, as associated with the compound Poisson process, until breakdown is studied; and, since the assumptions are nonparametric, the results are generally in the form of useful bounds. Detailed proofs are included, and it is noted that the wear on railroad tracks could be well described by such a model. M.W.R.

Review: This paper presents some very interesting results for the compound-renewal damage model. The proofs rest heavily on the references but the mathematics is clearly of high quality. Interest is centered on the random time of failure T_x where failure occurs when the process crosses a given threshold X (which may also be random). Upper and lower bounds on the mean and variance of T_x are obtained under rather general nonparametric assumptions. In the second theorem more specific assumptions are made and hence more specific results obtained. As far as the practical researcher is concerned, the paper does lack examples; and one wonders how good the given bounds are. Otherwise this is a well-written technical paper. (See also R66-12535 which covered a paper by the same author.)

R67-13509 ASQC 821; 431

INFLUENCE OF THE RELIABILITY OF REPAIRABLE SYSTEMS FOR A STATIONARY PROCESS.

I. A. Ushakov

Telecommunications and Radio Engineering, Part 2, Radio Engineering, vol. 21, 1966, p. 121, 122. 1 ref.

Upper and lower bounds are determined for the reliability during a specified time interval of repairable systems, under the assumption that the probability of finding the system in an operating state is equal to one. Formulas are evolved for an arbitrary reliability parameter on the basis of renewal theory. M.W.R.

Review: This very brief note is extremely difficult to read, due either to the wording of the original version or to the English translation. For example, a parenthetical statement in the first paragraph seems to imply that the system is "operating" at all times. Does this mean that it never fails? There appear to be several "typographical" errors, also. In the equation in the middle of p. 122, $R_a(t)$ should be replaced by $1\text{-}R_a(t)$ but then the inequality goes in the wrong direction. Thus the quality of the paper cannot be evaluated.

R67-13510 ASQC 822; 838

THE EFFECT OF STANDBY REDUNDANCY IN SYSTEM'S FAILURE WITH REPAIR MAINTENANCE.

V. S. Srinivasan (Defence R & D Organisation, New Delhi, India).

Operations Research, vol. 14, Nov.–Dec. 1966, p. 1024–1036. 2 refs.

Two models, which differ in their definitions of system failure, are considered in a theoretical study of the effect of standby redundancy on the time to failure of a system that is used intermittently and whose units are subject to breakdowns and repairs. In one model, the demand pattern for usage of the system is taken into account; while in the other system, it is not. A detailed derivation of the Laplace transforms of the probability density functions for time to failure is presented for both models. M.W.R.

Review: This paper gives a detailed derivation of the distribution (or its Laplace–Steiltjes transform) of time-to-failure under very realistic conditions of standby redundancy with repair provisions. The unique feature of one of the models is that the device is used only intermittently and system failure occurs only when the device is in the failed state *and it is needed.* As one would expect, the formulae in such situations are *extremely* complicated and one wonders if they can be used at all in this generality. Certain special cases where the results simplify are also given.

R67-13516 ASQC 824; 432; 838

RELIABILITY PREDICTIONS FOR REPAIRABLE SYSTEMS CONTAINING REDUNDANCY.

D. J. Creasey (Birmingham University, Dept. of Electronic and Electrical Engineering, Birmingham, England).

Microelectronics and Reliability, vol. 6, May 1967, p. 135–142. 7 refs.

(A67-30063)

Queuing theory is used to calculate the reliability of redundant systems. Approximations are made to reduce the resulting reliability equations to a simplified form. Justification for these approximations is given by comparing the simplified equations with data obtained from a computer simulation of a redundant system. Author (IAA)

Review: A simplified theory of the reliability of redundant repairable systems is presented. Queuing theory is used to obtain the equations for the overall steady-state system reliability. Approximations used in simplifying the equations are justified by computer simulation. The presentation is clear, concise, and well documented. The paper thus makes a worthwhile contribution to reliability theory/methodology.

R67-13526 ASQC 821; 837; 844

Joint Publications Research Service, Washington, D. C.

EFFECT OF STRESS CONCENTRATION AND DIMENSIONAL FACTOR ON FATIGUE STRENGTH IN A STATISTICAL ASPECT

V. P. Kogayev 8 Nov. 1965 36 p refs Translated into ENGLISH from the book "Voprosy Mekhanicheskoy Ustalosti" (Moscow), 1964 p 67–100

(JPRS-32768; TT-65-33346; N66-11186) CFSTI: $3.00

Mechanisms which are responsible for the influence of the stress concentration and the scale factor on the fatigue strength and the spread of endurance characteristics in metal specimens are described by the statistical strength theory of the weakest link and the Weibull distribution function. Equations derived can be used to form a series of probability curves for the machine member to characterize the service life and the limiting stresses of the members. A model is presented to permit the design of a machine with optimal fatigue life, and the theoretical aspects involved are considered. M.W.R.

Review: This paper will be of interest to the researcher rather than the design engineer. It is lengthy and extremely difficult to follow because of its mathematical nature. The mathematical relationships which the author develops appear reasonable, but they were not completely checked. The idea of designing a new machine for optimum fatigue life from a statistical strength theory of the "weakest link" (based on failure probability, stress concentration, and gradients in the principal stresses) is a good one and one which ought to be pursued. Just how accurate the model is, though, is something else again. There is considerable evidence, especially on large specimens, that the elements are not statistically independent items with total failure caused by the failure of any one element; i.e., the weakest link model is inadequate. The work reported here is a step in the development of this theory, but much more experimental effort is required before all of the interrelationships are understood.

R67-13544 ASQC 820; 844

Battelle Memorial Inst., Columbus, Ohio.

SOME UNIFYING CONCEPTS IN RELIABILITY PHYSICS, MATHEMATICAL MODELS, AND STATISTICS

Ralph E. Thomas *In* RADC Phys. of Failure in Electron., Vol. 5 Jun. 1967 p 1–17 refs (See N67-38461 23-09)

(N67-38462)

The basic concepts of dimensional analysis are used to make a general examination of reliability physics, mathematical models, and statistics. Beginning with reliability physics, an examination of Eyring's equation is made using Buckingham's Pi theorem. The Arrhenius equation is then seen to be an approximation to the Eyring equation. The use of dimensional analysis in constructing mathematical models based on empirical investigations is considered. The appropriate dimensionless variables are first identified, and then are used in experimental exploration and for subsequent mathematical modeling. The probability density functions of statistics may be associated with patterns of "noise". Statistical methods are used for extracting signals from a pattern of noise and for judging the statistical significance of the signal-to-noise ratio. Author

Review: The purpose of this paper, namely, "...to explore the possibilities of unifying the languages used by researchers engaged in studying the physics of failure" is laudable, but there are too many difficulties in the paper for it to be regarded as definitive. The amount of space devoted to topics in some cases is out of proportion to their importance. The importance of dimensional analysis seems over-emphasized even though there is little question that dimensional analysis is a useful tool. Dimensionless parameters are certainly very handy things to have around. One section is entitled "Derivation of Eyring's Model Using Dimensional Analysis"; this is not at all what the author has done. What he has shown is that there are two independent dimensionless parameters of the five that appear in the absolute-reaction-rate-theory equation and that these are consistent with the Eyring equation. The form in which the Arrhenius law is given is apparently not the form in which Arrhenius gave it. In a concluding paragraph the author states, "As a direct consequence of the Pi theorem, it follows that every formulation of a problem in physics should be ultimately expressed in terms of dimensionless variables." It is not at all obvious that this should be done and as a matter of fact most of the constitutive equations in physics are not so expressed, for example, $F = ma$ and $E = IR$. It is easy to infer from some of the text that equations which contain dimensional constants are to be denigrated but this should not be so. In the next section on Signals and Noise in Statistics, the author states that the standard deviation is the only unit of measure in statistics and that it is a measure of "noise." Since the author defines the latter to be so, its proof is trivial, but there is much more to measure in statistics than a standard deviation. Witness the case of two Gaussian distributions having the same variance with their means separated by a distance of three individual standard deviations. The variance of the combined distribution is not a very good measure of anything. The exponential distribution is another case where the standard deviation does not give a good picture of what is happening. The author's comments generally apply only to unimodal Gaussian-like distributions. The quantity s_x is not clearly defined. In one case it is apparently the standard deviation of a sample and in another case it is the square root of the unbiased estimate of the variance from a sample. The proofs that the product of the probability density function and the differential of the random variable is dimensionless, that the mean has the same dimensions as its components, and that the standard deviation does likewise are tedious. The author does wisely point out that not rejecting the null hypothesis is not equivalent to accepting the null hypothesis. In the formula for the difference between two means it is not pointed out that the samples must come from Gaussian distributions which have the same (unknown) variance. In a final paragraph the author states, "It should be emphasized that the above examples are not isolated examples but are typical of the general situation." Unfortunately all the examples use Gaussian distributions which are not necessarily always typical of the general situation. The idea of trying to associate a statistical quantity with signal-to-noise ratio is a good one although it would appear to need more developing in accord with the author's stated purpose of exploring the situation. All in all the article is more suited to a talk than it is to an archival document.

