FINAL REPORT

James W. Altman

JUNE 1964

Conducted under Contract No. NASr-194
National Aeronautics and Space Administration

Technical Monitor
Stanley Deutsch
Office of Advanced Research and Technology

Institute for Performance Technology
AMERICAN INSTITUTES for RESEARCH

HUMAN FACTORS INFORMATION REQUIREMENTS FOR SPACE SYSTEM DEVELOPMENT

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SUMMARY

A survey was made of practices in existing human factors programs as a basis for projecting long-term requirements for human factors information in space system development. The basic survey consisted of about 50 detailed interviews with life scientists, human factors engineers, and other system development personnel. Interview comments were supplemented by literature survey and an analysis of system development decisions.

There was a total of 74 individual requirements identified. They can be organized into the following areas:

1. Basic Data Generation and Dissemination, including the generation of selected basic data concerning human functioning, improved availability of technical reports, development of a human factors data storage and retrieval system, and development of a technique for establishing research priorities.

2. Definition and Control of the Human Factors Process, including improved communication between human factors and other personnel, definition of the role for skilled operators in establishing human factors requirements, and specific requirements relating to integrated procedures for human factors program planning and control.

3. Function Description and Processing, including all of the requirements relating to function allocation; system, function, and task analysis; and job design and personnel forecasting.

4. Human Factors Design, including all of the requirements relating to human engineering; selection, training, and proficiency assessment; and informational job performance aids.

5. Design Assessment, including all of the requirements relating to human factors evaluation and testing.

BRIEF OF THE STUDY

Objective

The objective of this study was to survey practices in existing aerospace programs as a basis for projecting long-term requirements for human factors information in space system development. Included in this objective is a summary evaluation of existing human factors technology as a basis for defining research and development required to generate the needed information.

Method

The basic method used in this study was interviewing human factors personnel currently engaged in some aspect of aerospace research or development, followed by analysis and evaluation of interview comments to derive future requirements for human factors information. This basic approach was supplemented by literature review and an analysis of decisions involved in each requirement. That is, if interview comments suggested a possible requirement for human factors information, an attempt was made to determine whether:

1. The information was currently in existence and simply not widely enough available or whether the information was actually lacking.

2. There were legitimate development decisions to be supported by the information and, if so, what these decisions might be.

Findings

The major portion of this report is devoted to a presentation of the findings, combined with implications for long-range planning. There were a total of 74 individual requirements identified. Six requirements are general to all areas of human factors in development and 68 are specific to one of eight areas of human factors activity. For each of the eight areas, there is a requirement to develop integrated procedures in support of more effective activity in the area. The remaining 60 requirements are for specific state-of-the-art improvements in the different areas of human factors activity.

The general criterion used in establishing a given requirement was that it should define a need which could reasonably be met with a separate research or development project. No assumptions have been made about the desirability of establishing projects for individual requirements or for any combination of requirements. It is only assumed that a worthwhile project could be established for each requirement. A brief description of the characteristics of a possible project is included as part of the statement of each requirement.

There are important interactions among the various requirements. An attempt has been made in describing each requirement to identify the more significant of these relationships. Progress toward meeting any of the general requirements will contribute toward achievement in all areas of human factors activity. Conversely, progress in any of the activity areas will at least serve to further define the general requirements. Progress toward the integration of procedures for any of the activity areas will depend to a major extent upon progress in meeting the specific requirements within the area.

A requirement, as the term is used in this report, obviously does not imply an absolute need which, if unfulfilled, will result in the failure of the United States space program. It is intended to imply, however, that failure to meet a requirement will result in one or more of the following consequences:

1. Unnecessary cost in terms of developmental time, money, or use of scientific and engineering talent.

2. Less effective systems than with full use of human potential and appreciation of human limitations.

3. Inadequate peeloff of knowledge from the space program concerning bio-technology for other areas of our modern society.

It is not surprising that many of the requirements reflect a need for more information about man's characteristics with respect to new tasks and environments. Neither is it surprising that many requirements reflect the need for techniques to use this information in the design of space systems. What is perhaps surprising is the emphasis on practical constraints in the application of knowledge and techniques. It is impossible to say whether the gulf between human factors researcher and theoretician on the one hand and the practitioner on the other is narrower or wider than previously. It seems clear, on the basis of findings from this study, however, that there is an increasing awareness of the importance of rapprochement between theory and application. Requirements as defined in this report, therefore, place considerable emphasis on the need for new knowledge and techniques as they have potential for practical application in the design and development of future systems.

An overview of requirements is presented in Figure 1.

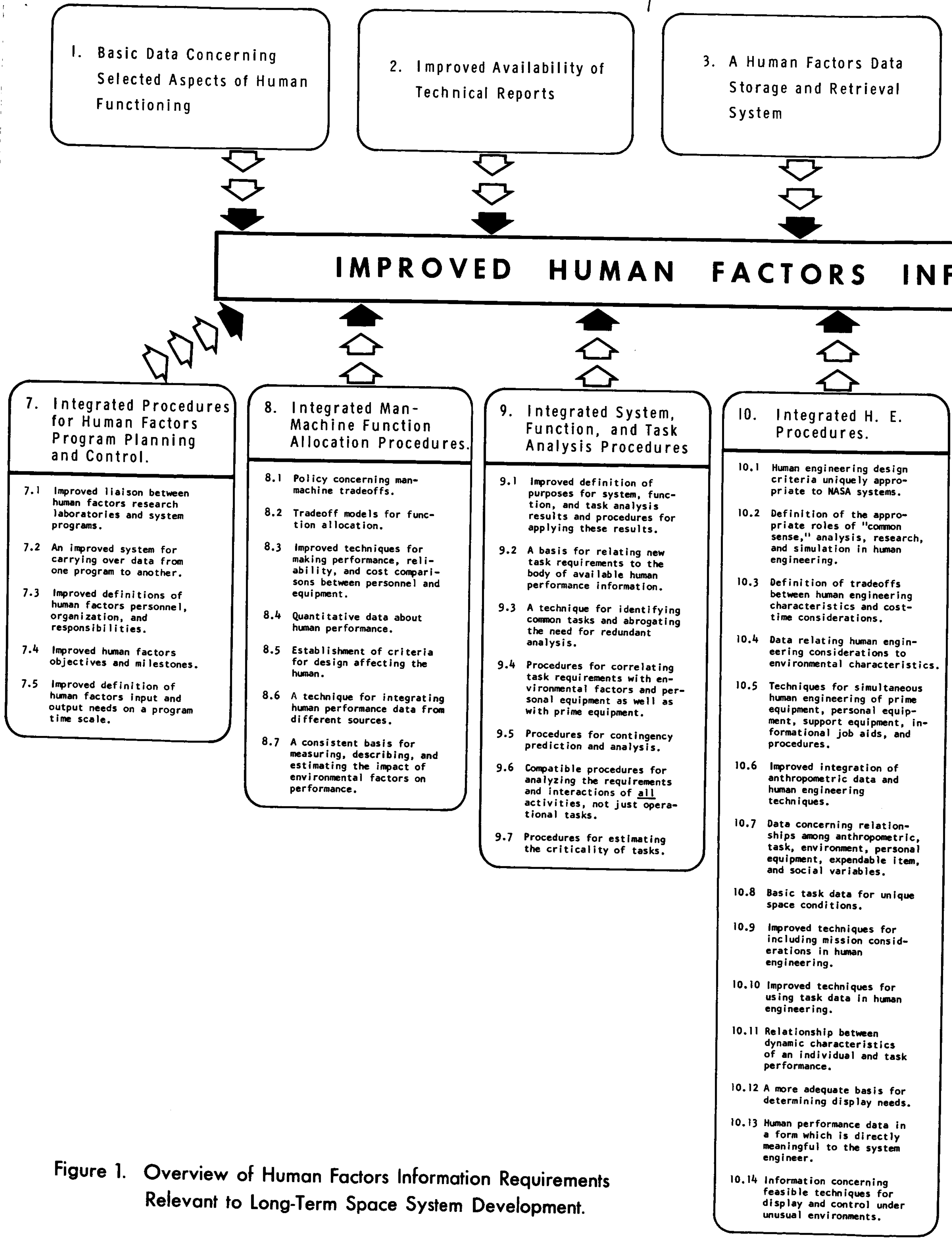

Figure 1. Overview of Human Factors Information Requirements Relevant to Long-Term Space System Development.

4. Definition of the Trade-off Between Application of Existing Research Results and Initiation of New Research

5. Improved Communication Between Human Factors and Other Program Personnel

6. Definition of the Appropriate Role of the Skilled Worker in Establishing Requirements

ORMATION FOR SPACE SYSTEMS

11. Integrated Job Design and Personnel Forecasting Procedures.

11.1 Improved procedures for job design.

11.2 Improved procedures for personnel forecasting.

11.3 Improved availability of information concerning job design and personnel forecasting experience on previous systems.

11.4 Information concerning the <u>availability</u> of personnel.

12. Procedures for Integrating Personnel Selection, Training, and Proficiency Assessment.

12.1 Delineation of populations from which it will be appropriate to draw trainees.

12.2 Identification of appropriate selection variables, methods, and techniques for validating selection.

12.3 Determination of selection requirements for long-term adjustment and stress tolerance.

12.4 Improved techniques for determining training requirements.

12.5 A rigorous basis for relating training requirements to training methods, aids, equipment, facilities, and schedules.

12.6 Learning and retention curves for various performance parameters on different classes of tasks; as a function of training techniques and aids.

12.7 Determination and codification of space environment characteristics having unique training requirements.

12.8 State-of-the-art information about training techniques, aids, equipment, and facilities.

12.9 A technique for determining proficiency measurement requirements early in development.

13. Procedures for Integrating Human Factors Efforts and Data in Development of Job Performance Aids.

13.1 Definition of the role for human factors data in informational job performance aids.

13.2 Human factors criteria for informational job performance aids.

13.3 Determination of more effective methods for presenting job information.

13.4 Delineation of a role for human factors personnel in the preparation of informational job performance aids.

13.5 Guidance on the use of subject testing in preparation of informational job performance aids.

13.6 Information about current practices in the development and use of informational performance aids.

14. Procedures for Integrating Human Factors Evaluation and Testing.

14.1 Definition of the appropriate role of evaluation versus testing.

14.2 Development of a human factors evaluation and testing model which is dovetailed with system development phases.

14.3 Procedures for establishing appropriate objectives, standards, criteria, and measures for human factors evaluation and test.

14.4 Guidance concerning appropriate evaluation and testing costs.

14.5 Further development of operability and maintainability indexes.

14.6 Guidance concerning the selection of human factors aspects for testing and evaluation.

14.7 Guidance on the qualification testing of hardware developed by human factors groups.

14.8 Definition of the role of operational equipment, prototype equipment, system simulators, and mockups in human factors testing.

NOTE: Code numbers used on this diagram are also used to identify requirements throughout the body of the report, both in titles and for cross-referencing.

REQUIREMENT 1: BASIC DATA CONCERNING SELECTED ASPECTS OF HUMAN FUNCTIONING

Delineation

The main thrust of human factors research is, of course, the gathering of basic data concerning human functioning; including at least its bio-mechanical, bio-medical, physiological, performance, and social aspects. It would be both presumptuous and foolhardy to attempt to codify all, or even the major, areas of needed research relating to man's functioning as it may have an effect on space system development.

This survey did underscore the importance of an improved system for defining basic data needs on the basis of real problems of system development. Even in the space age, it is not uncommon to find researchers who are being supported by aerospace funds who are generating carefully controlled data which development personnel feel are essentially worthless for their efforts. At the same time, critical development decisions concerning human well being and performance are being made by fiat, successive approximations, best available judgment, and ad hoc or "quick and dirty" research. All of these bases are appropriate system development tools, as required. Nevertheless, there seems to be a significant requirement for more, better, and more relevant basic data concerning human functioning than is currently used in system development.

Consequences

Failure to more fully orient research toward obtaining data which are basic to development decisions concerning man's role in space will have the following consequences:

1. Too many human factors decisions in space system development will continue, of necessity, to be made on a less sound basis than relevant research data about the human functions involved.

2. The payoff from human factors research which is supported by aerospace funds will be less than could be realized.

3. There will be an increased chance that potentially useful programs will be cut off as part of the reaction against programs that do not pay off.

Research and Development

Some of the more obvious areas in need of basic data are:

1. Defining error likelihood for tasks on which error rates are very low but which may be critical. This will involve the development of refined techniques for measuring tendency toward error.

2. New departures in selection, training, classification, and proficiency measurement of highly pre-selected, motivated, and proficient groups.

3. Studies on control of human behavior beyond any which has been achieved to date; including "brainwashing" techniques, electrodes, drugs, and hypnosis.

4. Development of techniques for measuring stress effects which do not influence normal task performance and determination of the implications of such effects for long-term space missions.

5. Confinement studies directed at the interaction of multiple stresses and synergestic aspects of behavior.

6. Development of reliable measurement techniques for a full array of physiological variables under real space conditions.

7. Development of the most meaningful tasks and measures for weightless and artificial gravity experiments.

8. Continued study and refinement of techniques for the study of performance and physiological concomitants under realistic acceleration, noise, and vibration profiles.

The principal import of this study, however, is the need for increased participation of top-level behavioral and bio-sciences personnel in the advanced conceptualization of systems and, particularly, the dissemination of implications from these deliberations throughout the human factors community.

Relationship to Other Requirements

Basic data about human functioning does and will, of course, contribute to increased effectiveness in all areas of human factors activity. Improved availability of technical reports (2) and a data system (3) will substantially aid in the dissemination of these data as they become available.

Interview Comments	No. of Interviews
Quantitative human performance data that are not currently available are required for advanced space system development.	11
Many available data are:	
• not applicable to space tasks	2
• too general for application to a specific system	1
Emphasis is needed on:	
• performance of skilled operators	1
• "field response" as opposed to "lab response"	1
• decision processes	1
• operator reliability	1
• learning ability	1
• ability to deal with the unforeseen	1
• relationship of human performance parameters to training and job-aid characteristics	1
• motivational baseline data and effects of motivation on performance	1
• techniques for applying performance data to design problems	1
• applications to problems of advanced planning	1
Generation of performance data should include the use of:	
• psycho-physical methods to determine capability	1
• "busy-boxes" in space system simulators	1
Additional basic data are required concerning the effects of the space environment on the human.	7
Effects of the following on human performance are worthy of priority study:	
• work-rest cycles	3
• use on non-operational ("free") time	1
• isolation and confinement	3
• tumbling	1
• spinning and rotating	1
• 1/6 G	1
• weightlessness (long-term)	1
• stress	1
• empty space (effect on perception)	1
• low-frequency, high-intensity sound	1
• vibration	1
• synergistic (combined variables) effects	1

	No. of Interviews
Physiological effects of long-term weightlessness should receive increased attention.	2
There must be an improved definition of "meaningful" physiological parameters to measure for space systems.	1
Immediate attention should be given to defining cabin space requirements for different numbers of persons.	1
For advanced planning, increased sophistication is required in determining potential adjustment to unfamiliar environments and conditions.	1
There is too great a tendency in human factors research to focus on specific regions of relationship (point data). Many studies should be expanded (while point data are being obtained) to generate data on the full continuum of relationship.	1
Studies of control of behavior (other than by training and usual communications) should be initiated. Application of "brainwashing" techniques, electrodes, drugs, and hypnosis should all be considered.	1
NASA needs a centralized research capability, both to conduct and contract for basic human factors research.	1

REQUIREMENT 2: IMPROVED AVAILABILITY OF TECHNICAL REPORTS

Delineation

Even with awareness of sources of technical information such as the Scientific Technical Aerospace Reports, Defense Documentation Center, the Tufts human engineering reports service, and various abstracting and bibliographic services in specific fields; there is feeling that a fully adequate document service is lacking. In particular, there is concern about the lag between completion of research and the availability of publications through regular channels. It has been suggested that availability of reports from the Aerospace Medical Laboratory is considered to be the best to date.