83 DESIGN

R67-13500 ASQC 831

Sperry Rand Corp., Blue Bell, Pa. Univac Div.

INVESTIGATION OF LOGIC CIRCUIT COMPLEXES "RELIABILITY AND FAULT-MASKING IN N-VARIABLE NOR TREES" Scientific Report No. 1

M. Dunning, B. Kolman, and Leon Steinberg 15 Apr. 1965
87 p refs
(Contract AF 19(628)-4051)
(AFCRL-65-295; AD-617516; N65-30342)

Three methods for masking faults in the general tree by adding NORs are developed to yield restoring, quadding, and generalized majority trees. Methods of computing system, function, and signal state reliabilities are presented as functions of the failure probabilities of the diodes and transistors which compose the trees. Computation of system reliability is considered, and upper and lower bounds are computed for quadded and restored trees. These computations are made for n = 1, 2, 3, and 4, and the resultant curves provide comparisons between the fault masking techniques under consideration as well as comparisons between upper and lower bounds for system reliability. Curves are drawn for n's of system reliability for the three types of trees as functions of NOR element reliability. Representations of the n-variable functions using multiple input NORs are discussed, and restored and quadded versions of these inputs are described. A method is given for selecting the number of inputs of the NOR to optimize system reliability of the general n-variable multiple input NOR tree. M.W.R.

Review: This report is a very thorough presentation of reliability in NOR tree structures. It is written for the reader who already has a good understanding of reliability theory and is of most interest to someone who has a direct use for the extensive solutions which are given. Probably because of the anticipated audience, the authors have not taken much care with their bibliography, which is quite inadequate. In both the abstract and the introduction the "preceding final report" is referred to as background, but no direct bibliographic reference is made. One can assume that this is item 2 of the bibliography. On the whole this is a very good piece of work. Its chief drawback is that the reader is apt to get mired down in tabulations and tables. Perhaps the authors felt that this was unavoidable in the subject matter with which they are dealing. There could, however, have been more separation of methods and solutions than they achieved. On page 50, the lower and upper bounds should have been indented and underlined to emphasize them, for example. A somewhat disconcerting error (which one assumes was not the authors' fault) was the repeating of the abstract between pages 65 and 66. This sends the reader in a hunt to find what, if any, material has been displaced by this. (Apparently none is.) Despite the negative comments given above, this is an excellent source of information on NOR tree reliability, and the authors are to be commended on presenting here a prodigious amount of useful information. Perhaps the next "final report" will be more readable.

R67-13504 ASQC 831; 837

THE CASE AGAINST STATISTICAL LOGIC DESIGN TECHNIQUES.

David S. St. Lawrence (Honeywell, Inc., Computer Control Div., Minneapolis, Minn.).

Computer Design, vol. 6, June 1967, p. 18, 20.

The application of statistical techniques to the design of a digital system logic network is considered to increase the costs of the basic logic element. While the statistical approach to logic design can show a possibility of significant improvement in the system performance and requires only the specification of the logic element delay distributions, it requires more elaborate and expensive inspection of materials and suitably specified devices. The designer must, therefore, balance the desirability of using fewer elements for equivalent system performance against the increased cost of these specified devices. The use of worst-case design techniques with identical devices that are less expensive because of reduced specification requirements is offered as an alternative. M.W.R.

Review: This argument uses the propagation time delay through a logic network as an illustration of statistical design.

There are, of course, other properties that might be considered, but this one illustrates the author's particular contentions well enough. The essential problem is that statistical design techniques require some knowledge of the actual probability distribution of the variable under consideration. It is difficult and expensive to monitor incoming components, or for a manufacturer to monitor his outgoing components, to meet a particular distribution. If there is close coordination between the manufacturing group and the user, some knowledge of the actual distributions being produced can be transferred and the design is based on that (such might be the case for in-house production) and there are surely cases in the design of computers where some other property of the mechanical frame or electronic circuits are such that statistical design can be used. An interesting approach is found in a recent article (see R67-13401) wherein the author attempts a much less restricted approach to statistical design and calls it worst distribution analysis. The usual specification and screening thereto of electronic parts is not as simple as it seems in this paper. Not every possible condition of operation is a controlled variable of manufacture (e.g., high-temperature low-voltage performance) so that something more than simple conformance to a given specification is required in design. The last paragraph is a very fair statement and should be understood by anyone who is considering the design of systems. It is much more reasonable and less far-reaching than the tone of the remainder of the paper.

R67-13511 ASQC 838

DEVELOPMENT OF FAILURE-CORRECTING FLIGHT CONTROL SYSTEM.

F. C. Neebe (General Electric Co., Armament and Control Products Sect., Schenectady, N. Y.).

In: Proceedings of the Aerospace Vehicle Flight Control Conference, Los Angeles, Calif., Jul. 13–15, 1965. Conference sponsored by Society of Automotive Engineers, Inc., and National Aeronautics and Space Administration. New York, N. Y., Society of Automotive Engineers, Inc., 1965, p. 41–46 and 108.

(SAE Paper-650573) Members: $8.00; Nonmembers: $13.00.

The application of triple redundancy with majority logic voting is considered to increase safety and reliability of aircraft stability augmentation and/or automatic flight control equipment. Primary deterrent to the further extension of automatic control modes is considered to rest with the present rate of in-flight failures; and this triply-redundant failure correction technique attempts to increase overall reliability. The HYDAPT, hybrid digital-analog pulse-time, technique used accomplishes long-term zero-drift memory, function generation, gain changing, and integration. In addition to the triple redundancy technique, three other means of accomplishing increased safety and reliability are discussed: (1) hammock networks, (2) dual actuators with model and automatic fault removal, and (3) failure-correcting redundant power supplies. To predict the inherent reliability of majority logic circuits, calculation method for determining the effect of the majority logic voter on system operation is detailed for a system composed of three identical parallel subsystems. M.W.R.

Review: This is a brief paper which can serve to acquaint other engineers with the kind of thing being done, as was probably its intention. Thus it is qualitative and descriptive rather than analytic. The article appears to have been based on physical models and analysis rather than on actual operating equipment. There are two assumptions inherent in the analysis which are implicit rather than explicit. The first is that good–bad is an adequate description of each part of the circuit and the other is that failure events are statistically independent. The latter will not be the case if uncertain variations in the environment will cause appreciable changes in the hazard rate. The MTBF calculations presume that at the end of each mission the system is restored to its original condition. If the article is taken for what it is and no more, it can be considered a good one.

R67-13512 ASQC 838

THE POTENTIAL OF MONITORLESS CONTROL SYSTEMS OF HIGH REDUNDANCY EFFICIENCY.

E. A. O'Hern (Autonetics, Anaheim, Calif.).

In: Proceedings of the Aerospace Vehicle Flight Control Conference, Los Angeles, Calif., Jul. 13–15, 1965. Conference sponsored by Society of Automotive Engineers, Inc., and National Aeronautics and Space Administration. New York, N. Y., Society of Automotive Engineers, Inc., 1965, p. 47–52 and 108. 5 refs.

(SAE Paper-650574) Members: $8.00; Nonmembers: $13.00.

Within the category of fail-operational systems is a class of monitorless systems possessing high redundancy efficiency that is considered for application to tactical military aircraft flight control. Output selection techniques, redundancy efficiency, and failure status indication are considered in detail for such a control system; and it is concluded that a passive, monitorless channel output selection technique can be used in triple redundant applications. Such a system permits continued operation along with system simplicity, high reliability, and low cost advantages. High redundancy efficiency can be achieved by increasing the number of output selection points along a control axis without increasing the complexity of a monitorless system. M.W.R.

Review: This paper is largely a discussion without detailed mathematical models. The philosophy is in contrast to that in the previous paper in the same proceedings and yet they both sound good. Either they are talking about different things which is not obvious, or one is incorrect which is still not obvious. Before accepting the conclusions in this paper one would need more detailed mathematical models and probably some physical models to insure that unpleasant considerations are not omitted. An example of possible confusion occurs in the discussion of failure indicators. The argument goes that failure indicators for the pilot are more likely to degrade system operation than they are to help anything. But this presumes implicitly that after each mission the maintenance crew has a way of checking to see if there are any partial failures. If this is not done, obviously the presumed increase in reliability is not available. As is usual (unfortunately) in articles of this type, the assumption of statistical independence of failure events is implicit rather than explicit. The authors do, however, consider that good–bad is an insufficient description for the elements in the system and that the way in which the elements are bad can be important. This is not to say that the author is wrong but merely that the whole story is not told in this paper, as is reasonable, and that before accepting the conclusions as final truth there should be further exploration of the situation.

R67-13513 ASQC 838

HYDROLOGIC REDUNDANT SYSTEMS.

D. Wood (Hydraulic Research and Manufacturing Co., Burbank, Calif.).

In: Proceedings of the Aerospace Vehicle Flight Control Conference, Los Angeles, Calif., Jul. 13–15, 1965. Conference sponsored by Society of Automotive Engineers, Inc., and National Aeronautics and Space Administration. New York, N. Y., Society of Automotive Engineers, Inc., 1965, p. 53–88.