A major problem is the difficulty which busy research and applications personnel find in keeping up with original sources, even in their area of specialization. This places heavy reliance on secondary sources such as reviews, summaries, and handbooks.

The seeming importance of handbooks came as something of a surprise in the current survey because of the tendency in some circles to downgrade the importance and value of human factors handbooks. The NASA Life Sciences Data Book has been well received although there are a number of criticisms and suggestions for improvement. It is felt that the data require greater qualifications of the conditions under which relationships are valid. Lack of human performance data was cited as a drawback. Specific areas mentioned as needing more information include:

1. Metabolic rates.
2. Radiation effects.
3. Visual effects of lunar and other reflection and refraction.

Some difficulty in applying the NASA Life Sciences Data Book data to specific support responsibilities has been reported.

Human factors personnel report making extensive use of handbooks, guides, specifications, and standards. However, they report that many of them are getting out of date and there are important gaps remaining, particularly with respect to basic human performance data. It is felt that it is important for any source book to be set up so that information relevant to a particular design problem can be readily identified and located, interpreted appropriately for the specific situation, and applied using stated techniques and procedures.

Consequences

Failure to provide better access to technical reports, and especially failure to provide appropriate secondary sources, will perpetuate the use of obsolete data and techniques and excessive dependence upon expertise in system development. This will inevitably hamper the growth of human factors as a technology-based discipline.

Research and Development

Research and development directed toward improvement and availability of technical reports should proceed along two separate, but related, lines. The first of these is a continued and renewed support for efforts to improve information retrieval systems and to apply them fully to the life sciences and human factors data. Of particular importance and relevance are the development of more effective indexing schemes and advances in the technology of technical information abstracting (Payne, Munger, & Altman, 1962; Payne & Hale, 1964).

The second major area for research and development is the preparation of up-to-date and improved handbooks and other secondary source material. To a major extent, this project was directed toward the identification of requirements for such handbooks and all of the requirements stated in this report have implications for human factors handbooks. The next essential step in the preparation of advanced handbook material is an extensive review of existing literature, particularly referring back to original sources. The current state of secondary source materials is one of partial and complete redundancy with inadequate reference to original data sources. It is essential that definitive handbook preparation at this time start with a clear and scholarly treatment of the existing literature.

It seems probable that much of the current confusion about both the status and the utility of human factors handbooks results from the effort to make human factors information and standards available to engineers, training aids personnel, technical writers, and other persons not trained in any of the life sciences. The first requirement is for handbook materials which are aimed at human factors personnel which do not oversimplify, omit references to basic sources, or delete important qualifications and limitations. It then becomes a much simpler and justifiable procedure to prepare a more limited and simple guide for persons not trained in any human factors discipline.

Relationship to Other Requirements

Availability of technical reports will influence progress in all of the other requirement areas and will, in turn, be influenced by progress in these areas. However, the major functional relationship of this requirement is with development of a human factors data storage and retrieval system (3). It is, in fact, entirely conceivable that these two requirements may merge into a single area at some point in the future. However, at the present time efforts toward a human factors data storage and retrieval system must be much more limited in scope than any attempt to encompass the full body of existing and steadily increasing life sciences and human factors literature.

Nevertheless, effective progress toward a data storage and retrieval system and efforts toward improved access to reports and secondary sources should be ultimately symbiotic.

Interview Comments	No. of Interviews
Findings of A Critique of Standard Reference Works in Human Factors (Lovinger & Baker, 1963) apply here.	1
Improved procedures are required for making human factors data available.	8
Inadequate documentation and availability of information result in unnecessary duplication of effort.	1
Defence Documentation Center (DDC) is terrible.	1
The human factors literature has not been systematized to provide basic data.	1
Publication lag is too great.	1
Data from Mercury were slow in dissemination.	1
Something in NASA like the Aerospace Medical Laboratory technical report series (but more rapidly available) would be desirable.	2
There is special need for availability of quantitative data on human reliability.	1
A NASA serialized bibliography of bioastronautics reports would be helpful.	1
Quality of industry reports should be improved, and authorship should be indicated to assign responsibility.	1
Industry must provide time for each individual to read literature in his field or assign abstractors on a full-time basis.	1
Micro cards would be helpful.	1
A Federal agency for information dissemination should be established.	1
A document such as an "Annual Review of Human Factors" would be helpful.	1
The cost of a human factors data catalog would be prohibitive.	1
Behavioral scientists, especially those with administrative responsibilities, do not have much time to read original sources. They must depend heavily on secondary sources.	1

	No. of Interviews
Existing human factors handbooks must be supplemented and revised.	9
The Life Sciences Data Book is useful, but requires more qualification and delineation of the conditions to which data apply.	3
The following types of additional data are required in handbooks:	
• more metabolic data	1
• radiation effects (biological and behavioral)	1
• lunar and other reflection-refraction effects on vision	1
• effect on human from changes in conditions	1
• human engineering standards applicable to space	1
• quantitative methods and data for predicting human performance	3
• comparison of human performance implications of major design alternatives	1
• human performance	1
There is a need for an encyclopedia of human behavior in space systems	1

REQUIREMENT 3: HUMAN FACTORS DATA STORAGE AND RETRIEVAL SYSTEM

Delineation

The problem of disseminating technical information has already been discussed within the context of making technical reports more readily available (2) both in their original form and as secondary sources. There is also a requirement for more exotic techniques, almost certainly involving the use of high-speed electronic computers. The basic need is for the ability to insert something approximating raw human factors data into a central store and to pull out the data and various summaries of data with a high degree of flexibility.

Such a data system should be both intra- and inter-program. That is, there should be a central data system for all human factors information generated and used on a given space system development program and compatible interfaces across all system programs. This would mean that human factors personnel would be able to obtain up-to-the-minute information about the general state-of-the-art in bioastronautics as well as up-to-the-minute information about the status of human factors design within a given program.

Consequences

Failure to develop an adequate data storage and retrieval system will mean that potential solutions to a major constraint on human factors effectiveness will be ignored. Failure to apply the potential of modern information processing systems to human factors data will mean an unnecessary waste of human factors potential.

Research and Development

A preliminary study contract was let jointly by the Air Force and NASA to Computer Concepts and the American Institutes for Research (A.I.R.) (letter agreement dated 12 June 1964, under Prime Contract AF 33 (615)-1557). This first-phase effort is to develop concepts and explore feasibility of improved computer methods for handling and using human factors task data. Anticipated follow-on phases are the development and testing of data-handling procedures.

Relationship to Other Requirements

It is a temptation to think that an effective data storage and retrieval system will resolve all of the other problems in human factors support to space system development. Certainly, such a system can play a central role in human factors programming. However, the ultimate effectiveness of a storage and retrieval system will necessarily be limited by the techniques for generating and applying the data and the quality of the data themselves. These are the major concerns of the other requirements described in this report.

Interview Comments	No. of Interviews
A computerized human factors data handling system is desirable.	5
Although a computerized data retrieval system is a good idea, the Tufts bibliography series is the best system yet, and it should be continued.	1
An up-to-date compilation on all systems for both NASA and the military would be helpful, but might run into classification problems.	1
Storage of technical publications in digital computers for those who interact with such computers as a normal part of their job seems especially suitable.	1
Microfilm might supplement the use of computers.	1
There should be a data store, not just an index of articles.	1
Relationships of human performance parameters to other variables could be computerized for rapid storage, update, and retrieval.	1
Source data must be readily identifiable for a given need, interpretable for a specific situation, and compatible with existing procedures.	1
Existing systems of automating personnel-equipment data and task analyses already provide fast retrieval times for program status data and timelines oriented by equipment, function, mission phase, location, and specialty code.	1
Data summary techniques require improvement since present techniques sometimes result in invalid conclusions.	1

REQUIREMENT 4: DEFINITION OF THE TRADEOFF BETWEEN APPLICATION OF EXISTING RESEARCH RESULTS AND INITIATION OF NEW RESEARCH

Delineation

The problem of deciding when to initiate applied research includes at least two basic issues. The first is how to establish priorities for advanced research which is intended to provide support across a number of systems. The second is when to initiate applied human factors research within a given program.

The establishment of general priorities has involved at least two different approaches. One is the use of a master matrix with the marginals defined by variables which may affect human functioning in a space system. The individual cells of the matrix then define separate studies which can be rated in terms of their priority. Although this approach does help to define the limits of potential research, it involves a considerable subjective element in establishing the priorities. Another approach is to consider the types of systems and missions which may occur in the foreseeable future and use of mission analysis to detect potential problems. These potential problems can then be compared against available knowledge and research already programmed to determine problems in need of research.

In establishing research needs within a given system development program, an appropriate approach would seem to include an early mission and functions analysis as a basis for identifying research problems for which adequate research data are lacking.

Neither for establishment of general priorities nor for the planning of program-specific research do there seem to be well-defined techniques. It has been suggested that some of the "giants" of human factors might be used to chart the course for system support research planning, although there is no guarantee that these experts will have special sensitivity to the unique problems of future space flights.

Consequences

Failure to develop improved techniques for the identification of most-needed research will result in research which cannot be fully used, in the non-availability of research data needed for critical decisions, and a crash program of research in lieu of more definitive work.

Research and Development

Research and development to improve the identification of needed human factors support research might include the following activities:

1. Identification of specific instances in which applied research results had been developed and were available to support the making of critical decisions. Also, there should be an identification of decisions which were in need of research support, but for which research results were either lacking or had to be obtained on a crash basis.

2. Analysis and generalization from the specific instances in an attempt to identify the critical characteristics of effective research programming.

3. Review of the critical factors that make for effective applied research programming in highly developed areas such as electronics and atomics.

4. Integration of critical characteristics into methods and procedures for the identification for research needs.

5. Trial application and evaluation of procedures on specific programs and areas.

Relationship to Other Requirements

This requirement is similar to the requirement for obtaining basic data concerning selected aspects of human functioning (1). However, this requirement is more aimed at the development of procedures for the identification of research needs and priorities than at the general enhancement of life sciences and human factors technology. Research and development might well be combined for these two requirements, however.

Interview Comments	No. of Interviews
Utilize human factors "giants" to chart the course for research planning.	1
There are two contrasting strategies for defining man-machine integration problems:	2
Look at all categories of man and try to supply all possible data needs.	2
Try to predict mission requirements for the future and gather relevant data only for projected requirements.	2
The second is, by far, the better approach.	2
There is, and should be, a strong element of subjectivity and personal preference in defining research problems and goals.	1
A possible strategy in defining a human factors research program for space would be to look at rather well developed areas such as electronics, to see how they have progressed, and see what the implications are for human factors support to space.	1
Literature review can be important in defining research programs for human factors in space.	2
Long-term research is required to obtain unique information to support system development.	1
A method is needed to identify what problem areas have priority.	1
A mechanism is needed to permit research capabilities to anticipate future design problems. Military human factors research people never got enough feedback to know if they were being effective.	1
When empirical laboratory studies must be limited, they should be reserved for application to unique system requirements.	1
There is a tendency to use full-scale factorial experiments in support studies where simpler designs would suffice. More explicit guidance on minimum adequate designs would be helpful.	1
There is still confusion about the division of responsibility for particular areas of human factors research in NASA. A firm and appropriate delegation of responsibility is needed.	1

	No. of Interviews
A directory of human factors personnel in the aerospace agencies of Government and in industry would be useful in programming research.	1
NASA should be sure that existing research facilities and capabilities of the country are being fully used prior to developing their own.	1

REQUIREMENT 5: IMPROVED COMMUNICATION BETWEEN HUMAN FACTORS AND OTHER PROGRAM PERSONNEL

Delineation

There is a major need for intermingling of disciplines in a large-scale space system development. Effective joint work of human factors personnel with others is sometimes limited by lack of inter-disciplinary communications. Human factors specialists often have an inadequate understanding of the work and information flow in system development. On the other hand, the concepts and terminology used by human factors personnel are frequently difficult for engineers and other systems personnel to understand. There is currently no general basis for translation between human factors and other systems personnel.

Consequences

Inadequate communications between human factors personnel and other systems development personnel inevitably leads to less effective incorporation of human factors in systems development than would be the case with adequate communication.

Research and Development

Research aimed at improving communications between human factors and other systems personnel might include at least the following activities:

1. Obtaining specific reports from both human factors and engineering personnel of specific instances in which communication was either a real asset or detriment to effective development.

2. Obtaining actual interpretation of key words, concepts, measures, techniques, and policies from both engineering and human factors personnel and comparison of interpretation to identify areas of misunderstandings.

3. Obtaining nominations of system personnel who have extensive joint backgrounds in engineering and human factors or who have been nominated as being particularly

effective communicators. Such personnel might then be interviewed to identify techniques which they used to enhance communications.

4. Incorporation of results from 1 through 3 above in the development of guidelines and orientation material to improve inter-disciplinary communications.

5. Tryout and verification of both procedures and orientation materials.

Relationship to Other Requirements

One of the important objectives of all techniques and procedures development and data formating should be to enhance communications across disciplines.

Interview Comments	No. of Interviews
There are both major needs for and problems in communication between human factors personnel and other systems personnel.	5
Many of the data about the human are not in the proper frame of reference for engineers. Missing data make translation into the engineers' terms impossible. Time constraints prevent the conduct of specific experiments to obtain the exact required information.	1
Translation of psychological and physiological data now available is required for application to system development.	1
A big problem of human factors specialists is inadequate understanding of the work and information flow in system development.	1
There is a tendency toward over-jargon in function and task analysis and allocation. This tends to be detrimental to over-all system development.	1
Psychologists have difficulty understanding data concerning the "black box" which comes from the engineer.	1
Communication problems result from the separation of laboratory scientists who must generate human factors data and those in the space program who require it. (Note: These comments also apply to 7.1: Improved Liaison Between Human Factors Research Laboratories and System Programs.)	6
Behavioral scientists are often a step or two removed from actual system development.	2
Handbook data that would make man more efficient through human engineering are not always used.	1
Human factors handbooks must be available in a form usable by engineers, who will be exposed to human factors by these guides and come to specialists with further questions.	1
There needs to be a program or process for human factors support. Design engineers lack familiarity with the capabilities of Government human factors research and development offices. Lacking a mechanism to trigger requests for assistance, they do not get support which would be useful to them.	1

	No. of Interviews
The following were mentioned as factors which can or do reduce communication problems between human factors and other areas:	
• operational and engineering orientation on the part of the human factors person	4
• human factors experience or orientation on the part of engineers	3
• a human factors "generalist" on the design team, through whom all inputs from "specialists" pass	1
• assignment of a human factors specialist to all significant human factors problems and not simply giving data to the engineers	1
• dissemination by NASA of descriptions of appropriate areas for human factors support and technical objectives	2
• a human factors program, and not just an offer of piecemeal support	1
• editing and translation of all human factors reports by senior engineers	1
• interface between computerized human factor data banks and other computerized programs such as reliability	1
Much of the resistance to human factors stems from the perception by "experts" that the psychologists will, at some point, systemitize and quantify what they now "expertize" on. This is a threatening situation.	1

REQUIREMENT 6: DEFINITION OF THE APPROPRIATE ROLE OF THE SKILLED WORKER IN ESTABLISHING REQUIREMENTS

Delineation

There are a variety of views within the Government and the aerospace industries concerning the appropriate role of man in space. At least three divergent points of view can be identified:

1. Many scientists and engineers feel that man's role in space should be, at best, that of a passive observer or as possible backup to automatic equipment in the event it might malfunction.

2. The general view of test pilots and astronauts is that man should play a much more active role than he has to date and that his abilities can enhance reliability, increase performance, or cut costs.

3. The view of many human factors personnel is that design decisions and man-machine tradeoffs have tended too much to be decided either on the basis of test pilots or astronauts preferences or on the basis of available state-of-the-art in automation. In their view, both available equipment techniques and preferences of skilled operational personnel such as test pilots and astronauts are simply two of the factors that should go into formal decision-making about both man's role and design to support his well being and performance.

One of the major problems in achieving an appropriate balance among the various views is the lack of generally accepted techniques and rationale for using suggestions, opinions, and preferences within a framework of optimizing man-machine system design.

Consequences

Lack of definitive rationale for the use of skilled workers in establishing man-machine requirements will continue to result in unresolved conflict concerning man-machine design. It will probably also result in a space system sub-optimization.

Research and Development

Research to define an appropriate role for operational personnel in defining system requirements might include rational analysis of the bases on which judgments are made by operating personnel and experimental comparison of implied performance judgments against actual performance. Such a program of comparison can serve as a basis for defining the short cuts which expert opinion can provide over an extensive testing program and also indicate the areas in which simulation, testing, and analysis are essential to support the preferences and opinions of operating personnel.

Relationship to Other Requirements

Skilled workers will probably play a major role in function allocation (8) and human engineering (10). However, there are also a number of unresolved issues concerning the appropriate role of skilled workers in defining training requirements (12), specifying informational job aids (13), and defining evaluation and testing procedures (14).

Interview Comments	No. of Interviews
Criteria and methods for determining operator acceptance are needed:	1
Acceptance of "predictor" and "director" displays has been poor and has prevented their application in situations where they might have been effective.	1
Life-support systems will become increasingly a part of the active control situation; operators will want much more control over life-support systems than was contemplated in Mercury planning, but what control is not yet clear.	1
Standard methods of task analysis are satisfactory, but where they fall down is where experienced operators do not participate.	1
NASA can no longer afford to have its systems human factored by test pilots. High-level scientists are needed in positions which have authority and responsibility for design.	1
There is a need to collect performance data in the field, using experienced operators as subjects.	1

REQUIREMENT 7: INTEGRATED PROCEDURES FOR HUMAN FACTORS PLANNING AND CONTROL

Delineation

Human factors personnel seem to have survived the transition from air age to aerospace age with relatively little modification, let alone breakthroughs, in techniques or approaches to planning and control of large-scale programs. This is not because there is great enthusiasm for existing techniques. Rather, it would seem to be because human factors practitioners have been forced to attend to the day-to-day pressures of supporting ongoing system development and have either not had time or inclination for a general review of the methods by which human factors are incorporated in systems. Research-oriented personnel seem to have devoted relatively little effort toward improving the methods for conducting human factors development programs.

The principal efforts at comprehensive codification of human factors program efforts seem to have been in-house efforts of various military and other Governmental agencies. They seem typically to be the re-statement of methodological research conducted some years ago and cast in the framework of the particular development requirements of the agency. The results of such efforts to apply, as requirements, the concepts and methods of earlier guidance and research seem, at best, to have had limited success.

Human factors programs, then, seem already to have been outpaced by the sophistication of the systems which they are to support. In the future, they can be expected to be even less adequate to the requirements of advanced space systems unless creative research and development is undertaken to enhance the programming of human factors efforts in support of space system development.

Consequences

Failure to develop improved procedures for human factors planning and control will have at least three detrimental consequences:

1. Inability of human factors support programs to make the contribution to space system development of which the discipline is potentially capable.

2. Generation of data and analytic results by program personnel which are not or cannot be used because they are not at the right place, at the right time, in a form which can be used.

3. The efforts of applied human factors researchers will continue to be less fully directed at the central problems of space system development than they might and should be.

Research and Development

Assuming that research and development outlined under the specific requirements in this area has preceded or is concurrently accomplished, the research and development for integrated procedures for human factors program planning and control might be limited to creative development to combine the results of the various specific areas, making use of top-level reviewers to critique preliminary procedures, and evaluation of applications of the procedures to real programs.

Relationship to Other Requirements

Program planning and control procedures will help to focus and implement all of the general requirements.

Interview Comments	No. of Interviews
Improved methods are needed for generalizing from old designs to new systems.	5
Seven specific Government specifications were cited. (Note: Insofar as could be determined in the interviews, the intent was to be informative only, and not to imply that the cited documents resolved program planning and control problems.)	3
NASA needs a comprehensive human factors specification.	3
NASA requests for proposals should include greater specification of desired human factors objectives and more mission data than is required for human factors programming.	2
The following programming techniques were cited as having limitations for human factors programming:	
PERT (time-consuming and ineffective)	4
SAIM (time-consuming and costly, but gross application sometimes useful for program troubleshooting)	1
Personnel subsystems approach (excessive mass of data)	1
The critical path concept (PERT) is valuable. Sometimes the critical path is an individual (astronaut). PERT-type programs must consider the man elements.	1
It is imperative that human factors personnel get into the program early enough to develop a really good PERT for human factors or they are always busy trying to catch up.	1
NASA should take the following actions:	8
• more clearly define human factors responsibilities	3
• require added recognition of human factors through enforced documentation	1
• accelerate the trend toward divisional support responsibilities instead of having project offices be self-sufficient	1
• give contractors more human factors responsibilities	1
• limit centralized human factors responsibility in NASA to coordination	1
• make increased use of existing human factors capabilities and reduce the tendency to obtain personnel from other organizations	1
• integrate human factors more fully into design effort	1
• put human factors, for a specific system design, under "design integration" and not under the "medical" area	1

	No. of Interviews
Improved models of and methods for human factors programs are required.	9
Increased information about human factors program requirements is required (e.g., schedules, money, personnel).	3
Human factors programs for space systems should include the following:	12
• use of simulators, centrifuge, etc.	1
• identification of the effects of human factors requirements on mission requirements	1
• flexible and fast-response personnel requirements	1
• allowance for the application of academic psychology	1
• flow diagramming of human factors tasks, showing how each task helps meet system requirements	1
• integration of operational and maintenance areas	1
• separation of program-specific and criteria research	1
• an on-the-spot human engineer during design	1
• simultaneous human engineering of equipment and procedures	1
• continuous filing of human factors "critical" reports	1
• human factors inputs for specifications, operations, and maintenance plans	1
• translation of specifications into design	1
human factors contribution to the "doctrine level" in early design	1
• a realization that human engineering does not necessarily solve all human factors problems	1
• more effective setting of intermediate program goals	1
NASA requires a high-level human factors group. Headquarters people should <u>not</u> be developing hardware, but should be deciding requirements, phasing, etc.	1
There is a great deal of competition among centers for human factors responsibility. An over-all assignment of areas and responsibility is critical to any effective human factors within NASA.	1
Specific life-sciences responsibility needs to be assigned within every appropriate operational research and development group.	1

	No. of Interviews
There is a shortage of human factors talent. Care is needed to insure that the "systems" considerations are handled by top people, with lesser people focusing on specific details.	1
In monitoring human factors in system design, it is imperative that the NASA man be full-time on the system, and know the details of it as well as any contractor human factors specialist.	1
In at least one NASA center, the human factors complement cannot fulfill all of its immediate design responsibilities, much less monitor contractor programs. Each request for support must be priority-evaluated on criticality and payoff.	1
In groups composed of scientific personnel the efforts tend to be quite independent. In order for human factors to be systematic the lines of responsibility must be very clear.	1
The quality of human factors obtained on any system development depends upon the "power" of the industrial human factors group.	1
A human factors person should work directly with engineers to provide support and to ensure that the human factors effort has the latest information about design problems.	1
There should not be "human factors" groups. The only way to operate is with a team effort to solve design problems.	1
A major disadvantage of assigning small groups of human factors people to specific developmental efforts is that they lose touch with the discipline and become submerged in the system. It is perhaps better to have a centralized group monitoring the design effort and sitting in at specific developmental points.	1
A human factors group should be made up of both behavioral scientists and engineers.	2
The human factors group should have both hardware and software responsibilities.	1
A cross-comparison of organizational structures and procedures at different organizations would be useful for the aerospace industry.	1

REQUIREMENT 7.1: IMPROVED LIAISON BETWEEN HUMAN FACTORS RESEARCH LABORATORIES AND SYSTEM PROGRAMS

Delineation

There are two major elements to the requirement for improved liaison. The first is an emphasis on the need for a clear guiding philosophy to define human factors responsibilities for each of the NASA centers and to define the appropriate nature of interaction among them. It has been suggested that there is confusion concerning what group has responsibility for various areas of human factors research. Firm and appropriate delegation of responsibility for the different areas has been suggested as a requirement. Concern has been expressed, however, that human factors activities not be centralized within NASA. Rather, it has been suggested that the centralized human factors functions be limited to coordination, with the structure of the central organization being defined by groups such as controls and displays, maintenance, training, etc.

The second major element of the requirement involves an emphasis on the dissemination of information about who the human factors personnel are in aerospace, in government, and industry and what their functions and responsibilities are. It has been suggested that an up-to-date directory of both people and organizations would be useful to applied researchers in defining and selecting problems and to system program people in seeking research assistance. The personnel part of such a directory might be similar to the Human Factors Directory but much more complete.

Although the statement of this requirement emphasizes liaison between laboratory and system program, it is also almost certainly true that such improvement will result in improvement in inter-laboratory and inter-program liaison and coordination.

Consequences

Failure to improve liaison between system programs and other elements of the aerospace human factors network will have the following direct consequences:

1. Space programs will draw less fully upon the human factors technology than it should for optimum man-machine design.

2. Applied research programs will be less relevant to the real needs of the space program than they could be with improved liaison.

3. Competition among Governmental groups for human factors responsibility (already reported to be high) will increase.

Research and Development

Research and development efforts directed toward improved human factors liaison might appropriately include:

1. Description of existing liaison through interviews and/or questionnaires from human factors and life sciences personnel, supplemented by review of system development documentation. This should include a comparison of liaison objectives with actual performance. It should also include an analysis and explication of the limitations and constraints under which liaison must take place.

2. Review and description of methods and procedures currently available for the establishment, maintenance, and control of organizational liaison and technical communication.

3. Establishment of an idealized model for human factors liaison on the basis of existing organizational-communications models and through creative development.

4. Establishment of realistic objectives for human factors program liaison on the basis of analysis and comparison of results from one through three above.

5. Definition and development (as required) of methods and procedures for accomplishing the objectives established under four above.

6. Identification of the policy to be established or changed in order to facilitate or support the liaison procedures defined under five above.

7. Tryout and evaluation of liaison guidelines on one or more system development programs.

Relationship to Other Requirements

Improving liaison between development programs and laboratory efforts will enhance planning and control of human factors programs (7) by providing increased external verification for the program efforts and an increased data base for conduct of the program. The additional information from the laboratories resulting from improved liaison may be useful in all areas of human factors design and development activity.

Improved liaison should result in a more relevant definition of requirements for basic data concerning selected aspects of human functioning (1). The availability of technical reports will be improved (2) through liaison since access to informal reports and informal distribution of formal reports should both be increased as a result of stronger working ties. Improved liaison can be expected to result from and contribute to design and operation of a human factors data storage and retrieval system (3). Ultimately, the effectiveness of a human factors data storage and retrieval system will be limited by its use for both intra- and inter-program communication.

More effective communications between laboratory and applications personnel will almost inevitably improve the availability of information relevant to decisions about new research to be initiated (4) in support of development requirements. Improved communication within the human factors aerospace network will not necessarily improve communication between human factors personnel and other program personnel. However, to the extent the human factors network becomes an improved communications channel, improved techniques for cross-discipline communication should become more generally available. An analogous situation obtains with respect to definition of the appropriate role of the skilled worker in establishing system design requirements (6).

Liaison research might be included with the development of integrated procedures for human factors program planning and control (7) and/or with research and development involving the improvement of technical report availability (2), development of a human factors data storage and retrieval system (3), development of procedures for determining applied research needs (4), and improvement of communications between human factors personnel with others (5). All areas of human factors activity will generate appropriate technical content for liaison and will, therefore, necessarily be involved in liaison research.

REQUIREMENT 7.2: AN IMPROVED SYSTEM FOR CARRYING OVER DATA FROM ONE PROGRAM TO ANOTHER

Delineation

It has been contended that there is both an excessive lag in the availability of human factors data from one program to another and an unfortunate loss of data and experience in the transfer. At the present time, neither the types nor amounts of data to be transferred are well defined. Less yet are the procedures for optimum transfer clearly delineated. There appears to be a general, but vague, feeling among human factors personnel that too much potentially valuable experience from one program is not available at the proper time for other related programs, whether they are overlapping or sequential.

Consequences

If it is in fact true, as some human factors personnel have claimed, that there is a serious inability to capitalize on the experience of earlier programs, the consequences are likely to include the following:

1. Wasted time in trying to obtain relatively inaccessible data.

2. Duplication of effort in resolving problems to which answers already exist.

3. Sub-optimization of design either because available resources were unnecessarily expended on redundant effort or because solutions on subsequent programs might actually be inferior to earlier programs.

Research and Development

Research and development operations relating to the carrying over of data from one program to another might include the following:

1. The verification of a need for increased carry-over through the gathering of reports on actual instances in which non-access to available experience was detrimental to an aerospace program.

2. Codification and classification of the varieties and amounts of information which can productively be used on other programs.

3. Evaluation of benefit in comparison to the costs of making data available.

4. Delineation of specific policies, procedures, and techniques for the carry-over of data from one program to another.

5. Theoretical and empirical comparison of advantages and disadvantages of having support responsibilities for different human factors areas assigned to centralized groups versus relatively complete human factors responsibility within the project office.

Relationship to Other Requirements

The most promising route to improvement in carrying over data from one program to another is in development of a human factors data storage and retrieval system (3). Improved availability of technical reports from system development programs (1) will also be of potential benefit in carry-over from one program to another. Data and experience are, of course, an obvious starting point for human factors planning for a new system (7) in all areas of endeavor.

Research and development for improved carry-over of data from one program to another might be included with development of integrated program planning and control procedures (7), development of improved technical reporting techniques, or with development of a human factors data storage and retrieval system (3).