(SAE Paper-650575) Members: $8.00; Nonmembers: $13.00

Redundant systems are considered for overall flight control system requirements along with various approaches for accomplishing control, the hydrologics concept, and typical applications. The hydrologics concept described is considered to exhibit superior features and to be a very flexible self-monitoring redundant system. The operate/fail-safe hydrologic system consists of a servovalve with a dual tandem second stage power spool plus a monitor channel driving a dual tandem actuator; and a comparator that monitors the second stage power spool performance of the two channels. Operating components of the system are described in detail; and typical hydrologic redundant system applications are included. A review of the Concorde supersonic transport redundant system is presented, along with that for a typical heavy logistic transport redundant system. A summary of SST flight control system failure analysis is tabulated. M.W.R.

Review: This is a long paper. It deals with hydraulic systems apparently designed by the author's company and uses trade names to describe the components. The reasoning is essentially asserted to be sound and unique, but differs from the previous two papers in the same proceedings. Words such as optimum reliability, significant improvement in reliability are used but are not defined. The author does show in an unnecessarily complicated way that simple operating redundancy is not a very effective way to improve the MTBF (providing, of course, the MTBF is calculated over the life of the equipment rather than a mission). Much of the paper is taken up with descriptions of various kinds of hydraulic systems. Whether these are actually in use or are in the model stage or just on paper is not made clear. The reliabilities of the comparators and what indicators may exist do not appear to be discussed. Much of the paper seems like a soft sales pitch although the detail may be necessary to acquaint aeronautical design engineers with the products of this company. For one to get much out of the paper he will have to have a fairly good, accessible background in control systems for aircraft. Reliability engineers without this background will be virtually at a loss in reading the paper.

R67-13515 ASQC 831; 844; 874; 884

FINDING THE MTBF OF REPAIRABLE SYSTEMS BY REDUCTION OF THE RELIABILITY BLOCK DIAGRAM.

J. A. Buzacott (Birmingham University, Dept. of Engineering Production, Birmingham, England).

Microelectronics and Reliability, vol. 6, May 1967, p. 105–112. 6 refs.

(A67-30062)

Systems consisting of units with independent failures and with adequate repair facilities to initiate the repair of any unit when it fails are considered. Such systems can be assumed to be made up of independently operating units. The representation by reliability block diagrams of how successful operation of such a system is determined by the successful operation of its constituent units is well known. In the same way that reliability block diagrams can be reduced to find the reliability of a nonmaintained system, the reliability block diagram of a system of independent units can be reduced to find the availability of the repairable system. Using the same reduction procedure, the MTBF of the system can be found in terms of the MTBF and availability of the individual units. The formulas for reducing the different basic connections of blocks are derived. However, the reduction procedure applies only to systems of the series-parallel type; the method of extending it to systems that would be series-parallel if some unit were replaced either by a short circuit or by an open circuit is discussed. Author (IAA)

Review: An easy-to-follow presentation is concisely given of (a) reliability (and availability) block diagrams, (b) system availability equations, and (c) system time between failures equations based on subsystem information. The useful findings of several earlier, theoretical papers (by other authors) are woven together and are expressed in a simplified manner. Assumptions and notation are stated. A most important assumption which the paper is mute on is that the formulae which are given regarding item (c) above are not restricted to the conventional exponential distribution of failure and repair times. Also, the reader who is just skimming the paper should note that time between failures as defined here is the sum of conventional up and down times. The author remarks that this is normal notation; but that is questionable, as MTBF conventionally is ambiguous. This paper would be helpful to those trying to apply the findings of the theoretical papers which are cited. Those who want to see how the formulas which are given in the paper come about will need to go to references 4, 5, and 6 of the paper. In this regard references 5 and 6 will be found in the March or Number 1 issue of the journal which is otherwise adequately identified.

R67-13517 ASQC 833; 770; 844

COMPARATIVE RELIABILITY TESTS ON SILICON-PLANAR-SWITCHING TRANSISTORS OF EUROPEAN AND U.S. MANUFACTURE.

G. Guekos and M. J. O. Strutt (Swiss Federal Institute of Technology, Dept. of Advanced Electrical Engineering, Zurich, Switzerland).

Microelectronics and Reliability, vol. 6, May 1967, p. 143–162. 10 refs.

(A67-30064)

The aging behavior of Si-planar transistors (five different makes) is investigated by means of storage tests during 5000 hr at 170, 90, and −30°C. The variation with time of the current gain (short circuit), the collector-base saturation current, and the collector-base breakdown voltage is measured and discussed. The "creep" of the base current and the effects of temperature drift are discussed. The makes are ranked according to their behavior during the test. Finally the most important conclusions are given. Author (IAA)

Review: Approximately 13 of this paper's 20 journal pages consist of data plots showing the stability of various electrical parameters of silicon planar transistors under storage tests at different temperatures. The problem examined is the same as that previously studied in detail by Young and Mason (Y & M) and reported in the same journal (see R67-13445). As with the Y & M work, large numbers of measurements were made over extended periods of time. The present authors do not attempt to deduce any failure mechanism from their data (this was a major part of the Y & M work) but do contrast the planar silicon results with similar tests performed with germanium transistors. As might be guessed, the planar silicon units performed better—were more stable—on all accounts. Generally their characteristics became even more stable with increasing storage time. Life test data for storage at −30°C are not plentiful in the literature; this paper shows such data to be more interesting than is commonly supposed—the units of several manufacturers fared worse at this temperature in regard to stability of current gain than at 170°C. Significant differences among manufacturers were observed on many tests. This paper is crisply written and well organized. The rankings of the different manufacturers may not be clear without reference to previous cited publications from the same group (two of which were covered by R66-12874 and R66-12875).

R67-13522 ASQC 830; 844

Douglas Aircraft Co., Inc., Santa Monica, Calif.

SOME CONSIDERATIONS IN THE FATIGUE DESIGN OF LAUNCH AND SPACECRAFT STRUCTURES

R. H. Christensen and R. J. Bellinfante Washington, NASA, Jun. 1965. 112 p refs

(Contract NAS7-298)

(NASA-CR-242; N65-25274) CFSTI: HC$3.00/MF$0.65

Five years ago, metal fatigue was considered by many to be an unimportant problem in the design of space vehicle systems. Within this period, potential problems were reviewed periodically as experience in the operation of these vehicles increased. No fatigue design criteria have yet been formally documented for this new class of vehicles. Now, trends in future space system design, in addition to some current experience, dictate that the problem can no longer be neglected. This report is intended to supply background information useful in the design of space vehicle system structures. The report presents a definition of the fatigue problem as it relates to the strength of structure. It briefly reviews present knowledge in designing to prevent the occurrence of this undesirable phenomenon. Current evaluation methods and guides for use in design, test, and analysis are also reviewed. Several appendixes appear at the end of the report. Their purpose is to serve as a checklist for the designer on those aspects of the problem that are often neglected or are not well known. A review of the appendixes will also reveal those areas in which additional research is required. Author

Review: This covers a broad range of fatigue topics pertaining to launch and spacecraft structures. Of particular interest are design guides and testing methods based on fail-safe techniques to assure a safe structure. Much of the information is extrapolated from experimental data and is discussed in terms of conventional cumulative damage concepts, environmental effects on crack growth, effect of biaxial loading, and failure-safe design. This paper touches on nearly every standard procedure and analysis used in anti-fatigue design. The type of loads experienced in launch and methods for simulating these loads are discussed in an excellent fashion. The paper is well documented but suffers somewhat from a lack of continuity. This lack of continuity stems from covering so many aspects of the fatigue problem in a paper this short. Most readers will not be familiar with all the subjects covered, but they can get an appreciation for the necessity of designing to avoid fatigue failures in spacecraft and the difficulties of so doing.

R67-13523 ASQC 830; 844
Naval Research Lab., Washington, D. C.
REVIEW OF CONCEPTS AND STATUS OF PROCEDURES FOR FRACTURE-SAFE DESIGN OF COMPLEX WELDED STRUCTURES INVOLVING METALS OF LOW TO ULTRA-HIGH STRENGTH LEVELS
W. S. Pellini, R. J. Goode, P. P. Puzak, E. A. Lange, and R. W. Huber Jun. 1965 89 p refs
(NRL-6300; AD-619574; N66-13876) CFSTI: HC $3.00/MF $0.65

The report presents integrated analyses and substantiating data on problems of metallurgical optimization and solutions to fracture-safe design and fabrication of large welded structures, utilizing high strength metals. The apparent complexities of attaining practical engineering use of high strength metals derive primarily from lack of appreciation of the close interrelationships that exist between the intrinsic susceptibilities of these metals to various failure modes and the intrinsic structural mechanics features of the structures. Metals of high intrinsic resistance to failure may be matched to structures of high intrinsic design complexity and ordinary fabrication techniques with assurance of structural safety. Metals of low intrinsic resistance to failure must be matched only to structures that are exactly stress analyzable and thereby are restricted to designs of the utmost attainable simplicity, and to fabrication by techniques of utmost attainable simplicity, and to fabrication by techniques of utmost precision. TAB

Review: This 84-page report presents test methods and procedures for optimizing the use of high- and low-strength steels in welded structures. The crack arrest temperature range and the fracture propagation energy are used to establish an index for the resistance to fracture under various environments and structural conditions. A considerable portion of this paper discusses the development and validity of a new Drop Weight Tear Test for such investigations. This test uses a brittle-weld crack as the flaw for initiating failure under impact. The authors hope that materials can be indexed so that those with high resistance to failure can be selected for use in stress-indeterminate structures while those with low resistance to fracture can be used in a structure which is simpler and easier to design and analyze. In a latter section of the report a relationship is given for crack growth rate in low cycle fatigue tests. The evaluation of the strength concept is important because inadequate attention to its exact nature can lead to gross unreliability. (This paper is difficult to assimilate, not only because it has extensive technical content, but because it tends to wordiness and overly long sentences.)

R67-13536 ASQC 837; 844
Philco Corp., Palo Alto, Calif.
WORST-CASE CIRCUIT ANALYSIS: NON-COMPUTERIZED
William W. De Ville Nov. 1965 10 p Presented at the ASQC 1965 Aircraft and Missile Div. Conf., Cocoa Beach, Fla., 8–10 Nov. 1965
(N67-85855)

Some reliability-based worst-case analyses performed during circuit development are described, including the non-computerized analyses of a 180 Mc power amplifier and a 20 Mc class C amplifier. Circuit degradation analysis is mentioned, as is the analysis of a line-filter solid tantalum capacitor used in a spacecraft dc/dc converter. The examples presented indicated savings in design turnaround time and provided a quick accept–reject criterion for circuit suitability by manual methods. M.W.R.

Review: An example of circuit reliability analysis using an actual application is given. This paper illustrates nicely the analysis tasks called for in typical reliability specifications—stress, degradation, failure modes, and prediction. Whereas the typical reliability specification will call for these as separate analysis tasks, this application shows that they are intertwined. There is really nothing new here; rather, this is a description of a real-world application, which is always worthwhile material for a paper.

R67-13538 ASQC 838
Rome Air Development Center, Griffiss AFB, N. Y. Reliability Branch.
REDUNDANCY CONSIDERATIONS FOR COMMUNICATION RELIABILITY
Julius Widrewitz May 1965 22 p ref
(EME-TM-65-2; N67-85857)

Some conditions under which the use of redundancy techniques lead to a reduction in the reliability of a communication system are indicated. A simple model is presented, and redundancy and error correction are discussed. It is shown that the use of redundancy in the form of error-correcting codes can degrade system performance, and that a tradeoff can be established between the relative decreases in communication unreliability and information transmission rate by using an error-correcting code. It is concluded that the desirability for and extent of redundancy in any particular case may depend upon stated minimum values for reliability and information transmission rates, and that redundancy techniques other than error-correcting codes may be required to supply satisfactory performance levels. M.W.R.

Review: In this mildly interesting short report the author investigates the use of error-correcting codes (specifically, Hamming codes), and analyzes their degrading effects on transmissions containing more errors than the code is designed to correct. Table I, which describes the generation of redundancy bits (check bits), is very useful. The effect of the error-correcting code as a "corrector" of errors is shown in expressions 9 and 10. A curve would have presented this in a far better fashion. The author's admission that trade-offs involving reliability are partly intuitive (or, at any rate, non-mathematical) does not detract from the paper but gives data which will help to make trade-off decisions. There is no bibliography. A reference to Hamming's paper, however, occurs in a footnote on page 3. The paper does not make any profound contributions to the state of the art, but does provide an interesting, well-illustrated observation.

R67-13539 ASQC 831; 824
General Electric Co., Philadelphia, Pa. Re-Entry Systems Dept.
SYSTEMS ESTIMATION FROM VARIABLES PERFORMANCE PARAMETERS
S. Demskey 30 Nov. 1966 48 p refs
(Doc.-66SD342; N67-35168)

This report describes VAEP (for Variables/Attributes/Error Propagation) which should provide satisfactory system estimates from variables data until an exact multivariate tolerance formula is developed. Although reduced sample size is the benefit most easily recognized, there are others of importance and interest. Although the entire gamut of statistical method is used, the combining of statistical tolerance limits and error propagation is the unique ingredient in VAEP. Author

Review: This paper was provided as a corrected version of the one reviewed in R67-12943. There remain several errors in the revised version; the notation is awkward and difficult to follow, and some of the concepts are still not clearly explained. In particular, terms are omitted from summations and the index of summation seldom appears in the formulas, as for example, in the equations on the top of page 22. The discussion in C.3 on page 24 concerning the effect of dependence on the estimation of the system variance is still poorly done although some of the previous errors have been eliminated. On page 25 the author could have written $C_s^2 = \Sigma C_i^2 + 2\sum\sum_{i<j} C_iC_j \approx (\Sigma C_i)^2$, and hence the effect of complete dependence (worst case) yields $C_s^2 = (\Sigma C_i)^2$ as compared to the case of independence which yields $C_s^2 = \Sigma C_i^2$. Clearly the former can be much greater than the latter for reasonable *values of the coefficients of variation.* In conclusion, considerable work remains to be done in order to provide a well-written document which describes the concepts so that workers in the field may evaluate them.

84 METHODS OF RELIABILITY ANALYSIS

R67-13501 ASQC 844
Army Electronics Labs., Fort Monmouth, N. J.
FACTORS AFFECTING TRANSISTOR FAILURE IN DC TO DC CONVERTERS
Bernard Reich Jul. 1965 14 p ref
(ECOM-2620; AD-623359; N66-14474) CFSTI: HC $3.00/MF $0.65

The purpose of this report is to indicate assignable causes of failure of transistors in dc to dc converters. While seemingly power transistor converter failures occur with no apparent cause after many cycles of operation, an examination of the load characteristics can reveal a potential failure pattern. The load line characteristic coupled with the safe area limits of the transistor has revealed potential failure patterns in converters described in this report. This analysis has lead to a much better understanding of transistor failures observed with the types of converters analyzed. Author (TAB)

Review: This paper uses conventional engineering analysis in more depth than usual to uncover the reason for circuit failure. Instead of using a very simple-minded model for the circuit and analyzing it, the actual voltage-current curves have been measured for the circuit in operation. These are not the ones that would have been expected and they show that operation can easily occur in forbidden areas. This is the kind of attention to detail that is necessary for high-reliability operation, and one of the reasons why computer-analysis of circuits is not the be-all and end-all of circuit design. In most cases the circuit model that the computer analyzes will be of the simple-minded variety and occasionally that is not enough. A cryptic portion of the paper says, "Most data generated on semiconductor devices can be related to wear-out mechanisms..." whereas virtually all of the literature asserts that *wear-out mechanisms are practically nonexistent in semiconductor* devices. This point is irrelevant to the thesis of the article and is not pursued further, but remains an interesting anomaly. (Perhaps the meaning of "wear-out" is not clear.)

R67-13505 ASQC 844; 775
INFRARED TECHNIQUES FOR THE RELIABILITY ENHANCEMENT OF MICROELECTRONICS.
Leon Hamiter (NASA, Marshall Space Flight Center, Parts and Components Reliability Engineering Branch, Huntsville, Ala.).
Semiconductor Products and Solid State Technology, vol. 10, Mar. 1967. p 41–49, 62.
(A67-22977)

Outline of conventional means for the evaluation of design and production of microelectronics with comment on the need for a new tool which is capable of investigating areas beyond the reach of conventional test equipment. The IR evaluation concept is discussed, and its capability of fulfilling the above stated requirements is described. The IR microscopes used for microelectronics evaluation are evaluated, and the results of their operation are illustrated. Capabilities which are unique to the IR *techniques are described,* such as detection of defects in the bond between semiconductor chip and heat sink and the ability to locate exactly the second breakdown point without having the transistor reach the thermal runoff condition. IAA

Review: The gist of this paper is that the capability of equipment for infrared scanning of operating microcircuits is improving. The resolution and speed of operation of the Fast-Scan Infrared Microscope described here appears adequate to make production screening by this technique possible. The paper gives a brief discussion of the principles of infrared microscopy and describes in general terms the Philco thermal plotter and the Barnes thermomicrograph, two commercial-available infrared microscopes. The Fast-Scan Infrared Microscope, developed by Raytheon under NASA sponsorship offers scanning, greater speed and resolution than commercial units. The tone of the paper is generally that of the "popular" press, aimed at the interested non-expert. A particularly interesting correlation between chip-to-header bond quality and infrared trace is shown in Fig. 19, suggesting that infrared traces are an effective screen for ferreting out poor chip-to-header bonds.

R67-13506 ASQC 844
HOW TO RUIN SCRs.
Keith Sueker (Westinghouse Electric Corp., Semiconductor Div., Youngwood, Pa.).
EEE, Aug. 1965, p. 45–48.

Failure modes and mechanisms in SCRs are reviewed in terms of difficulties that might be encountered by both amateurs and professionals. Conduction characteristics are illustrated for the SCR, a three-terminal four-layer semiconductor with controllable turn-on for one polarity of applied voltage. A two-transistor analogy is used to explain its operation. Emphasis on all phases of circuit operation is required to insure high reliability of SCRs, and attention is to such aspects as anode-lead bending that can cause leakage, weak gate drives, poor heat sinking due to incorrect mounting, and thermal contact. M.W.R.