REQUIREMENT 7.3: IMPROVED DEFINITIONS OF HUMAN FACTORS PERSONNEL, ORGANIZATION, AND RESPONSIBILITIES

Delineation

There are a variety of questions which must be answered in defining who human factors personnel are and determining what their responsibilities should be. Included among these questions are:

1. What should be the nature of Government requirements for a human factors program in space system development? There appears to be general agreement, at least within the human factors community, that some type of Government requirement is appropriate; but there is far from uniform agreement as to its extent or nature. Adequately justified cost guidelines are not generally available. It is not difficult to find Government personnel who feel that greater specification of areas for human factors support on the part of contractors is required. Neither is it difficult to find contractor personnel who feel that their human factors efforts are already over-controlled, sometimes to the detriment of achieving the most effective system. The relative roles of written specifications and Government technical monitors have not been well established. The desirability of clear responsibility is generally agreed upon; but the nature of optimum allocation of responsibility is not in itself clear.

2. What should be the role of human factors personnel? It is practically a truism among human factors personnel that they feel they should participate in early system analysis and design when doctrine concerning man's role is being decided. However, the role of human factors at this crucial stage is not well defined. It has even been suggested that the term "human factors" does not carry an appropriate system connotation and, in addition to better ways to integrate human factors into systems analyses and design, a new term is needed. The problem of "power" is relevant to defining the human factors role since the quality of human factors actually incorporated in a system will depend to a large extent upon the power of the industrial human factors group. Power in this instance probably connotes some signoff responsibility, but it has long been generally agreed that

the primary role of the industrial human factors engineer should not be that of an inspector, however appropriate that role might be in final Government acceptance of the system. The issue of the relationship between human factors personnel and engineers is also relevant here. Air Force experience has suggested that it is not sufficient simply to provide human factors data to engineers in order to ensure good human factors design. Rather, it has been suggested that the human factors specialist must play an active role in the design. In addition, it has been suggested that offers of piecemeal support to the engineer are less effective than definite objectives and a program on the part of the human factors specialists. Finally, there is the issue of balance among the various human factors roles. For example, it has been claimed that there is a tendency in NASA to believe that solving <u>human engineering</u> problems will automatically solve other human factors problems such as selection and training, although this is not necessarily so.

3. What should be the characteristics of human factors personnel? The central issue here seems to revolve about the relative importance of systems engineering versus specialized knowledge in some life sciences discipline. At the extremes, it seems to be generally clear that specialized life sciences personnel have a role in providing data to the development effort and that a systems engineer is ultimately responsible for the incorporation or non-incorporation of the data in design. There is, however, a wide area of ambiguity between the extremes. Also, the potential contribution of experienced personal-equipment and crew-stations design personnel who have little formal human factors knowledge is not well defined.

4. What should be the structure and composition of human factors groups? The basic issue is whether or not there should be human factors groups as such in system development efforts. There are obvious advantages to having integrated design groups with all of the relevant disciplines permanently represented. In particular, the responsibilities of such groups can be made very clear since they are responsible for specific products. Also, the human factors person can work closelv with the engineers to ensure that human factors considerations are being taken into account and he will have direct access to design information at each stage. The major disadvantage of assigning small groups of human factors people to specific developmental efforts is the possibility of their losing touch

with their parent discipline and becoming submerged in the specific system details. It has been suggested that design groups composed of about equal numbers of engineers and human factors personnel are ideal, although systematic verification of this ratio is lacking. The particular mix for different types of design groups has not been defined in any general way. An additional issue is the establishment of organizational structures such that the various areas involving human factors will be maximally coordinated. That is, the organizational framework for human factors personnel should facilitate coordination across areas such as operator station design, maintenance, training, etc. It is also desirable that organizational structures facilitate compatibility of techniques across different design groups involving human factors. Finally, since human factors talent can be expected to be in short supply for the foreseeable future, organization should support the making of key system decisions by top people, with less highly qualified people focusing on specific details.

Consequences

Failure to define adequately the role of human factors personnel results in waste of human factors talent which is already in short supply, in the making of design and development decisions concerning human factors without adequate information, and in less coordinated treatment of various areas of human factors concern than could readily be achieved with better defined roles.

Research and Development

Research and development directed toward an improved definition of human factors responsibilities and roles might include:

1. A comparison of organizational structures for human factors currently existing, or recently abandoned, within the aerospace community. This description and comparison should involve an explication of the rationales for the various organizations and evaluation of the effectiveness of various configurations.

2. A review of organizational theory and principles and their current applications in a variety of technical fields. In particular, a study should be made of the rationale underlying organization and operations for total system development.

3. Development of model human factors organizational structures and information networks to handle the full spectrum of space system problems and constraints, including different types of parent organizations.

4. Delineation of appropriate human factors responsibilities and principles of organization.

5. Tryout of guidelines for human factors organization and role in actual space system development efforts.

Relationship to Other Requirements

Definition of the human factors role is central to the development of integrated planning and control procedures (7). It will also interact importantly with all of the areas of human factors activity. The variety of roles defined for human factors personnel will also play an important part in optimizing a human factors data storage and retrieval system (3). In part, the definition of role for skilled workers in establishing human factors requirements (6) and the role for human factors personnel are interdependent.

Any research and development related to a definition of human factors personnel, their effective organization, or assignment of responsibilities necessarily has direct implications for integrated procedures for human factors program planning and control (7), and might well be subsumed under the development of such procedures. In particular, definition of the human factors role should be fully coordinated with research and development relating to improved human factors objectives and milestones (7.4) and definition of input and output needs (7.5). To a lesser extent, it is desirable that coordinate definition of general responsibilities and development of integrated procedures in all of the areas of human factors activity proceed simultaneously. However, establishment of a reasonable set of working assumptions about responsibilities and roles should probably suffice for major advances in each area until more intensive research and development toward improved definitions of human factors personnel, organization, and responsibility can be accomplished.

At least rudimentary progress toward definition of human factors organization and role is essential in the development of a human factors data storage and retrieval system (3) and in improving communication between human factors and other program personnel (5).

REQUIREMENT 7.4: IMPROVED HUMAN FACTORS OBJECTIVES AND MILESTONES

Delineation

The final and interim products of human factors in system design are not well defined in any general way. This results in less clear objectives and milestones for specific programs than is desirable for maximum contribution. Realistic intermediate goals for key points in the program are important. Identification of the goals which a human factors program can and should achieve, determination of optimum ways for reflecting goal achievement in specific products, and specification of ways in which goal-achievement can be evaluated can potentially make substantial contributions to improved effectiveness in human factors programming for space system development.

Consequences

The immediate consequence of not having more clearly defined objectives for human factors programs in space system development is great difficulty in assessing the value of such programs. There are inadequate criteria by which to judge the adequacy of human factors program performance. Also, it would seem probable that a program for which neither interim nor final products are carefully specified at the outset will be less effective than one for which products are required on an organized basis and for which the standards of performance are made explicit.

Research and Development

Human factors objectives and milestones are tied to the over-all space system development in two important ways. First, the final criterion of effectiveness for a human factors program is its contribution to the total system design. Second, feasible human factors objectives are constrained by the nature of the total system development program. For both these reasons, it would seem that research and development for human factors objectives and milestones must emphasize review and analysis of the space system development process in order to identify desirable and feasible human factors contributions.

Research and development for human factors objectives and milestones might include the following activities:

1. Analytic review of the objectives, constraints, and work flow for a number of space system development programs. From this review should emerge a model or general framework suitable for defining the contexts in which human factors work is to make its contribution.

2. Review and description of existing and past human factors aerospace programs to identify potential objectives and milestones.

3. Analytic review of guidance documentation concerning the conduct of human factors programs to augment and verify data from specific programs.

4. Preparation of general guidance concerning appropriate objectives and milestones for a human factors program in development of a space system.

5. Tryout and verification of guidance on one or more actual development programs.

Relationship to Other Requirements

This requirement for improved milestones and objectives is most closely related to the requirement for improved definition of human factors input and output needs (7.5). However, this requirement is more concerned with what should and should not be built into human factors programs in the way of schedules, interim and final products, program review and evaluation techniques. The input-output requirement (7.5) is more concerned with data flow to support whatever program is defined and scheduled.

Research and development on objectives and milestones might readily be combined with development of integrated procedures for human factors program planning and control (7) and/or with development of a human factors storage and retrieval system (3).

Objectives and milestones will, of course, come from all human factors areas and serve to motivate and constrain all areas.

REQUIREMENT 7.5: IMPROVED DEFINITION OF HUMAN FACTORS INPUT AND OUTPUT NEEDS ON A PROGRAM TIME SCALE

Delineation

There is general agreement that inputs to and outputs from a human factors program need to be determined relatively early in space system development. However, there is no generally available or accepted set of inputs and outputs. Further, there is no generally accepted technique for establishing input and output needs for a specific human factors program.

Aside from not having any general taxonomy of inputs and outputs, the major problems in defining input and output needs can be organized into three general areas:

1. Program control techniques.
2. Reporting.
3. Data form and specificity.

Program control techniques. Various system management and other policy documents, particularly for the Air Force, describe program phasing and approaches to program control. No one approach, however, seems to have gained wide or enthusiastic support for programming human factors in space systems.

The most widely used general program control technique at the present time, of course, is the Program Evaluation and Review Technique (PERT). There are some human factors personnel who feel that PERT is of value in planning and controlling a human factors program. It is felt that, if human factors is to be part of a PERT network, it is imperative that human factors personnel get into the program early and interact extensively with Government project personnel if the effort is to have merit. Experience on at least one major program suggested that PERTing by functional areas such as biomedical, human engineering, etc., did not work nearly so well as did PERTing according to major developmental threads such as preparation of crew performance specifications.

It is not difficult to find human factors personnel who are opposed to PERT as an aid to effective human factors programming. It is felt by some that PERT is simply not suited to the human factors problems or, at best, it requires a great deal more work than it is worth. It has been claimed that the trouble with PERT is the basic data. The first line supervisor is asked what he is going to do. This is then built into the network and goes back to him to manage his efforts, but he didn't know what to do in the first place. In general, it would seem that, with the current state of human factors technology, PERT is of ambiguous value as a human factors programming tool.

The reaction to the Air Force personnel subsystem guidance seems to be even less favorable than the reaction to PERT, ranging from a feeling that it results in a great deal of data which is of doubtful value to four letter vulgarisms. The System Analysis and Integration Model (SIAM) (Shapero & Bates, 1959) seems to have received no wider acceptance, being criticized as too time consuming and costly for its benefits except as an aid to specialized analyses for problem areas.

Matrices, functional analysis, and block or flow diagrams have all been suggested as useful techniques in planning and control of human factors programs. There seems to be no formal technology to support the application of these or other techniques at the present time, however.

Reporting. There seems to be no major controversy about the necessity for extensive reporting of human factors activities. However, there does seem to be disagreement about the desirability of separate human factors reports versus integration of human factors data with other reports. There is no set of organized criteria for choosing between these alternatives in either general or specific cases.

Data form and specificity. It is commonly thought that human factors data, especially data about human performance, are too general to be immediately applied to most system design problems. On at least one major space program all reports too and from the human factors group are funneled through a group of senior engineers for review and editing to ensure maximum transfer of information in both directions. In another context, it has been claimed that the most serious lack is not information but techniques to ensure that information is usable and used. It has also been suggested that general guidance would be useful for the preparation of data-collection forms.

Consequences

Failure to define more adequately the inputs and outputs of a human factors program will continue the relative lack of communication between human factors and other program personnel, result in continued generation of unused human factors data, and perpetuate the relative isolation of human factors which is still typical of many programs.

Research and Development

Research and development aimed at enhancing the definition of human factors inputs and outputs might include the following activities:

1. Identification of both real and theoretical information flow on existing programs.

2. Identification of discrepancies between theoretical and real communication and generation of principles for minimizing such discrepancies on future programs.

3. Review of input-output considerations for other disciplines such as reliability, maintenance engineering, etc., to derive ideas and methods applicable to human factors.

4. Preparation of models for ideal human factors program communication.

5. Identification and explication of the constraints for inputs and outputs for a human factors program in space system development.

6. Development of practical procedures for establishing input-output schedules on specific programs.

7. Codification of the classes and types of human factors inputs and outputs relevant to space system development.

8. Tryout and evaluation of guidance concerning human factors communication on actual system developments.

Relationship to Other Requirements

The input-output area can certainly be explored in conjunction with more general research concerning program planning and control (7). The close relationship of this requirement to objectives and milestones (7.4) has already been pointed out.

Improved information concerning inputs and outputs for human factors programs will help to define requirements for basic data concerning human functioning (1) and the nature of requirements for improved availability of technical reports (2). The relationship of the input-output requirement to the development of a human factors data storage and retrieval system (3) is an extremely close one since the data storage and retrieval system should have as its major objective the expediting of inputs and outputs. However, there is an important distinction between the two requirements in that the input-output requirement is primarily directed at defining the communication which should occur during the life of a human factors development program; whereas, the data storage and retrieval system has as its major emphasis flexibly supporting whatever communication is, in fact, involved in a program and across programs.

The major content of inputs and outputs will, of course, be determined by the various areas of human factors activity.

REQUIREMENT 8: INTEGRATED MAN-MACHINE FUNCTION ALLOCATION PROCEDURES

Delineation

There are few objective techniques for making man-machine function allocation. An effective cross-discipline method for making tradeoffs is required. The problems of function allocation are especially great for space systems because of their research nature, which tends to make the carryover from one system to the next less than is the case with operational systems. Also, the usual problems of functional allocation are complicated by special information requirements in areas such as the following:

1. Unusual environmental constraints.
2. Special sensitivity to work-rest cycles.
3. Numbers of people versus space requirements.

Consequences

Inappropriate function allocation will result in excessively costly and potentially unreliable systems which require excessive development time. Also, inadequate attention to human requirements during early conceptual design can inadequately allow for human limitations and unnecessarily strain human capabilities.

Research and Development

Development of integrated man-machine function-allocation procedures will consist primarily of pulling together the results of specific research and development under the various sub-requirements of this general area. It may include additional specialized research as needs are identified, either on the basis of meeting the individual requirements or in integrating them into the total function allocation procedures.

Relationship to Other Requirements

Basic data concerning selected aspects of human functioning (1) and special research aimed at supporting function allocation (4) will play an important role in function allocation. Results of system, function, and task analysis (9) from both the system under development and from previous systems will also play an important role.

Interview Comments	No. of Interviews
Function allocation is extremely important. We must, however, start out with some policy. For example, we might start off by assigning everything to the man that isn't ridiculous. Iteration can then be used to back off from the original allocation toward a more optimized allocation. Improved methodology in this area is highly desirable.	1
Improved techniques and models for optimizing tradeoffs between automation and manual operations are required.	4
Improved techniques are required for obtaining, organizing, evaluating, and comparing the following tradeoff factors:	9
Equipment information.	5
Data on human capabilities and limitations.	1
Task analyses, including work overload.	3
Operator acceptance limits.	1
Human and equipment reliability data.	2
Cost information.	1
Total mission requirements.	2
Population resources.	1
Improved quantification of human performance data is required for effective man-machine function allocation.	2
Where decision or action speed is critical, there is a dynamic interaction between function allocation to the man and information sampling rates--predictive displays.	1
The concept of function allocation for systems having research as their primary mission is not yet well established.	1
Improved techniques are required in cases where man is already a "given" in the system, for logical and systematic allocation of functions to man, even though he may not be able to perform them as well as a machine.	1
There are many unknowns concerning the optimum man-machine allocation in other than near-earth orbital vehicles. Man-machine allocation may be made systematic and rational, but emotional, philosophical, and political considerations are likely to override.	1

	No. of Interviews
Simulation and game theory are desriable to predict human behavior for space systems, but they are currently difficult to apply.	2
Current NASA emphases in function allocation are wrong, resulting in extreme hardware sophistication and concentration on man's back-up functions. There is need to concentrate more on his primary functions.	1
Man-machine function allocation must be performed concurrently with design. It is a problem to keep up-to-date with task data for each crew member. A computerized analysis and retrieval system is very desirable.	1
The current pool of human performance data is weak. A centralized pool needs to be established.	2
The philosophy and history of earth exploration needs to be examined for ideas useful in allocating functions to man in space exploration.	1

REQUIREMENT 8.1: POLICY CONCERNING MAN-MACHINE TRADEOFFS

Delineation

Function allocation must begin with some policy which establishes objectives, defines constraints, and sets the rules by which the allocation will be accomplished. For example, policy may be to start off by assigning everything to the man that isn't ridiculous. Iteration can then be used to back off from the original allocation toward a more optimized allocation. There is some feeling that the current emphasis in NASA is wrong. It is an outgrowth of the missile business and does not place enough emphasis on the man but does place too much emphasis on the hardware. This results in extreme hardware sophistication and an attempt to make everything fully automatic. Because of this hardware philosophy, there is concentration on the identification and implementation of man's backup functions. Future systems should concentrate more on simplifying the hardware and exploiting man's primary functions.

A policy for function allocation should include the following elements:

1. Consideration of the fact that if a man is required for any purpose at a given place within a given block of time, he should be fully used unless this utilization will be detrimental to system performance.

2. Consideration not only of the original allocation, but of verifying that a given allocation is, indeed, optimum by stated criteria.

3. Rules for generalizing from old designs to new systems and justifiable bases for deviating from established tradition.

4. An indication of allowable assumptions about the population from which system personnel can be drawn.

Consequences

Failure to provide an explicit policy for function allocation may have at least the following direct consequences:

1. A patchwork of inconsistent decisions about man's role which optimize no general criteria.

2. Allocation decisions which optimize by criteria other than those which are ultimately desired.

3. Design specifications that inadequately allow for the man and his job. Such specifications are likely to result in many modifications to the vehicle and to personal equipment which will be expensive and time consuming.

Research and Development

Research and development relating to man-machine tradeoff policy might include the following activities:

1. Review of previous function allocation decisions and explication of the policy underlying such decisions. In which case, the actual alternative chosen might be critiqued in terms of a retrospective judgment of its appropriateness. In particular, operational incidents involving space systems might be reviewed in order to determine the possible effect of different functional allocation decisions.

2. Gaming or simulation of various types of space missions with alternative policies, doctrines, or strategies for function allocation. Results of the various games or simulations might then be assessed as a function of the alternative policy.

3. Review of the role played by various personnel in a variety of earth explorations in an attempt to identify ideas which might be useful for man's role in space.

4. Review of various human factors and other methodological documents to identify policy elements and alternatives.

5. Development of alternative policies and application to realistic problems, followed by critique of the results of these applications.

Relationship to Other Requirements

Policy concerning function allocation will have important implications for the form in which research data were reported (1) and in the kinds of applied research undertaken (4). Also, this policy can have an important effect on the demands placed on the storage and retrieval system (3), the nature of communication between human factors and other program personnel (5), the role played by skilled workers in establishing requirements (6), the nature of liaison between programs and laboratories (7.1), and the definition of human factors responsibilities (7.3).

REQUIREMENT 8.2: TRADEOFF MODELS FOR FUNCTION ALLOCATION

Delineation

There is virtually no theory or systematic rationale underlying man-machine function allocation. Neither are there pure cases or clearly identified extremes of the function allocation problem. Perhaps most seriously, there is no rigorous idealized model of the process which is isomorphic to realistic function allocation problems.

Consequences

Lack of even a rudimentary rigorous model for function allocation means that function allocation decisions must be made on an ad hoc and generally informal basis. Although the clear intent of functions allocation is to optimize system performance, lack of a rigorous definition of optimum makes the probability of inadvertent sub-optimization high.

Research and Development

Development of models for tradeoffs between men and machines must necessarily be largely a creative, and probably individualistic, process. However, there are some existing mathematical and logical systems which seem to be worth consideration as points of departure for models of the function allocation problem. These include information theory, dynamic and linear programming, and computer simulation techniques. Models of man-machine allocation must not only be systematic and rational but must also allow for optimization of residual degrees of freedom when certain decisions have been pre-empted by emotional, philosophical, and political consideration.

Relationship to Other Requirements

The form and parameters of function allocation models will have important implications for data on human characteristics from all sources.

REQUIREMENT 8.3: IMPROVED TECHNIQUES FOR MAKING PERFORMANCE, RELIABILITY, AND COST COMPARISONS BETWEEN PERSONNEL AND EQUIPMENT

Delineation

Functions allocation is a major interface between the engineer and human factors personnel. At this interface it is essential that the two disciplines have a common language or basis for comparison. More specifically, there must be a common language for describing the following characteristics of both personnel and equipment:

1. Performance characteristics including not only performance time and accuracy but capability for overload and ability to perform at all under limited conditions.

2. Reliability not only in terms of mean time to failure but also including the degree of failure, probability of self-correction, and consequences of various classes of failure.

3. The cost in terms of development time, payload, and dollars; as well as other cost factors relevant to the specific system context.

4. Capability for use for multiple functions, as, for example, the capability of a computer to check itself.

Consequences

Failure to provide a common language for equipment and personnel is likely to result in the making of allocations on the basis of differences in terminology rather than on the basis of functional capability.

Research and Development

Research concerning bases for making comparisons between personnel and equipment should include at least the following activities:

1. Evaluative review and codification of existing techniques for making personnel and equipment data comparable.

2. Selection of a sample of representative man-machine function allocation problems and delineation of all of the bases on which personnel and equipment might be compared.

3. Selection of the most promising techniques and further development of these techniques.

4. Evaluative tryout of techniques and procedures for comparing personnel and equipment.

Relationship to Other Requirements

Definition of the dimensions on which man and machine comparisons are to be made will have important implications for all human research data. They will also have important implications for the manner in which functional and task data are obtained and reported (9).

REQUIREMENT 8.4: QUANTITATIVE DATA ABOUT HUMAN PERFORMANCE

Delineation

Perhaps the most obvious and serious limitation on effective man-machine function allocation at the present time is a lack of quantitative data about human performance. Although an identification of possible personnel functions and tasks may become available early in system conceptualization, information is likely to be of relatively little use in function allocation until it can be translated into performance and quantitative estimates of performance levels.

Consequences

Until generally satisfactory techniques for the quantification of function and task requirement information become available, it is unlikely that the state-of-the-art in function allocation will advance significantly.

Research and Development

Preliminary progress has been made toward the quantification of human performance from function and task information in the development of a general store of compatible quantitative estimates of performance time and reliability for a relatively wide variety of behaviors (Payne & Altman, 1962). It was found during the current survey that this data store is being expanded, modified, and used at the present time in a number of system development efforts.

It should be noted, however, that the original intent of this data store was much more limited than the current applications. It is clear that a reconceptualization and expansion of existing techniques is in order. Recent publications and symposia (Irwin, Levitz, & Freed, 1964; Rook, 1962; Smith, 1961; Williams, 1958; Brady, 1962; Meister, 1962; Majesty, 1962; Rabideau, 1962; Meister, 1962; Swain, 1963) suggest the gradual emergence of a technology in this area. A symposium on quantification of human performance is scheduled for August of 1964 at the University of New Mexico. This symposium is further evidence of current interest in this area.

Relationship to Other Requirements

This requirement is essentially a sub-requirement to improve techniques for making comparisons between personnel and equipment (8.3). Quantification of data about human performance, however, is of central importance to the entire development of improved function allocation procedures.

REQUIREMENT 8.5: ESTABLISHMENT OF CRITERIA FOR DESIGN AFFECTING THE HUMAN

Delineation

Reliability, performance, and cost criteria have already been suggested (8.3) (8.4). There may, however, be additional criteria which are relevant to function allocation. For example, the acceptability of allocation decisions may transcend any rational model of which the state-of-the-art is currently capable.

Consequences

Failure to identify all of the potentially relevant criteria by which function allocation may be judged can lead to later unnecessary reversals of allocation decisions.

Research and Development

Research in this area might include review of past allocation decisions and later modification of decisions in order to identify the application of criteria which are not currently obvious.

Relationship to Other Requirements

This requirement is essentially an adjunct to tradeoff models (8.2) and comparison techniques (8.3).

REQUIREMENT 8.6: A TECHNIQUE FOR INTEGRATING HUMAN PERFORMANCE DATA FROM DIFFERENT SOURCES

Delineation

Human performance information relevant to function allocation will undoubtedly come from a variety of sources. These will include information from previous systems, simulation exercises, general handbooks and data stores, and estimates based on function and task analyses. Further complicating the problem of these multiple sources are:

1. The possible simultaneity or proximity of tasks.

2. Variable environmental considerations.

3. Differences in motivational and anthropometric baselines for NASA personnel versus standard reference populations such as the Air Force.

4. Combination of functions allocated to a single individual which may make for unreasonable selection of training requirements.

5. Concurrence of man-machine function allocation with design, which results in a dynamic and changing situation.

Consequences

Failure to adequately integrate all of these multiple sources and considerations is likely to result in the use of only part, and quite possibly the least cogent part, of the available data.

Research and Development

Research in this area should take an extensive sample of performance data from all of the varieties of sources and all of the complicating circumstances. Individual situations should then be worked out on the best basis possible. These data should be supplemented by specific reports of analogous situations in actual system development. These specific resolutions of allocation problems should then be generalized into principles and techniques for data integration.

Relationship to Other Requirements

It would ultimately be desirable to establish compatible procedures for all potential sources of human performance data so that requirements for reconciliation would be minimal. Also, it would ultimately be desirable for the human factors data storage and retrieval system (3) to include a sub-routine for optimum data reconciliation.

REQUIREMENT 8.7: A CONSISTENT BASIS FOR MEASURING, DESCRIBING, AND ESTIMATING THE IMPACT OF ENVIRONMENTAL FACTORS ON PERFORMANCE

Delineation

The difficulties of obtaining consistent quantitative performance measures and estimates for relatively standard conditions have already been mentioned in a number of contexts. These difficulties are, of course, considerably complicated by the varieties of unusual environments which are relevant to the problem of space system development. To mention only a few of the more obvious problems, there is a need for consistent scaling of effects from multiple environmental stresses, various methods of remote manipulation, acceleration and reduced gravity, and tumbling. Complicating this problem is the problem of scaling field responses to laboratory responses.

Consequences

Failure to achieve consistent scaling of environmental influences very likely would result in gross misinterpretation of the available data, at least in some cases.

Research and Development

There seems to be no short cut to a program of rigorous research concerning the various environmental effects and a constant checking against field data. However, it would appear that substantial improvements in efficiency can be achieved by a centralized "bookkeeping" and specification of reference conditions.

Relationship to Other Requirements

It is essential that work toward this requirement be closely coordinated with work on quantification of human performance data (8.4). Progress in both of these areas will have direct implications for basic data (1) and for definition of research requirements (4). Additionally, progress in these areas will have important implications for the human factors data storage and retrieval system (3) since quantitative human performance data will, hopefully, be a major type of content for this system.

REQUIREMENT 9: INTEGRATED SYSTEM, FUNCTION, AND TASK ANALYSIS PROCEDURES

Delineation

The requirement for improved system, function, and task analysis procedures represents a paradox. In one sense, there is no such requirement because few, if any, respondents indicated that they could not obtain adequate personnel function and task data from existing procedures. Rather, most indicated that these procedures are essentially adequate. In another sense, the requirement for improved system, function, and task analysis procedures represents a central requirement. Certainly, function and task data represent the central information core of most human factors programs, particularly those human factors aspects having to do with human performance rather than with life support. However, considerable dissatisfaction was expressed with the use of function and task data in most programs. It would seem, then, that the essence of this requirement is to have function and task data available when they are needed and in a form which can be readily used. This will mean that not only will system, function, and task analysis procedures have to be established in such a way that they are compatible with program decision-making processes, but that program planners will have to be aware of the capabilities represented by function and task analysis.

There is currently considerable flexibility and variability in the application of techniques in different organizational contexts and to different kinds of problems. Such flexibility and variability is desirable and should not be reduced by future developments in system, function, and task analysis techniques. However, there is also reported considerable variability in the quality of task and function data turned out by different groups and also considerable variability in the utilization in different programs and different parts of programs. These latter kinds of variability should be reduced through a general increase in the quality of data derived and with maximum utilization rates.

Consequences

Failure to improve system, function, and task analysis procedures will result in continued undesirable variability in the quality and utilization of data. System effectiveness may be diminished due to decisions made on the basis of partial human factors information.

Research and Development

Research and development for this requirement will consist essentially of incorporating the results of the specific requirements within this area to a consistent total package. The resulting specification of system, function, and task analysis must be compatible with all of the other human factors area requirements (7, 8, 10-14).

Relationship to Other Requirements

In addition to the relationships implied under the research and development section, there will also be an important interaction with development of a human factors data storage and retrieval system (3), since one of the major current problems with the use of system, function, and task data is the lack of accessibility and flexibility in making modifications. Both of these problems can be more effectively resolved with a human factors data system than they can currently using manual techniques.

Interview Comments	No. of Interviews
Improved system, function, and task analytic data are needed to accomplish more effectively:	11
Definition of "acceptable" human performance standards.	1
Over-all programming of the human factors effort.	1
Function allocation.	1
Human engineering.	4
System simulation.	1
Definition of research requirements.	1
Determination of human transfer functions.	1
Forecasting of mission decisions and information requirements.	1
Preparation of general requirements and standards.	1
Description of anticipated environmental requirements.	1
Quantification of performance predictions.	2
Current analytic techniques are inadequately integrated or compatible with the general body of human factors data, resulting in an inadequate role for human factors in the early conceptualization of the system and excessive "unique" analysis during later stages of design.	6
In industry, particularly at proposal preparation time, there is not time for the hit-or-miss approach that has typified functional analyses.	1
Matrices, information theory, computerized models of operator loading, and the American Institutes for Research operability index are tools having promise for improving human factors analytic techniques.	4
Analyses should cover all functions which the man might perform and not just operational tasks.	1
System, function, and task analysis have never accurately predicted human reliability. In addition to the kinds of time estimates currently associated with task analysis, engineers want confidence limits for the estimates. A general methodology for estimating reliability and time effectively would be highly desirable.	1

	No. of Interviews
Nobody has developed a really good technique for contingency analysis. This is particularly critical for long-term missions.	1
We don't really know much more at the present time about how to extract skills and knowledges than we did 10 years ago. This is still an important problem.	1
Improved techniques are needed for estimating the criticality of tasks and establishing priorities for their detailed description and analysis.	3

REQUIREMENT 9.1: IMPROVED DEFINITION OF PURPOSES FOR SYSTEM, FUNCTION, AND TASK ANALYSIS AND PROCEDURES FOR APPLYING THEIR RESULTS

Delineation

For more than a decade, efforts have been made to define the purposes for such analyses. Examples of such efforts include the work of Van Cott and Altman (1956), Rabideau, Cooper, and Bates (no date) in a joint effort by the American Institutes for Research staff (1960), in the most recent statement by Robert B. Miller (1962), and the Handbook of Instructions for Aerospace Personnel Subsystems Designers (HIAPSD). Even today, in the context of advanced space system development, little fault can be found with the statements of objectives found in these and other documents. However, the simple fact seems to be that, in many instances, even simple or rudimentary human factors system, function, and task analysis are not being undertaken to support design decisions for which they are considered to be appropriate. In other instances, available system, function, and task analysis results are either ignored or considered not to be adequate to support the very types of design decisions for which they are intended.