Review: This paper on failure modes and mechanisms for SCRs is written to be easy to read and serves to show that detailed consideration of all phases of the circuit operation are necessary to insure high reliability. Everything from poor thermal contact to rate of rise of gate current is considered. Enough reasoning is given about the faults and correct procedures so that the average design engineer can learn an appreciable amount from the article. Its easy style encourages him to read on. The lack of attention to some of these subtle details is perhaps the reason for the former very poor reputation of the SCR in high-reliability applications.

R67-13518 ASQC 844; 775

Southwest Research Inst., San Antonio, Tex. Dept. of Electronics and Electrical Engineering.

NONDESTRUCTIVE EVALUATION OF METAL FATIGUE

Final Report

Felix N. Kusenberger, Byron E. Leonard, John R. Barton, and W. Lyle Donaldson Mar. 1965 94 p refs
(Contract AF 49(638)-1352)
(AFOSR-65-0981; AD-619685; N65-33449)

Factors which influenced the selection of focused ultrasonic Rayleigh wave techniques for use in the nondestructive evaluation of metal fatigue are included. Methods investigated for generating and focusing Rayleigh waves are presented. The selection of specimen materials and designs are presented, including engineering drawings of the steel and aluminum fatigue specimens. Experimental results obtained from small drilled holes in a number of specimen materials and geometries using surface wave techniques (plane wave) are shown including a number of Polaroid photographs of the reflection signal patterns. Ultrasonic plane wave and magnetic inspection results on steel fatigue specimen No. 18 containing a tiny fatigue crack are given. Many inspection records and surface photographs are also shown. Reproductions of Polaroid photographs of ultrasonic signal patterns obtained while stress cycling an aluminum specimen are shown. Inspection records showing a large increase in signal amplitude corresponding with the development of fatigue damage in the form of a crack are included. X-ray diffraction measurements, using a 0.004-inch diameter collimator, were made in the vicinity of the tip of a small fatigue crack, and the results of these measurements are reported. Author

Review: Metal fatigue is one of the most important failure modes in structures; thus this paper has direct application to improvement of reliability. Very few papers are as well written, organized and documented as this one. The paper deals primarily with non-destructive tests to determine the location of fatigue cracks by using generated Rayleigh waves (ultrasonic technique); some attention is given to the use of magnetic probe and X-ray diffraction techniques. The theory developed to describe the generation and propagation of Rayleigh waves for locating cracks is excellent. Specimen preparation, equipment design, and crack location techniques are discussed in a lucid manner. The paper is aimed at methods to spot fatigue cracks in structures for the purpose of providing some warning-time before failure. The time from actually spotting cracks until failure occurs is obviously highly desirable information, particularly in aircraft design. There is little to indicate, however, that any of the techniques would be useful in the field; it appears necessary that they be used primarily in connection with simulated structures and loads. The results from such tests could possibly be extrapolated to actual field conditions. The paper makes an important contribution to the state of the art, but additional work is still needed. (R65-12148 covered an earlier report on the magnetic probe which is Ref. 10 of this paper.) In a private communication the first author has stated that ultrasonic surface waves are in the prototype stage for field use and that magnetic methods are now in field use.

R67-13519 ASQC 844

Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

METHOD OF ESTIMATION OF FATIGUE STRENGTH WHEN THE PROCESS OF REPEATED LOADING IS DIVIDED INTO TWO STAGES

R. D. Vagapov *In its* Plant Lab. 28 Sep. 1965 15 p refs
(See N66-15301 06-34) CFSTI: HC$3.00/MF$0.65
(N66-15304)

It is proven that for obtaining complete information on strength of materials under fatigue overload a system of combined statistical and functional analyses is required of experimental laws of fatigue when the process of repeated loading is divided into the stage of accumulation of microcracks ending with the formation of a surface crack and the stage of fatigue separation of the body by a large crack. Author

Review: Considerable clarity is lost in the translation of this article from Russian. In many cases the symbols used are not defined and the reader must make his own interpretation. The article deals with fatigue crack initiation, its propagation to failure, and how these processes are related in the fatigue history of a failed specimen. Type of testing, loading, shape of specimen, and stress concentrations must all be given consideration in estimating fatigue strength when using methods to estimate duration of life separately in the crack initiation and propagation stages. The degree of damage during each progressive cycle is shown to depend on previous load cycles. This accounts for the fact that an equation based on constant damage per cycle cannot, in most cases, predict failure with any degree of accuracy. This paper will not be understood without rereading several times or by anyone who is not engaged in fatigue research. The topic, of course, is essential to the design for high reliability of mechanical structures.

R67-13520 ASQC 844; 775

National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

APPLICATION OF ULTRASONICS TO DETECTION OF FATIGUE CRACKS

Stanley J. Klima, Daniel J. Lesco, and John C. Freche Washington, NASA, 1965 31 p refs Presented at the 2d Intern. Congr. on Exptl. Mech., Washington, D. C., 28–30 Sep. 1965; Sponsored by Soc. for Exptl. Stress Analysis
(NASA-TM-X-52109; N66-18328) CFSTI: HC$3.00/MF$0.65

An ultrasonic system was developed and used to observe the formation of fatigue cracks in center notched sheet specimens of unalloyed aluminum, two aluminum alloys, a mild steel, and a nickel-base alloy tested in axial tensile fatigue. S–N curves of life-to-initial detectable cracks as well as life-to-fracture were obtained. With the reflection technique, fatigue cracks that ranged in length from 0.0005 to 0.005 inch were detected while the test was in progress. Cracks were detected within approximately one to three percent of total specimen life for all of the materials considered over the range of stresses considered. The through-transmission technique was utilized to measure relatively long cracks. Author

Review: This is a slightly shortened version of NASA TN D-3007 by the same authors. Reference should be made to the latter because it is more complete and the available copy is easier to read.

R67-13521 ASQC 844; 775

National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

ULTRASONIC TECHNIQUE FOR DETECTION AND MEASUREMENT OF FATIGUE CRACKS

Stanley J. Klima, Daniel J. Lesco, and John C. Freche Washington, NASA, Sep. 1965 24 p refs
(NASA-TN-D-3007; N65-32647) CFSTI: HC$3.00/MF$0.65

An ultrasonic system was developed and used to observe the formation of fatigue cracks in center-notched sheet specimens of unalloyed aluminum, two aluminum alloys, a mild steel (approx. 0.035 percent carbon), and a nickel-base alloy. The reflection technique was used to detect minute fatigue cracks. The through-transmission technique was used to a limited extent to measure relatively long cracks. Actual lengths of detected cracks were determined by microscopic examination. Stress-life (S–N) curves of life to initial detectable cracks as well as S–N curves of life to fracture were obtained. In the sharply notched specimens utilized in this investigation, cracks were detected within approximately 1 to 3 percent of total specimen life for all the materials over the range of stresses considered. It was possible to detect smaller cracks with the reflection technique than with the through-transmission technique. The effects of crack orientation on instrument output with the reflection technique was studied by means of slots machined into flat plates. Slot surfaces normal to the direction of the ultrasonic waves produced the greatest voltage output. Author

Review: This paper deals adequately with the principles and applicability of ultrasonic crack detection, both the reflection and through-transmission techniques. An excellent treatment is given of the type of equipment and how it was used in detecting fatigue cracks in the experiments performed. This tool is apparently not yet ready for use in the detection of cracks in aircraft in field use. There are good reasons to believe, however, that such equipment would be of considerable value for crack initiation and propagation studies in controlled laboratory tests. The method is particularly suited for nondestructive testing and can be used on materials regardless of their electrical or magnetic properties. The paper is short for the extent of information and detail that is given and will be of particular interest to people engaged in fatigue research. Cracks observed using the equipment described were generally less than 0.001 inch long.

R67-13525 ASQC 844
Joint Publications Research Service, Washington, D. C.

FATIGUE AND BRITTLE FRACTURE OF WELD JOINTS

V. I. Trufyakov 8 Nov. 1965 13 p refs Translated into ENGLISH from the book "Voprosy Mekhanicheskoy Ustalosti" (Moscow), 1964 p 46–56
(JPRS-32768; TT-65-33346; N66-11186) CFSTI: $3.00

Tests were made to determine what caused the transition of fatigue fractures into brittle fractures, as well as the size at which the fatigue fracture becomes the seat of a brittle fracture in the case of welded joints. Nominal breaking stresses are shown as a function of (1) testing conditions and type of fatigue failure and (2) fatigue failure depth. Samples tested without impulsive loading have not exhibited a noticeable decrease in strength, even though they were ruptured along the cross sections which included the fatigue fractures. Samples simulating joined specimens were tested, as were butt joints formed from steel and welded channel iron specimens. Under low pressures and below the metal yield point, fractures in welded joints will not be of the brittle type unless an impulsive load is applied. Fatigue fracture is considered critical when it reaches a depth of approximately 4 mm. M.W.R.