Assuming that the stated purposes and basic techniques of system, function, and task analysis are appropriate; it would seem that problems of non-use must result from one or more of the following:

1. Poor phasing.
2. Inaccessibility of the data.
3. Inappropriate form or level of the information.
4. Inappropriate role of human factors personnel in the decision process.
5. Lack of awareness on the part of key decision makers of the capability represented by system, function, and task analysis techniques.

Consequences

The techniques of system, function, and task analysis represent major forward steps in the formalizing and systematizing of human factors programs. With the increased sophistication of space systems, the need for formal and systematic techniques will evitably increase. Failure to use these available techniques will result in the use of ad hoc procedures and expertizing in situations where they are increasingly inappropriate.

Research and Development

The important first step in research leading to improved use of system, function, and task analysis must be an identification and examination, in detail, of instances where results of such analyses were, in fact, found to be useful in making of critical system decisions. Also, instances must be identified and examined in which:

1. Analyses were not performed even though they would have been appropriate to support decision making.

2. Analytic results were available, but were not used in the decision process because:

    a. Decision makers were not aware of them or of their potential use.

    b. An attempt was made to use them, but they were found not to be useful.

The results of the first phase effort must then be integrated into a definition of the critical factors that make for use and non-use of system, function, and task analysis results. Once these critical factors have been identified and delineated, a matrix of types of analyses, levels of analysis, purposes, phases of development, and program context must be established. Included throughout this framework for defining analytic requirements, must be a statement of the role which human factors personnel must play in order to ensure appropriate use of results.

Relationship to Other Requirements

The role of system, function, and task analysis is an important determinant for the content of procedures for human factors program planning and control (7).

REQUIREMENT 9.2: A BASIS FOR RELATING NEW TASK REQUIREMENTS TO THE BODY OF AVAILABLE HUMAN PERFORMANCE INFORMATION

Delineation

System, function, and task analysis have never been highly accurate predictors of human reliability. In addition to the kinds of time estimates currently provided by these analyses, systems engineers want confidence limits for the estimates. A general method to provide effective reliability and time estimates would be highly desirable.

There are a number of problems in providing the desired kind of methodology. The existing body of performance information is not entirely adequate to support the development of aeronautical and ground systems. It is extremely limited with respect to space system tasks. The generation of an adequate body of knowledge is likely to be hampered by incompatibilities between both the values and language of the laboratory psychologists who are the most likely persons to generate the data and those in space programs who require it.

At some point, the body of performance information needs to be scaled against actual system performance by skilled operators. The number of such skilled operators is, and is likely to remain, quite small. Opportunities to observe actual space system past performance is likely to remain quite limited.

All of this suggests the need for highly efficient methods of generating the required performance data and for relating these data to system, function, and task descriptions. Basic to this entire problem is a classification of behavior in common between the methods for analyzing systems, functions, and tasks and the body of performance information.

Consequences

Failure to relate task requirements to performance data will mean that analytic procedures will have limited application regardless of how well they are defined and prescribed in other respects.

Research and Development

The initial requirement is for a conceptual framework which places function and task requirements on a common base with performance information. Analytic procedures will then have to be cast in a form which generates requirement information in compatible form.

Relationship to Other Requirements

This requirement is the source of quantitative performance information specified for all areas of application, including function allocation (8.6), human engineering (10.13), and system evaluation (14.5).

REQUIREMENT 9.3: A TECHNIQUE FOR IDENTIFYING COMMON TASKS AND ABROGATING THE NEED FOR REDUNDANT ANALYSIS

Delineation

A great deal of system, function, and task analysis work is performed which is not used in the making of important system decisions. One of the reasons for this seems to be that many of these analytic results seem redundant to information which is already known. If the system, function, and task information which is redundant to previous systems could be early and easily recognized, the efficiency of detailed analyses could be substantially enhanced. However, there is, at present, no generally accepted technique to aid the identification and judgment of commonality.

Consequences

The principal consequence of not having an appropriate technique for judging function and task commonality is that a great deal of work goes into analysis of redundant material, when it could be much more profitably expended on detailed studies of unique performance aspects for the new system.

Research and Development

There is not likely to be a fully satisfactory solution until what Robert B. Miller (1962) has called a task taxonomy has been established. Certainly this requirement supports the hopes for the development of such a taxonomy. However, until the possibly distant day when such a taxonomy is available, there are some more immediate actions which can be taken to improve the identification of function and task redundancy with minimum analytic work during the development of a specific system. This work might proceed along two related lines:

1. Microscopic study of the decision and judgmental processes by which expert analysts go through bodies of equipment and task data to decide where there are identities and commonalities.

2. Detailed review of the structure generated for equating task requirement and performance data (9.2). This review should lead to a differentiation of the implications of each category and dimension of the structure for selection, training, proficiency measurement, human engineering, performance aids, and system testing. These differential implications can then be related to the purposes for which system, function, and task analyses are conducted; in order that there can be a systematic statement of when there are functional equivalences even though there may not be total identity. That is, the similarity may be sufficient to obviate a need for special analysis for a particular purpose even though there is not total behavior identity.

Relationship to Other Requirements

The requirement for a technique for identifying common tasks is closely related to improving the definition of purposes for analysis (9.1) and developing a basis for relating task requirements to performance data (9.2). Work toward the development of a technique for identifying commonalities might be incorporated with either or both of these requirements.

REQUIREMENT 9.4: PROCEDURES FOR CORRELATING TASK REQUIREMENTS WITH ENVIRONMENTAL FACTORS AND PERSONAL EQUIPMENT AS WELL AS WITH PRIME EQUIPMENT

Delineation

There has always been a part of function and task analysis to include the environmental and personal equipment characteristics which might have an influence on selection, training, human engineering, or performance. The advent of space systems, particularly the long-duration mission systems of the future, creates a much more intimate relationship among performance, environment, and personal equipment. Consequently, analytic procedures of increased power and sensitivity are required.

Consequences

The principal consequence of failing to have adequately powerful procedures for identifying the effects of environmental and personal equipment characteristics will be a failure to predict significant human factors problems, at least until so late in the developmental sequence that they may either be inadequately resolved or may disrupt the program.

Research and Development

Development in this area might include a basic review of the biological, physiological, anthropometric, and environmental engineering variables which might be relevant to space flight and incorporation of these variables in standard system, function, and task procedures.

Relationship to Other Requirements

Work toward the accomplishment of this requirement might be part of work on the development of improved handbooks (2) and development of a data storage and retrieval system (3).

REQUIREMENT 9.5: PROCEDURES FOR CONTINGENCY PREDICTION AND ANALYSIS

Delineation

There is not currently available any really satisfactory technique for contingency analysis. This is a particularly serious problem for long-term missions.

Contingency analysis involves something of a dilemma. It is just because contingencies cannot be predicted that man is likely to play an important role in the non-routine aspects of long-term missions; whereas, computers can probably be programmed to handle most of the routine activities. There is, however, an important distinction between programming a man and programming a computer. At least, for the foreseeable future, man will accept considerably less specificity in his programming than will a computer. This means that contingency analysis and prediction of classes of contingencies for man are likely to be much more fruitful than analysis of classes of contingencies for computers. In both instances, the more specificity, the better. However, the criteria for acceptable detail can probably be much less stringent when one is doing contingency analysis for the man than if one is doing it for computer programming.

Consequences

Failure to provide adequate contingency analysis and prediction can result in unsatisfactory human factors design for the most critical aspects of system performance--response to unlikely or occasional events.

Research and Development

Development of improved contingency analysis procedures might include the following activities:

1. Identification of the varieties of contingencies which have occurred in advanced aeronautical and space systems.

2. Review of contingencies and classes of contingencies which have been identified for past systems and differentiation of those for which there are records of operational occurrence and those for which no such contingencies have been known to occur.

3. Application of 1 and 2 above to the known characteristics of future space systems to determine relevance, needed modification and extrapolation, and as an aid to identifying new classes of contingencies for the future.

4. Establishment of a contingency structure for future space systems.

5. Establishment of procedures for judging the relevance and forecasting contingencies within each of the classes.

6. Development and tryout of an integrated contingency analysis procedure, and relating of this procedure to the main body of system, function, and task analysis procedures.

Relationship to Other Requirements

This is a relatively independent requirement which will provide a major input to the development of integrated system, function, and task analysis procedures (9).

REQUIREMENT 9.6: COMPATIBLE PROCEDURES FOR ANALYZING THE REQUIREMENTS AND INTERACTIONS OF ALL ACTIVITIES, NOT JUST OPERATIONAL TASKS

Delineation

In previous systems, it has been possible to restrict analysis to tasks leading directly to mission accomplishment. In long-term space missions, however, it will be necessary to consider the nature of non-operational activities and their interactions with task performance. Both the duration and qualitative characteristics of non-operational activities are important to consider.

Consequences

Failure to analyze and describe non-operational activities and their interactions with operational tasks may result in failure to consider important design considerations.

Research and Development

Development of procedures for analyzing non-operational activities might include a review of isolated site, submarine, and confinement study results as a basis for generating classes of non-operational activity and for determining the general relationship of each class to operational task performance. These determinations will be complicated, of course, by the need to use various work-rest cycles as independent variables.

Relationship to Other Requirements

This requirement establishes some of the needs for basic data (1) and specialized data (4). This requirement will contribute directly to the development of integrated system, function, and task analysis procedures (9).

REQUIREMENT 9.7: PROCEDURES FOR ESTIMATING THE CRITICALITY OF TASKS

Delineation

Criticality of the task is a function of its frequency of occurrence, the probability that it will be successfully accomplished, and the probable consequences if it is not successfully accomplished. These factors must be brought together in a meaningful fashion in order to establish priorities for analysis and design.

Consequences

Failure to establish task criticality may result in emphasis on the wrong aspects of human factors design.

Research and Development

Development of procedures for estimating the criticality of tasks will involve the adaptation of operations research techniques to the problem of human tasks.

Relationship to Other Requirements

Establishing estimates of task criticality is one important area in which improved communication between human factors and other program personnel (5) is especially important. More effective criticality estimates will, of course, be important in establishing priorities for all aspects of human factors design.

REQUIREMENT 10: INTEGRATED HUMAN ENGINEERING PROCEDURES

Delineation

Advanced space systems represent man's most ambitious effort to create a totally artificial environment which will sustain his life and permit him to work effectively over long periods of time. Design faults in either life or work support which might have been tolerated with ease in less exotic systems can have serious consequences in long-duration and fully-integrated space missions.

Consequences

Failure of advanced space systems to achieve the most effective human engineering design may result in reduced safety or errors which might fail or degrade the mission.

Research and Development

Research and development in support of improved human engineering procedures will involve the full gamut from basic data gathering to creative development, as reflected in the specific requirements in this area.

Relationship to Other Requirements

Human engineering is a major consumer of research (1, 4) and task requirements data (9). It is also a major interface between human factors and other system personnel (5, 6). The requirements for human engineering are defined in large part by function allocation (8). In turn, human engineering has a profound effect on selection, training, proficiency (12), and performance aid (13) requirements.

Interview Comments	No. of Interviews
Information is needed on how NASA population differs from standard (e.g., Air Force) populations.	4
Human engineering is best done by "common sense" and "trying it out."	1
Simulation is essential in order to perform good human engineering. Simulation provides data concerning unique aspects of operation when general data may not be enough.	1
Human engineers are dealing with a stochastic function involving the probability of an operator being at a certain place at a certain time.	1
Cost data are relevant to human engineering.	1
Space conditions have modified many of our "accepted" human engineering principles. These unique space requirements need to be more rigorously established and more adequately reported.	5
Operational equipment ought to be designed with training and maintenance of equipment in mind.	1
Design for effective troubleshooting ought to get more attention than it does now or than it is likely to. This may be especially important for space missions, since such questions as how many test points to make accessible in flight may be critical.	1
Considerably more work needs to be done on the study of manipulators since some of the current concepts may prove to be impractical.	1
A system should be described anthropometrically in terms of equipment and work space, not the man's measurements. For example, for arm reach, the anthropometric description should be in terms of how far from the arm rest the man can perform a particular task.	1
Strength, reaction time, and other dynamic anthropometric characteristics vary greatly between individuals, and also vary with the task. This variability makes human engineering difficult.	1
Current anthropometric data are specified on a plane. They should be specified in coordinates, to avoid erroneous assumptions about the man's ability to perform a task from an arbitrary center line.	1

	No. of Interviews
Surrounding tasks are important in human engineering for a specific task. This is particulary true for vigilance tasks.	1
Information is needed to permit the prediction of the equipment and supply storage space required per man on specific types of space missions.	1
Good human engineering is not obtained by just imposing requirements on a contractor.	1
Methods and techniques are needed so that human performance can be predicted from one human engineering configuration to another.	1
Task requirement information is required for human engineering of space systems, particularly reliability of performance requirements.	1
Research is needed on the amount of performance degradation on standard tasks from exposure to the space environment.	1
A more rigorous definition of maintainability is required for advanced space systems than currently exists.	1
There are many unanswered questions concerning the optimum displays and controls to use under environmental conditions of vibration, G, etc.	1
Space flight displays must provide information to diagnose malfunctions and make critical operational decisions. Adequate display is especially difficult to accomplish when control is on earth and the vehicle is thousands of m les away.	1

REQUIREMENT 10.1: HUMAN ENGINEERING DESIGN CRITERIA UNIQUELY APPROPRIATE TO NASA SYSTEMS

The human engineering design criteria which have been developed largely for military systems are in need of modification for the unique problems faced by NASA. However, since it is known that a number of projects to this end have been let or are under procurement, no attempt will be made to further develop this requirement here since the more specific and larger-scale studies will define this requirement in much greater detail than would be possible here.

REQUIREMENT 10.2: DEFINITION OF THE APPROPRIATE ROLES OF "COMMON SENSE," ANALYSIS, RESEARCH, AND SIMULATION IN HUMAN ENGINEERING

Delineation

There is no strong current consensus concerning the appropriate roles of "common sense," analysis, research, and simulation in human engineering for space systems. It is not simply that there is variability in the application of these techniques from one human engineering problem to another, there are no general rules concerning the conditions under which the different techniques apply.

Consequences

It is doubtful that all of the supporting techniques for human engineering are equally good for all situations. This means that some priority for techniques must be established if the optimum mix is to be used. Otherwise, less powerful tools will sometimes be used to the detriment of human engineering for space systems.