Review: This is a translation from a Russian-language book. The translation itself appears to be rather good, but there are several incorrect words and/or unusual word orders. The paper is short and of current practical engineering interest. The design engineer, in particular, will be interested in the author's conclusion that a minute impulsive load (tapping the specimen lightly with a hammer) will transform a fatigue fracture into a brittle fracture at a nominally low applied stress. The paper is editorially sound. The data are clearly presented in graphical and tabular form. The conclusions appear reasonable, but more substantiating data are needed. The specimen numbering system tends to indicate that there may have been more data than those which are reported. The author says that a statistical experiment was carried out; but there are only brief references as to the type of experiment, the scatter in the data, etc.

R67-13527 ASQC 844
Canada. Dept. of Mines and Tech. Surveys, Ottawa. Ferrous Metals Section.

THE STATUS OF THE HYDROGEN PROBLEM IN STEEL

R. D. Mc Donald Jul. 1965 21 p refs
(TB-72; N66-17165) Available from Queen's Printer, Ottawa: $0.50

Hydrogen problems in steel are described, with particular emphasis on the problem of embrittlement of ultra-high strength steels as manifested by delayed failure. Ways are described in which hydrogen enters steel and is recognized by tests. Theories that have been developed over the years of research are related and explained briefly in order of sequence up to the most recent proposals advanced. These theories serve to explain many of the observations concerning hydrogen. Alleviation of embrittlement still depends heavily upon diffusion treatments at baking temperatures, although many ways of preventing entry of hydrogen are being tried with moderate success. Author

Review: This is a review, narrative in form, of the general problem of hydrogen embrittlement in steel. This problem is a failure mechanism of current practical interest to the design or process engineer. The paper is useful as a first reference or a guide to gain initial insight into the hydrogen problem. Since it is a review, most of the material is treated in greater detail elsewhere, but the author does a good job of tying the work together. (The title of the paper is not very descriptive.)

R67-13528 ASQC 844
Martin Co., Baltimore, Md. Research Inst. for Advanced Studies.

ON THE MECHANISM(S) OF STRESS-CORROSION CRACKING Technical Report No. 65-7

E. N. Pugh Aug. 1965 66 p refs Repr. from *Environment-Sensitive Mech. Behavior,* 1966 p 351–401
(Contract DA-31-124-ARO(D)-258)
(AROD-5023-1; AD-620513; N65-36246)

A review has been made of some of the major theories of stress-corrosion cracking, with particular reference to the long-standing question of whether a single, generalized mechanism exists. It is concluded, largely on the basis of recent studies of α-brass and of aged aluminum alloys, that several different mechanisms are in fact operative in different systems, so that stress-corrosion cracking must be regarded as a generic term. Consideration is given to areas which require further study. Author

Review: This is a review of the mechanism of stress-corrosion cracking which is one of the important failure mechanisms in aerospace vehicles. The author does not consider liquid metal embrittlement or hydrogen embrittlement as stress-corrosion failures; therefore, they are not included. The material is of interest to both the researcher and the designer. The paper is written in a clear, concise, authoritative manner. Although it is long, there does not appear to be any easy way to shorten it without destroying its usefulness. The narrative of the paper is properly documented with references and appropriate graphical and tabular data. The quality of the micrographs in the DDC copy of the document is poor, but this seems to be the fault of the printing or reproduction process. In general, the paper is sound; the conclusions are reasonable and properly substantiated; consequently, it is recommended as a reference.

R67-13529 ASQC 844
Curtiss-Wright Corp., Caldwell, N. J.

AN APPROACH TO METAL FATIGUE

F. B. Stulen, J. H. Redfern, and W. C. Schulte Washington, NASA, Jun. 1965 86 p refs
(Contract NAS1-3170)
(NASA-CR-246; N65-25275) CFSTI: HC $3.00/MF $0.65

Factors that are of primary importance in the fatigue of metals were investigated. The material used was titanium 8 Al–1 Mo–1 V alloy sheet in the Triplex-Annealed condition. Three phases were examined: (1) the fatigue limit associated with a crack; (2) the rate of crack propagation; and (3) the stress interaction effect, or the delay-cycle effect. Each of these effects is described by one or more proposed formulas, and the parameters associated with each were obtained by standard statistical methods. The rms-error between the test data and the corresponding computed values was employed as a measure of the goodness-of-fit of the proposed formulas. Reasonably good fits were obtained between the test data and some of the proposed relations. A cumulative fatigue damage relation was developed based on these findings. Author

Review: Extensive experimental fatigue test data are reported for Ti–8Al–1Mo–1V alloy. The data, which are of current engineering interest, were analyzed statistically and by "eye estimate" and are presented in both tabular and graphical forms. The authors consolidate and integrate their work with other referenced studies in order to present a semiempirical approach to the fatigue problem. The conclusions are reasonable but are based on tests from one alloy only. In general, the paper is interesting and easy to read. The title is not descriptive; and the use of load-controlled, rather than strain-controlled, tests is questioned. The thoroughness of the investigators in their experimental procedures (machine calibration and alignment, test fixture design, analysis techniques, etc.) and their attention to detail lend an overall air of authority to the paper and credit the investigators as excellent experimentalists.

R67-13530 ASQC 844; 830

National Aeronautics and Space Administration. Langley Research Center, Langley Station, Va.

A REVIEW OF CUMULATIVE DAMAGE FOR FATIGUE COMMITTEE OF THE STRUCTURES AND MATERIALS PANEL, ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT

Herbert F. Hardrath [1965] 17 p refs Presented at the AGARD, Munich, 14 Jun. 1965

(NASA-TM-X-56749; N65-33918) CFSTI: HC$3.00/MF$0.65

The analysis of any practical fatigue problem almost invariably involves some consideration of the progressive accumulation of damage due to loads that vary in amplitude. It is the purpose of this paper to review the current state of the art of such analysis and to make recommendations for future action. Advance copies of the review were submitted to other members of the Fatigue Committee and their associates for comment. The writer gratefully acknowledges their contributions and several of these have been included in the present version of the report. Author

Review: The paper is a brief tutorial review of the state of the art for handling accumulation of damage under cyclic loading conditions. It is easy to read and understand. As becomes a tutorial paper, it contains no new information and is well referenced. Design engineers may find the discussion of problem areas useful. Groups or individuals working in the general area of cumulative damage will profit by studying the recommendations which are included.

R67-13531 ASQC 844

National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

INTERFACES BETWEEN FATIGUE, CREEP, AND FRACTURE

S. S. Manson Washington, NASA, 1966 84 p refs Presented at the Intern. Conf. on Fracture, Sendai, 14 Sep. 1965

(NASA-TM-X-52189; N66-18427) CFSTI: HC$3.00/MF$0.65

Three concepts are examined: an interface between fatigue and fracture in relation to the fatigue problem of quasi-brittle materials; the correlation of creep and fatigue by considering fatigue in the creep range at elevated temperatures; and cumulative fatigue damage. As cumulative damage is considered to be a process of initiating and propagating a crack, it is introduced as a second interface between fatigue and fracture. The value of separating the fatigue process into one of crack initiation and propagation was pointed out in discussing each concept, with the difficulty identified as defining the meaning of a crack and assigning quantitative formulas to use in computations involving these phases. An approach is also suggested in which instantaneous crack growth can be expressed in terms of microscopic local strain range, rather than expressing crack propagation as a closed form solution applicable only to specific cases. Also discussed is a method of universal slopes for predicting cyclic hardening or softening characteristics; an illustrative example for calculating notched quasi-brittle specimens is included. M.G.J.

Review: The subject matter presented in this lecture/paper constitutes a definite contribution to the concepts important to the disciplines of: fatigue and fracture; creep and fatigue, and cumulative fatigue damage (all of which are important in aerospace vehicles). The manuscript contains new views and thoughts which have not thoroughly matured concerning these old but important problem areas. The material, although somewhat speculative in nature, is of significant and sufficient value for detailed study by researchers and engineers; consequently, it is a recommended reference. The paper is lengthy; but, because of its scope, it would be difficult to shorten it without detracting from its importance. It could perhaps be divided into three papers—one for each major discipline—but this might also detract from its overall value. In general, the paper is editorially excellent, and it reflects the author's position as an authority in the field.

R67-13533 ASQC 844; 775

APPLICATION OF NOISE MEASUREMENTS TO THE RELIABILITY ANALYSIS OF SEMICONDUCTOR DEVICES.

A. P. Stansbury and R. A. Struble (Quan-Tech Laboratories, Inc., Whippany, N. J.).

Semiconductor Products and Solid State Technology, vol. 8, Nov. 1965, p. 32–35.

(A66-13217)

A method for turning the noise characteristics of semiconductor devices to advantage by utilizing noise measurements for reliability analysis is discussed. The various types of noise are classified and described, both quantitatively and qualitatively. The effect of transistor irregularities on noise is discussed. An analysis of diode noise is presented for three modes of operation, namely, forward-conducting, reverse-biased below breakdown, and reverse-biased in the breakdown region. Author (IAA)

Review: This account is an introductory presentation of the potential foreseen for noise measurements in device reliability assessment and non-destructive testing. It is an optimistic statement and does not foresee some of the more recent and less sanguine evaluations of the role of noise measurements in reliability (see R67-13423). The paper is very readable and easy to follow but is dated (planar diodes and transistors, for example, are not mentioned). More thorough and up-to-date discussions now exist (see R67-13204, R67-13423, and R67-13426), so there is little reason to refer to this paper any more. The paper lists no references or bibliography.