Research and Development

Research activities in this area might include:

1. Definition of the techniques available for the support of human engineering.
2. Identification of the constraints on the use of the various techniques.
3. Definition of classes of human engineering problems.
4. Establishment and empirical verification of principles and priorities for the application of techniques to the various classes of problems.

Relationship to Other Requirements

Function and task analysis (9) and evaluation and testing (14) include many of the basic techniques to be considered in defining appropriate roles for techniques in human engineering.

The skilled operator (6) may have an important role in defining human engineering requirements.

REQUIREMENT 10.3: DEFINITION OF TRADEOFFS BETWEEN HUMAN ENGINEERING CHARACTERISTICS AND COST-TIME CONSIDERATIONS

Budget and time tradeoffs and constraints are usually relevant to the acceptance or non-acceptance of human engineering recommendations. Yet, human engineering personnel are often almost totally unaware of cost and time information. It would be desirable if a general source of information of relevant cost and time information could be made available to personnel engaged in human engineering design. It may be noted that component engineering personnel are usually much more aware of cost considerations.

REQUIREMENT 10.4: DATA RELATING HUMAN ENGINEERING CONSIDERATIONS TO ENVIRONMENTAL CHARACTERISTICS

The generation of human factors data relating to environmental factors has already been discussed (1, 4, 8.7). The unique consideration here is the conversion of available research data into human engineering design principles which adequately take account of environmental effects.

REQUIREMENT 10.5: TECHNIQUES FOR SIMULTANEOUS HUMAN ENGINEERING OF PRIME EQUIPMENT, PERSONAL EQUIPMENT, SUPPORT EQUIPMENT, INFORMATIONAL JOB AIDS, AND PROCEDURES

Delineation

Human engineering aspects will be inter-related for advanced space systems as they never have been before. In-flight maintenance considerations will be tied in with operational considerations. Informational job aids and personal equipment will be an important part of the vehicular environment.

Life support systems will become increasingly part of the active control situation. Physiological instrumentation will probably be an important part of the immediate environment of the operator.

Human engineering of equipment and development of procedures must be done concurrently. It is important to develop methods and languages such that alternative procedures can be considered for system personnel rather than just a direct derivation from equipment. Field personnel typically do develop different procedures from the ones the engineers and human factors people intended. Methods are required for choosing the best procedures as part of the development sequence, particularly since the opportunities for custom fitting may be quite limited on a space mission.

Human engineering and training also need to be tied together more effectively than they have been in the past. It is not necessarily true that a well human-engineered system will have minimum training requirements. Procedures need to be developed to ensure that trainability is built into the design, since the training requirements for space crewmen are likely to be staggering even with the best of human engineering to minimize them.

Consequences

Failure to integrate adequately the various aspects of human engineering design may result in optimization of some design aspects at the expense of others which may, over the long run, be more critical.

Research and Development

The basic problem for the development of techniques in this area is to identify and formally define the relevant aspects of human engineering and relationships among them. The problem then becomes one of developing and verifying practical methods for concurrently designing all aspects while considering the various interactions.

Relationship to Other Requirements

The kind of human engineering design contemplated here will place a major burden on the definition of communications for a human factors program (7.5) and on a storage and retrieval system (3).

REQUIREMENT 10.6: IMPROVED INTEGRATION OF ANTHROPOMETRIC DATA AND HUMAN ENGINEERING TECHNIQUES

Delineation

For advanced space vehicle operators, anthropometry will have to be much more precise and customized than in most previous military or other large-scale systems. In particular, anthropometrics will have to be much more in terms of equipment and work space limitations than in terms of direct measures of the man. For example, in place of simply reporting arm reach, it will become increasingly important to define how far from his arm rest the man can perform a particular task under stated environmental conditions.

Consequences

Failure to fully integrate anthropometric approaches into the human engineering of advanced space vehicles may result in over-design due to erroneous assumptions about man's adaptability; e.g., failing adequately to account for the fact that the man can move as well as reach. Also, it can result in inadequate design to support man's limitations where he may be under special environmental constraints; e.g., constrictive clothing.

Research and Development

The first step is to pull together techniques and examples which give meaning to this "anthropometry on a new key." This might then serve as a point of departure for the identification of requirements for more advanced techniques and more sophisticated anthropometric data.

Relationship to Other Requirements

This requirement has implications for basic data (1), availability of technical information (2), a data system (3), applied research priorities (4), and improved communications (5). Meeting this requirement would obviously contribute directly to integrated human engineering procedures (10).

A more subtle, but perhaps more important, relationship is the desirability of expanding system, function, and task analysis procedures (9) to include rigorous consideration of anthropometric variables.

REQUIREMENT 10.7: DATA CONCERNING RELATIONSHIPS AMONG ANTHROPOMETRIC, TASK, ENVIRONMENT, PERSONAL EQUIPMENT, EXPENDABLE ITEM, AND SOCIAL VARIABLES

This requirement is essentially an information backup to techniques for simultaneous human engineering of prime equipment, personal equipment, support equipment, informational job aids, and procedures (10.5). Work toward the accomplishment of this requirement will draw heavily upon data relating human engineering to environmental characteristics (10.4), on advanced techniques for the generation of anthropometric data (10.6), on basic task data for human engineering (10.8), on improved techniques for using task data in human engineering (10.10), and on relationships of dynamic characteristics of the individual to human engineering (10.11).

REQUIREMENT 10.8: BASIC TASK DATA FOR UNIQUE SPACE CONDITIONS

This requirement is essentially a specialized statement of the need for data concerning human functioning (1, 4). However, this requirement points up the need for performance data on standard reference tasks which are uniquely relevant to advanced space systems. Human engineering alternatives can then be appraised in terms of their effects on performance of these reference tasks.

This requirement is analogous to the effort to quantify data about performance for function allocation (8.4) and to improve the relating of task requirement information to the main body of performance data (9.2).

REQUIREMENT 10.9: IMPROVED TECHNIQUES FOR INCLUDING MISSION CONSIDERATIONS IN HUMAN ENGINEERING

Delineation

Mission characteristics and profiles are important to all areas of human factors work. However, they have special relevance to human engineering since optimum human engineering characteristics may depend, to a considerable extent, upon the points in the mission at which the operator interacts with them. In addition, mission length may interact with hardware characteristics to define certain human engineering requirements. For example, a long mission with only moderately reliable electronic modules of relatively large size may dictate repair rather than replacement in-flight.

Consequences

Failure to develop techniques for the improved identification of mission implications for human engineering may result in inadequate attention to critical man-machine problems until too late in the developmental cycle for optimum design.

Research and Development

Development of improved techniques for the inclusion of mission considerations in human engineering can be combined with research to forecast future mission requirements for human engineering. Beginning with systems currently under development and stretching as far into the future as advanced concepts have been established, mission analyses can be performed to identify potential human engineering implications. The results of these analyses can be organized and generalized into techniques for the identification of human engineering implications from specific missions as they evolve during system development.

Relationship to Other Requirements

This requirement will involve many of the same techniques and considerations as the establishment of applied research priorities and objectives (4).

REQUIREMENT 10.10: IMPROVED TECHNIQUES FOR USING TASK DATA IN HUMAN ENGINEERING

Delineation

The major objectives of human engineering are to enhance the operator's safety, comfort, and performance. To ensure the last, if not the others, of these objectives, it is necessary to estimate the impact of human engineering alternatives on performance. For systems of the sophistication of advanced space vehicles, satisfactory estimation of performance probably implies quantification.

Consequences

Failure to consider adequately the impact of human engineering on task performance can result in the application of generally accepted, but inappropriate, human engineering design standards.

Research and Development

Unique development for this requirement is probably limited to the identification of improved ways of applying performance estimating techniques to the process of human engineering. Other aspects of research and development are implied under relationships to other requirements.

Relationship to Other Requirements

Basic data (1, 4), a processing system (3), performance data used in function allocation (8.4), task analysis techniques which draw on performance data (9.2), and evaluation and test results (14) will all serve as basic input to this requirement.

REQUIREMENT 10.11: RELATIONSHIP BETWEEN DYNAMIC CHARACTERISTICS OF AN INDIVIDUAL AND TASK PERFORMANCE

Delineation

Dynamic characteristics of an individual include strength, reaction time, attention, motivation, aptitudes and skills, temperament, resistance to stress, etc. Space crews, for the foreseeable future, can be highly selected on all such variables. Human engineering should be optimized for the crews which will actually operate the spacecraft and not for some other reference population.

Consequences

Failure to identify the implications of individual dynamic characteristics may result either in over-design or, even, design that will result in reduced performance for the population that will actually operate the space vehicle.

Research and Development

As with use of task data (10.10), the unique development here is limited to improved ways of applying information about the relationship of individual characteristics and performance to the problems of human engineering.

Relationship to Other Requirements

This requirement adds a whole new array of dimensions to basic research needs (1, 4). It also makes for added complexity for the data system (3). It establishes an area of possible interaction with selection variables (12.2, 12.3). All of these other requirements, in turn, will serve as basic input to this requirement.

REQUIREMENT 10.12: A MORE ADEQUATE BASIS FOR DETERMINING DISPLAY NEEDS

Delineation

In a strict manual control system, it is relatively easy to determine what information should be displayed, although the mixed acceptance of predictor or director displays does pose some interesting problems. The crewman of an advanced space vehicle, however, is likely to have monitoring, diagnosis, troubleshooting, decision-making, and observing as his major functions. Determination of optimum information to display for such functions is likely to prove to be a difficult problem. The man can easily be presented either too much or too little information or it can be presented in a form which is less useful than it might be.

Various forms of function and task analysis, as well as more traditional engineering approaches, are currently used to determine display requirements. It would appear, however, that no technique which will be fully adequate to the needs of advanced space systems is generally available.

Consequences

Failure to provide a more rigorous basis for defining display requirements will result in either over-burdening the operator or failing to provide him with information which might enhance mission performance.

Research and Development

Research and development toward a more adequate basis for determining display needs might include the following activities:

1. Review and consolidation of existing techniques to assess current capabilities and to help in the identification of promising directions for new departures.

2. Establishing a basis for describing all key operator functions quantitatively, particularly in terms showing the relationship of operator performance to mission effectiveness.

3. For the spectrum of anticipated advanced space missions, setting operator performance as a function of information and display characteristics.

Relationship to Other Requirements

A large proportion of the basic data about human functioning (1, 4) is potentially relevant to improved determination of display needs. This is true of a variety of quantitative performance data and quantification techniques (8.2, 8.4, 9.2, 10.10, 14). Also, improved access to a variety of performance data (2, 3) is essential.

REQUIREMENT 10.13: HUMAN PERFORMANCE DATA IN A FORM WHICH IS DIRECTLY MEANINGFUL TO THE SYSTEMS ENGINEER

Human engineering design often interacts with major system engineering considerations, and this seems especially likely to be the case in highly integrated systems such as advanced space vehicles. If the system engineer is to make reasonable tradeoffs between human engineering and other considerations, he must be able to understand the bases for human engineering objectives and be able to translate them into terms which are comparable to the other considerations which he must trade off. Safety is probably relatively easy for the system engineer to incorporate into his total considerations. Acceptance may be a little more difficult, but is probably essentially a matter of estimating how much effect, if any, non-acceptance is likely to have on performance.

Human performance is often difficult for the system engineer to assimilate and translate into terms that can meaningfully be compared with other design considerations. Quantitative estimates of the effect which human engineering design alternatives will have on performance, particularly if they can be related to mission effectiveness, would improve the consideration of human engineering factors in system tradeoffs.

This is essentially a specialized expansion of the general requirement for the improvement of communication between human factors and other program personnel (5).

REQUIREMENT 10.14: INFORMATION CONCERNING FEASIBLE TECHNIQUES FOR DISPLAY AND CONTROL UNDER UNUSUAL ENVIRONMENTS

Delineation

Acceleration, vibration, noise, weightlessness, rotation, and possibly other factors pose serious problems for control and display in advanced space systems. In some areas, this poses the need for radical departures from conventional control and display techniques. For example, control might be based on myograms or eye movement. Tactual systems or gross visuals might be used for display.

Consequences

Failure to exploit fully the currently untapped human capabilities may result in automation which is both more expensive and less reliable than an appropriately balanced man-machine design.

Research and Development

Experimental studies of broadly extrapolated conventional techniques and unconventional techniques should be investigated.

Relationship to Other Requirements

Display and control for unusual environmental conditions are important areas for basic (1) and priority-rated (4) research.

REQUIREMENT 11: INTEGRATED JOB DESIGN AND PERSONNEL FORECASTING PROCEDURES

Delineation

Three factors currently make the problem of job design and manning for NASA quite different from the problem for military and other systems:

1. The number of personnel and general allocation of duties to space vehicle crew members is often accomplished without reference to human factors considerations of personnel.

2. Personnel are typically tailor-trained for NASA jobs relating to a particular system, reducing the need for formal job definition.

3. Ground support is largely accomplished by contractor personnel who have either worked on design of the system or who are trained in the factory as part of the development and fabrication phase.

It is little wonder, then, that job design and personnel forecasting are in need of a careful review for future NASA space systems in order to define an appropriate role for job design and forecasting.

Consequences

Failure to define an appropriate role for job design and manning in space system development may either result in an excessive concern for human factors functions which do not have the importance for space systems which they do for some other systems, or in ignoring important new aspects of job design and personnel forecasting.

Research and Development

Research in this area must involve a basic look at the role for job design and personnel forecasting in development of advanced space systems. Once this role is defined, more detailed attention can be given to the specific methods and procedures by which this role might be supported.

Relationship to Other Requirements

To the extent that job design and personnel forecasting are appropriate for advanced space systems, they will require good function and task data (9) and may act as a feedback loop to function allocation (8). Job design and human engineering (10) must be coordinated in order to achieve optimum design. Job design may also have an important effect on selection and training requirements (12).

Interview Comments	No. of Interviews
Job design is an important area for methodological improvement. This has relatively high priority at one of the NASA centers.	2
Availability of personnel should be considered in job design. It is currently difficult to forecast availability in NASA.	2
A system for projecting <u>total</u> requirements for and availability of personnel in NASA would be desirable.	1
NASA tends to control duty allocation very closely. If changes are made from the original prescriptions, they usually grow out of the necessities of system and subsystem design.	2
Job design for space vehicle operation is unique in that there are no replacements available--no additional back-up manpower.	1
Things other than rational considerations seem to dictate how many people will be in the space vehicle. If a given design group had responsibility for the entire system, including ground support, there might be room for deliberation about crew sizes.	1
A major NASA need at the present time is information about types of skills and knowledges required for lunar and space exploration and appropriate combinations of skills to meet contingencies.	1
NASA needs information about the relationship between type and amount of expendables (Food, O_2, etc.) required, and numbers of individuals.	1
Functions analysis information will permit people who are knowledgeable about the system to do a good job of personnel forecasting. Personnel forecasting can only be done effectively by people familiar with the system. Task-equipment analyses are not useful when these experts are available, nor are they much good when they are not available.	1
Job design and manning should be based on a review of the approach used on previous systems.	1
A great deal of methodological improvement can be made in short-range personnel forecasting for NASA.	1
NASA has not done well in disseminating personnel forecast information to contractors who might be affected.	1
NASA currently tailor-trains for jobs. Requirements for advanced forecasting might become more urgent if NASA must prepare much larger numbers of persons for operator and maintenance jobs.	1

REQUIREMENT 11.1:
IMPROVED PROCEDURES FOR JOB DESIGN

Job design is probably assuming increased importance for space systems. There is no immediately available backup manpower on a long-duration space mission. The array of complex functions to be allocated to a relatively limited number of men is impressive. The complexity of ground support systems is increasing and demanding formal techniques to achieve a rational association of functions.