R67-13534 ASQC 844; 838

BRITTLE MATERIALS.

Ernest Robinson (California University, Lawrence Radiation Laboratory, Mechanical Engineering Dept., Propulsion Div., Livermore, Calif.).

Machine Design, vol. 37, Sep. 2, 1965, p. 118–122. AEC-Supported research.

(A65-35192)

Study of intentional cracking of structural components to increase strength and efficiency. The fracture behavior of some brittle and nonbrittle materials is considered, as are certain aspects of redundant support. The advantages of precracking brittle structures are pointed out, a method of controlling crack patterns is given, and the advantage of using concave surfaces on brittle components is explained. IAA

Review: This is an informative and somewhat philosophical communication rather than a technical paper. The title is far too general. The author suggests ways of using the high compressive strengths of brittle materials, in areas of possible catastrophic failure, through the use of redundant support. Such support is obtained by geometrical design which results in bridging and arching. He justifies his suggestions by presenting data from redundantly-supported test specimens which were obtained by precracking and end-constrained tests. This article is interesting and easy to read, and the suggestions or recommendations appear to be well founded. Design engineers, particularly ceramic design engineers, who are concerned with catastrophic failure will find these results useful.

R67-13537 ASQC 844
Stanford Univ., Calif.

PRESTRESSING AND FATIGUE

Henry O. Fuchs Oct. 1965 10 p refs Presented at Natl. Metal Congr. of Am. Soc. for Metals, Detroit, 21 Oct. 1965
(N67-85856)

An explanation of the very strong effect of shot peening on notched parts is reviewed, and test data are presented which confirm the proposed approximate failure theory that accounts for these compressive residual stresses on notched parts. Understanding fatigue of notched parts is considered in terms of the need for a practical failure theory. Transverse cracks in parts under compressive loads are discussed, as are the permanence of self-stress and optimum prestressing as a means of fighting metal fatigue. M.W.R.

Review: The reader will have to be well acquainted with the subject of fatigue in order to decipher the contents of this paper. The subject matter has not been presented and discussed in a manner that is easy to follow. Much is left for the reader to reconstruct, particularly with respect to the diagrams used and their discussion. Basically, the paper attempts to explain why prestressing by shot peening and similar methods is more effective on notched than on smooth parts. This empirical fact has been known for some time and now, apparently, a method has been found which can be used to take it into account in design work. This method also predicts that fatigue cracks will not propagate without the presence of critical alternating tensile stresses; and this has been verified experimentally. Additional work is needed on yielding in a notch and on the ratio of core strength to surface strength in various materials.

R67-13540 ASQC 844
General Electric Co., Syracuse, N.Y. Electronics Lab.

PROGRESSIVE FAILURE MECHANISMS OF A COMMERCIAL SILICON DIODE

J. F. Schenck *In* RADC Phys. of Failure in Electron., Vol. 5 Jun. 1967 p 18–35 refs (See N67-38461 23-09)
(Contract AF 30(602)-3624)
(N67-38463)

Two forms of progressive degradation of a commercial silicon signal diode are noted as a function of various stress and measurement variables. One mode results from reverse bias at high temperature, and the second is caused by prolonged stressing with high forward current. For both modes the rate of degradation can be greatly increased by raising the ambient temperature. The reverse current characteristic is the principal degrading parameter for both modes. Models are presented to relate the stress-induced increases in I_R to physical and chemical changes taking place in the diode. The reverse bias degradation mode is explained by a model based on the drift of impurity ions in the silicon oxide and the resultant inversion of the epitaxial n layer. The actual source of the reverse current is space charge generation in the stress-induced inversion layer. Author

Review: The models invoked here to explain the surface-controlled degradation of silicon p^+–n planar junctions are those previously discussed by Garrett and Brattain [1] and Atalla, et. al [2]. Three related facts make these data of particular interest: (1) the induced inversion layer is n-type rather than the usual p-type; (2) the influence of gold doping upon surface degradation is made apparent; (3) the excess reverse current present after forward bias stressing exhibits a large distinctive noise component. On p. 25 the statement is made that in the gold-doped diodes, bulk generation swamps any surface generation. The bulk generation referred to is that associated with the induced p-type surface channel rather than that of the diffused p^+-region. One could misinterpret the statement to mean that the gold greatly increases the generation current of the diffused junction. This conclusion would conflict with the model of diode degradation due to surface effects which is the theme of the paper. It is easy to infer that a failure program of significant magnitude is underway at GE; the output of these investigations certainly merits attention.

References: [1] C. G. B. Garrett and W. H. Brattain, "Some Experiments on and a Theory of, Surface Breakdown" J. Appl. Phys. 27, March 1956, pp. 299–306 [2] M. M. Atalla, E. Tannenbaum and E. J. Scheibner, "Stabilization of Silicon Surfaces by Thermally Grown Oxides" Bell System Tech. J. 38, May 1959, pp. 749–784

R67-13541 ASQC 844
Westinghouse Electric Corp., Baltimore, Md. Aerospace Div.

A PLAGUE-FREE ALUMINUM–GOLD SYSTEM ON SILICON INTEGRATED CIRCUITS

M. A. Schuster and W. J. Lytle *In* RADC Phys. of Failure in Electron., Vol. 5 Jun. 1967 p 506–518 (See N67-38461 23-09)
(Contract NAS8-5112)
(N67-38487)

A stable and reliable aluminum–gold system for interconnections, contact pads, and bonded lead wires for silicon integrated circuits is discussed. The system is completely consistent with the fabrication technology, packaging, storage, and operational requirements of standard integrated circuits. It is based on an isolation of the aluminum interconnection metal from the gold contact metal by the bulk substrate material. The interconnections are vapor deposited aluminum, contact pads are gold vapor deposited on a chromium wetting agent, and the bonded lead wires are gold. The interconnections are separated from the contact pads by a barrier domain of bulk silicon substrate material which has been degenerately doped. The system is not subject to degradation due to the intermetallic formation which is common in conventional aluminum–gold systems. Author

Review: The scheme described in this paper for avoiding the formation of undesirable intermetallic compounds between aluminum pads and gold wires which are bonded to the pads is simple and clever. The gold and aluminum are separated laterally on the device surface by a region of highly-doped silicon. The gold wire is bonded to a gold–chromium pad at one corner of the heavily-doped silicon "tunnel"; at the other end of the tunnel the aluminum intraconnection to the other elements of the circuit begins. The silicon tunnel is a series link in the interconnection path; its sole function is to physically separate the gold and aluminum portions of the interconnecting path. This scheme is shown to be more resistant to high-temperature aging effects than the conventional gold ball to aluminum pad bond. There is a price: (a) four added steps in fabrication, (b) an increase of 1.25 ohms in the resistance of each lead connection, (c) the area added to the circuit and the increased failure probability (each silicon tunnel adds junction area comparable to that of a transistor and must be satisfactorily isolated from the other elements of the circuit). In general this price is too high; it appears unlikely that this scheme will win many supporters, although in certain applications or for certain facilities such an approach may be the easiest and best solution. Less costly solutions, such as aluminum wires to aluminum pads or gold wires to gold–molybdenum pads, exist and will continue to be preferred. Some interesting photomicrographs of cross sections of gold wires and ball bonds vividly illustrate the mass transport phenomena and the consequent problems that arise at high temperature.

R67-13542 ASQC 844
Bell Telephone Labs., Inc., Reading, Pa.

PREVENTION OF STRESS-CORROSION FAILURE IN IRON–NICKEL–COBALT ALLOY SEMICONDUCTOR DEVICE LEADS

M. J. Elkind and H. E. Hughes *In* RADC Phys. of Failure in Electron., Vol. 5 Jun. 1967 p 477–495 refs (See N67-38461 23-09)
(N67-38485)

The susceptibility to stress corrosion cracking of the iron–nickel–cobalt alloy, commonly used for semiconductor device leads, is discussed. The work reported confirms that stress corrosion cracking of this alloy can occur very rapidly in the presence of a combination of condensed atmospheric moisture and stress. Detection of this phenomenon by accelerated tests is the basis for evaluating and introducing corrective measures to surmount this failure mechanism. Factors intensifying the alloy's susceptibility to stress corrosion when used as semiconductor encapsulation leads have been identified. Author

Review: The subject of this paper is one on which little information exists at present. Component failure due to stress-corrosion of package leads has generally been ignored in the past. The authors show that such neglect is generally justifiable, although in equipment demanding long-term reliability this conclusion is not valid. For long-term reliability ($\approx$20 years) the authors recommend a specific method of lead preparation and protection which they demonstrate to produce leads significantly more resistant to stress-corrosion failure than leads formed by the standard method. Although field experience is not available to confirm the improved resistance observed in laboratory tests, the latter results strongly suggest that the authors have made an excellent start on solving the long-term stress-corrosion problem. The authors' write-up of their work is clear; the content makes a valuable contribution to component failure physics in identifying a little-recognized failure mode and developing an effective preventive action. The details of stress-corrosion illustrated in the photomicrographs of Figs. 1 and 2 are not sharp; the caption of Fig. 10 is poorly punctuated and unclear.

R67-13543 ASQC 844
Fairchild Semiconductor Corp., Palo Alto, Calif. Research and Development Labs.

THE FAILURE OF THIN ALUMINUM CURRENT-CARRYING STRIPS OF OXIDIZED SILICON

Ilan A. Blech and Harry Sello *In* RADC Phys. of Failure in Electron., Vol. 5 Jun. 1967 p 496–505 refs (See N67-38461 23-09)
(Contract AF 30(602)-3776)
(N67-38486)

A new mode of metal failures is described—electrical opens in Al strips on SiO_2—resulting from the passage of direct current at high current density. The lifetime of aluminum strips was found to depend not only on the magnitude of the applied current, but also on its direction. At lower current levels (longer lifetimes), a much longer lifetime was seen when alternating current was employed than for direct current. This effect, together with the fact that aluminum films carrying direct currents have a blistered appearance suggests that an electrochemical or electromigration mechanism is involved in the disruption of the aluminum strips. While opens are very rarely seen at "normal" current densities, the failure mode is accelerated at high current densities and elevated temperatures. Author

Review: This paper gives a short crisp description of an important but previously unrecognized failure mode associated with conducting films of aluminum. The authors emphasize the preliminary stage of their investigation but this reservation means only that the electromigration phenomenon is not completely understood. Its occurrence is well established and users of integrated circuits must be aware of the current limitations thereby imposed. This paper or similar accounts of this work (the work is government funded and described in several government technical reports) should be required reading for everyone with a stake in reliability; it is of interest in its own right as a physical/metallurgical phenomenon.

R67-13545 ASQC 844; 775
International Business Machines Corp., Hopewell Junction, N. Y. East Fishkill Facility.

INFRARED ANALYSIS TECHNIQUE FOR DETERMINING ALUMINUM–PHOSPHOSILICATE REACTION

M. M. Nanda, E. A. Corl, and S. L. Silverman *In* RADC Phys. of Failure in Electron., Vol. 5 Jun. 1967 p 83–100 refs (See N67-38461 23-09)
(N67-38466)

Inversion, a major cause of semiconductor failure is frequently caused by the build-up of trapped charges in the vicinity of the silicon/silicon dioxide interface. A phosphosilicate layer introduced into the silicon dioxide structure reduces the failure incidence due to inversion, but aluminum interconnections react chemically with the oxide, reducing the phosphosilicate layer. Reflection infrared spectroscopy is a practical non-destructive technique in determining phosphosilicate layer thickness on oxidized silicon wafers. It was shown that depletion of the phosphosilicate layer occurs because of interaction with aluminum under various times and temperatures. The practical applicability of this infrared method in the quantitative determination of the depletion of the phosphosilicate layer is proven. Experimental findings show that the reflection technique can be used in process development and in production control of transistors and diodes using aluminum as interconnection. Author

Review: The motives of anyone presenting a paper in which basic information is deliberately withheld must be suspect. In this paper the metals of the metal–oxide–silicon systems investigated are labelled only metal A and metal B with the extra clue that they are "two typical conductor metals used in the semiconductor industry." If a work is truly proprietary, it should not be discussed at all. Even when the disguises that are insisted upon by competition-conscious management prior to approval for publication are easily seen through by a knowledgeable audience, the presence of such nuisances can leave an unprofessional taste with the listener or reader and prejudice him against whatever merit the work may have. In the present paper the disguise is either pointless or deliberately deceptive; the reader will assume that the metal discussed most frequently (metal A) is aluminum, since aluminum is by far the most common metal used for silicon device intraconnections and ohmic contacts; in addition, aluminum is the only metal named in the paper's abstract, or indeed the title. It appears then, with this uncertainty in mind, that the paper presents a fresh approach to investigating aluminum-oxide interactions during heat cycles that might be encountered in silicon device manufacturing. The specific oxide investigated is the phosphosilicate oxide glass that is commonly formed during phosphorus diffusions of silicon. The significant result is that little interaction between aluminum and phosphosilicate glass takes place at 500°C but that at temperatures above 560°C the reaction is appreciable in times on the order of one hour. The same general time–temperature relation holds for metal B except that metal B reacts faster. The message is that to minimize metal–oxide interactions the temperature of the oxidized silicon should be kept below 500°C after metallizations. This conclusion recommends the low-temperature sintering of aluminum to silicon (500°C for one hour) as a means of establishing ohmic contact rather than a higher temperature alloy cycle (600°C for five seconds). The IR techniques employed here are called non-destructive in that the oxide layer being examined is not destroyed during evaluation. The metal layer whose reaction with the oxide is being investigated must be removed prior to measurement, however, so that one could not use the technique for 100% testing of production units without incurring repair work.

R67-13546 ASQC 844; 770

Texas Instruments, Inc., Dallas.

RELIABILITY SCREENING PROCEDURES FOR INTEGRATED CIRCUITS

W. Gill and W. Workman *In* RADC Phys. of Failure in Electron., Vol. 5 Jun. 1967 p 101–142 refs (See N67-38461 23-09) (N67-38467)

Reliability screening techniques for integrated circuits are discussed which can be used in conjunction with a standard process that normally produces material suitable for less stringent reliability applications. Devices can be selected by subjecting this material to additional conditioning and selective procedures at three levels: precapsulation lot acceptance for metal adherence and bond integrity; 100% die and package inspections; and post capsulation conditioning and screening. The information obtained from accelerated stress tests, failure analysis, physics of failure studies and data analysis is used to demonstrate the effectiveness of new screening techniques. Author

Review: This is a long and detailed article which analyzes the reliability screening procedures and tests for an integrated circuit. The authors caution that the specific cookbook procedures developed for this particular integrated circuit may not be applicable to all integrated circuits but that the techniques themselves will be of value. Some knowledge of the construction of integrated circuits is necessary in order to understand the article and preferably one should have had some experience with the details of their failures. There are a great many typographical errors which are annoying while reading the paper but do not detract from its significance. An important statement in the text is that mathematical models which were designed to relate fixed and step stress could not be used since so few failures occurred. No numbers are given on the reliability or mean life of these devices either before or after screening.

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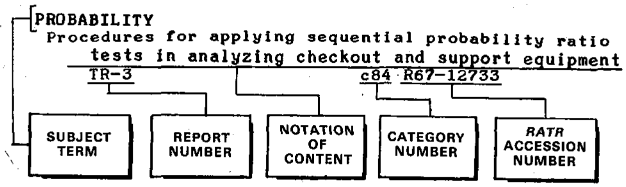
RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 7 NUMBER 12

Typical Subject Index Listing


PROBABILITY
Procedures for applying sequential probability ratio tests in analyzing checkout and support equipment
TR-3 c84 R67-12733

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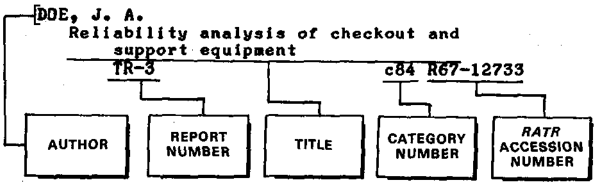

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This may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number preceded by the category number for locating the abstract-review in the abstract section of *RATR*. For purposes of this index, AD, N, and A numbers (accession numbers from *TAB, STAR,* and *IAA,* respectively) and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

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NASA-Langley, 1967

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Reliability Abstracts and Technical Reviews
ANNUAL INDEX

This Annual Index is an edited consolidation of the indexes to the individual issues of *Reliability Abstracts and Technical Reviews* for the calendar year 1967 (Volume 7, Numbers 1 through 12). There are four cumulations in this Annual Index. The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed; this index also includes a listing of the American Society for Quality Control codes for identifying the *RATR* accession numbers of items to which the codes have been assigned. A complete listing of these codes appears on the inside back cover of the Annual Index. The Accession Number Index identifies the issues and the categories in which the abstract-reviews appear in Volume 7.

Each entry in this index includes an accession number, e.g., R67-12345, a unique identification number assigned to each abstract-review that was indexed and announced in *RATR* during the year. In addition to the accession number, each entry in the Annual Index includes a 4-digit number (e.g., 10-84). The first two digits identify the issue of *RATR* in which the abstract-review is located. The two digits after the hyphen identify the ASQC category code assigned to the abstract-review.

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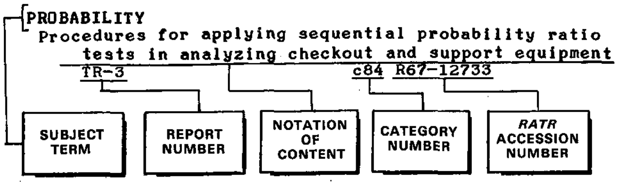

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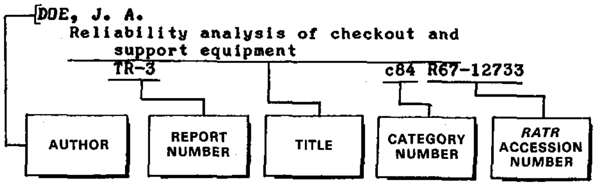

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