Human factors technology is not much more advanced in the extraction of skills and knowledges from function and task data than it was a decade ago. In particular, it is rudimentary in establishing homogeneous skills, although this is a central issue in effective job design.

Work currently in progress at the American Institutes for Research under a grant from the Ford Foundation (Altman, 1964) is concerned with the problem of identifying homogeneous skills and knowledges through the translation of task data into testable behaviors and factorial analysis of test results. This project promises to have important implications for improved job design logic and procedures.

REQUIREMENT 11.2: IMPROVED PROCEDURES FOR PERSONNEL FORECASTING

Although the factors mentioned under 11 are probably operating to change the nature of the problem for personnel forecasting, it is not at all certain that personnel forecasting, over-all, is assuming less importance than it has for massive military systems. The concurrent operation of multiple systems is likely to become common in the foreseeable future. This will place multiple demands on certain components of the ground support system, and will require careful forecasting and scheduling.

Advanced systems will probably include multiple vehicles and stations with resulting complexities in deciding the appropriate numbers of total personnel to be involved. Replacement rates, backup, and other considerations will require careful analysis of personnel requirements.

REQUIREMENT 11.3: IMPROVED AVAILABILITY OF INFORMATION CONCERNING JOB DESIGN AND PERSONNEL FORECASTING EXPERIENCE ON PREVIOUS SYSTEMS

Job design and personnel forecasting are areas of human factors which seem to be particularly susceptible to tradition. It is important, therefore, that full information about constraints, known compromises, rationale, and evaluation of results be carried over and not just the most obvious information about the personnel structure which finally evolved. Unless full information is carried over from one system to the other, inappropriate structures may be used on new systems simply because they are traditional and not because they are optimum for the new system.

This requirement is a special case of the general need to establish procedures for suitably carrying over data from one system to another (7.2). Personnel data is one class which seems appropriate for any ultimate data system (3).

REQUIREMENT 11.4: INFORMATION CONCERNING THE AVAILABILITY OF PERSONNEL

NASA flight operations have been relatively limited as compared to the magnitude which they will probably ultimately achieve. At that point, there will undoubtedly be severe drains upon available manpower tools. These could seriously disrupt program schedules and objectives unless individual programs are designed within realistic manpower constraints and unless there is effective coordination across programs.

All of this will probably dictate a computerized system for keeping current on manpower availability and generating both short- and long-term forecasts. A detailed and critical review of systems evolved by the military services would seem to be an appropriate starting place for development of such a system.

REQUIREMENT 12: PROCEDURES FOR INTEGRATING PERSONNEL SELECTION, TRAINING, AND PROFICIENCY ASSESSMENT

Delineation

For unmanned space probes, there may be little or no requirement for selection or training of personnel, since all of the operational functions may be carried out by the personnel who develop the probe and by personnel who handle launch and tracking as routine. Major new developments in launch vehicles may have important selection, training, and proficiency measurement implications. Major new manned space vehicles will pose a difficult array of selection, training, and proficiency assessment problems.

Psycho-technology is relatively well developed in selection, training, and proficiency measurement (see for example Gagné, 1962). However, the paradigms on which much of this technology is based assume large numbers of applicants, trainees, and operating personnel; with small or moderate investment in each. For advanced space systems, we can look to relatively small numbers of persons for final selection, for training, and for proficiency assessment. We can also anticipate situations in which quite a large investment in each individual can be justified. This, combined with special content requirements, means that new techniques and new emphases and adaptations of old techniques will be appropriate for the development of advanced space systems.

Consequences

Failure to advance and apply selection, training, and proficiency measurement technology for space systems will limit the contribution which man can make to space operations. It will also result in reduced mission effectiveness or achievement of effectiveness through automatic techniques which would be unnecessary if less expensive and sophisticated design were adequately supported by selection, training, and proficiency assessment.

Research and Development

Information about two kinds of relationships is of crucial importance in the development of selection, training, and proficiency measurement procedures for advanced space systems. The first is the relationship of measures taken on persons other than the ultimate system personnel to measures taken on the eventual operators. Information about this series of relationships is essential to an evaluation of the extent to which non-operator populations mignt be used for experimentation and tryout to support technique development.

The array of relationships between measures taken on the ground and those taken in flight is essential to an evaluation of payoff from various techniques, as well as providing valuable insights into the nature of required techniques.

At best, information about these relationships is likely to be a scarce and valuable commodity for the foreseeable future. Carefully coordinated planning for the gathering of maximum data, analysis and evaluation by the most powerful and efficient techniques available, and storage in a non-perishable and accessible form are essential.

Relationships among selection, training, and proficiency measures are obviously also of great importance.

Relationship to Other Requirements

Significant advances in codifying the behavior involved in advanced space systems (8.4, 9.2, 10.8, 14.5) will have an important impact on the content for improved selection, training, and proficiency measurement procedures. This will also be true of information about environmental effects (1, 4, 8.7, 9.4, 10.11).

There may be at least partial tradeoffs among selection, training, human engineering (10), and performance aid (13) variables.

Interview Comments	No. of Interviews
Research is needed on appropriate techniques for selecting personnel for future space missions, with special attention to:	6
Non-traditional types of selection criteria.	1
System-related performance samples rather than paper-and-pencil tests.	1
Dealing with a highly selected, motivated, and proficient group.	1
Physiological and psychological stress tolerance.	1
Long-term emotional stability and adjustment capability.	1
Information required for training development and that required for system design are quite different. Too often system design information is used for training.	2
The derivation of training requirements is still done largely without real methodology. This is an area where there is real gold to be mined.	5
Some type of task-training trainer taxonomy needs to be established to reduce the amount of specialized analysis and design that now is required for each prime equipment design change.	4
NASA needs to push hard for trainers and training which can quickly and easily be modified as changes are made in equipment. These changes should, ideally, require no more than software changes.	1
The Soviets have been more realistic about training than has the United States. Cosmonauts are considered raw material for training and are not given the same degree of self-determination as U. S. astronauts. This self-determination will become increasingly a problem as increasing numbers in space crewmen are needed in the future.	1
Training techniques should use information from academic research more fully.	1
During system design, more use should be made of the relationships between human performance and training time.	1
There is a need to form an identification of operating and maintenance personnel with the job during training.	1

	No. of Interviews
Information and techniques are needed to permit a determination of tasks that should be "designed in" just to keep astronauts busy and psychologically healthy.	1
Advanced planning, human engineering, and training need to be more closely allied. Research is needed to develop a set of principles for "teachability" design.	2
A technique is needed to permit the measurement of proficiency in terms of effect on the entire system. Establishment of proficiency measurement requirements is currently hampered by a need to get feedback data from system operation.	2
An important and largely unrecognized human factors information requirement is the stress associated with performance of specific tasks with specific proficiency. Stress may vary given equal proficiency.	1
The state-of-the-art in part-task simulators and other equipment useful for proficiency must be determined. There is presently no one good source of such information.	2
Proficiency measurement in space must be done through instrumentation. Thus, requirements for proficiency measurement must be identified early to anticipate penalties in closed systems.	1

REQUIREMENT 12.1: DELINEATION OF POPULATIONS FROM WHICH IT WILL BE APPROPRIATE TO DRAW TRAINEES

Flight personnel for systems to date have been drawn from relatively homogeneous populations of test pilots. As the scope of space missions increases, there will need to be a rational determination of whether the population should be broadened and, if so, in what ways. The population from which systems personnel will be drawn is basic information to the establishment of selection and training requirements.

REQUIREMENT 12.2: IDENTIFICATION OF APPROPRIATE SELECTION VARIABLES, METHODS, AND TECHNIQUES FOR VALIDATING SELECTION

Delineation

Selection variables and methods have been relatively restricted in the past by the need to operate large programs. Advanced space systems will involve relatively small numbers of operating personnel for each of whom the investment will be extremely large. In addition, the mission, task, and environmental variables to which selection may be relevant will reach new levels of complexity for advanced space systems. This means that there is a need to take a fresh look at selection objectives, variables, and techniques.

Consequences

Failure to develop adequate procedures for the selection of personnel for advanced space systems will result either in excessive training burden or in crew performance which is less adequate than it could be.

Research and Development

Research on selection should be aimed at not only the full array of skill and knowledge variables, but also should include work load capacity and other variables not normally included in personnel selection.

Consideration of selection techniques should not be limited to interviews, standard tests, and personal history, but should also include task simulation and other techniques which might not be practical in many other contexts.

Relationship to Other Requirements

Basic research data (1, 4) may suggest important selection variables. Advances in all areas of human factors activity may suggest ways of tying selection technology into other aspects of the human factors program.

REQUIREMENT 12.3:
DETERMINATION OF SELECTION REQUIREMENTS FOR LONG-TERM ADJUSTMENT AND STRESS TOLERANCE

This requirement is essentially a specific adjunct to the general requirement for improved selection techniques (12.2). However, stress resistance and long-term adjustment to difficult and unusual circumstances are of sufficient importance to warrant special attention. Both will involve a great deal of creative research if adequate progress is to be made in supporting future space systems.

There has been research done on these factors (Eilbert, Glaser, & Hanes, 1957; Gorham & Suttell, 1956; Gorham & Orr, 1957; Gorham, Orr, & Trittipoe, 1958; Gorham & Orr, 1958), but it is not at all certain that adjustment to the situation and stresses of space will be just like the problems of aircraft piloting, arctic duty, or confinement in a nuclear submarine.

REQUIREMENT 12.4: IMPROVED TECHNIQUES FOR DETERMINING TRAINING REQUIREMENTS

Delineation

The derivation of training requirements is still done largely without real methodology. Lack of methodology will become more critical as space systems increase in complexity and extrapolation from aeronautical systems experience becomes less appropriate. The basic problem of developing an improved methodology for the determination of training requirements is complicated by at least four additional factors:

1. Information required for training development and that required for system design may be quite different. There is a strong tradition and tendency to use the system design information rather directly for training.

2. System designers and engineers tend to be very familiar with the aspects of the system for which they are responsible and don't always recognize the need to train others. This may mean that one valuable source of training information may not be as available as would appear to be the case at first glance.

3. The period of orientation and training for space crewmen may overlap much of the developmental period for the system. This means that suitable methodology for determining training methodology will have to accomodate system information from earliest concept onward and include provisions for rapid and efficient updating.

4. Specialized characteristics of the system may create whole new sets of training problems, as for example training that may be required to overcome the effects of coreolis in spinning vehicles.

Consequences

Failure to develop and establish a formal methodology for the derivation of training requirements may not only result in considerable waste of valuable training time, but, more seriously, may fail to prepare personnel adequately for critical aspects of their job.

Research and Relationship to Other Requirements

The crux of creative development of a training requirements methodology seems to lie in the direction of defining some (hopefully small) number of behavioral categories which are differentiated with respect to the kinds and amounts of training required for satisfactory performance. Each category must then be related to a body of information about training methods, sequences, and supports (12.5).

There is a need to relate training requirements to the main body of human factors knowledge (1, 2, 3, 4). Also, the behavioral categories of importance to training requirements methodology are likely to be closely related to the structure which is found to be most useful for organizing performance information (8.4, 8.7, 9.2, 10.8).

Training requirements is one area in which improved definition of the appropriate role of skilled operators (6) is of particular importance. The Soviets have tended to consider cosmonauts as raw material for training, and have not given them nearly the same degree of self-determination as U. S. astronauts. The degree of appropriate self-determination for advance systems and greater numbers of personnel is a moot question.

REQUIREMENT 12.5:
A RIGOROUS BASIS FOR
RELATING TRAINING METHODS, AIDS, EQUIPMENT, FACILITIES, AND SCHEDULES

This is a logical extension of a methodology for deriving training requirements (12.4). Once categories of behavior having differential training requirements have been established, one of the bases for providing meaning to each category is to correlate it with information about appropriate training methods, aids, equipment, facilities, and programming. This implies, as a first step, the establishment of suitable taxonomies for each general class of training supports.

Throughout the development of a more rigorous basis for relating training requirements to training support, an important objective must be to make the training support flexible so that it can be modified quickly and easily in response to changes in equipment or mission.

Whatever taxonomy of training support may be established, it will have to be updated regularly on the basis of advances in state-of-the-art in training technology (12.8).

REQUIREMENT 12.6: LEARNING AND RETENTION CURVES FOR VARIOUS PERFORMANCE PARAMETERS ON DIFFERENT CLASSES OF TASKS; AS A FUNCTION OF TECHNIQUES AND AIDS

This is another logical extension of a methodology for deriving training requirements (12.4). It interacts with development of a basis for relating training requirements to supports (12.5) in that the principal rationale for associating or not associating a particular support with a given behavior is the effect of the support on the course of learning of the behavior. Cost, development time, and other practical considerations are also relevant, of course.

It is important that a base of data about the performance of untrained personnel be obtained for each class of behavior, since a comparison of untrained and trained performance will be a principal basis for deciding whether or not a significant training requirement does, in fact, exist. Also, a comparison of performance with and without informational job performance aids (13) is important to a rational decision about training requirements.

Choice of appropriate speed and accuracy performance measures is extremely important to the interpretation of learning and retention curves. Insofar as possible, performance measures taken during training should be compatible or identical with the measures used in basic research (1, 4) and used in any central stores of performance information (8.4, 9.2, 14.5).

Data generated or organized in support of this requirement should be computerized (3) for rapid storage, update, processing, and retrieval.

REQUIREMENT 12.7: DETERMINATION AND CODIFICATION OF SPACE ENVIRONMENT CHARACTERISTICS HAVING UNIQUE TRAINING REQUIREMENTS

There is a growing body of information about space environments as they exist in raw form and as they will impact upon the space crewman when they have been modified by his prime and personal equipment. Although there have been a number of reviews of training problems posed by the space environments (Altman, 1960; Smith & Altman, 1961; Eckstrand, 1961; Livingston, 1962), there is no detailed compendium of information about the effects of space environment characteristics on training requirements. Further, there is no generally available body of knowledge which can readily be drawn upon in determining training requirements for advanced space systems to ensure compatibility with environmental characteristics.

There are three related purposes served by codification of the effects of space environment characteristics on training requirements. The first is to support definition of required research in the training area (1, 4). The second is to support the derivation of training requirements (12.4), regardless of the state of the technology. The third is to expand the concept of learning and retention curves for different classes of behavior (12.6) by:

1. Including information about the effects of environmental conditions on performance throughout learning and transfer situations.

2. Establishing behavioral categories uniquely appropriate to dealing with the space environment.

REQUIREMENT 12.8:
STATE-OF-THE-ART INFORMATION ABOUT TRAINING TECHNIQUES, AIDS, EQUIPMENT, AND FACILITIES

The general availability of information in this area is, unfortunately, not good. Consequently, even if there were no technology uniquely applicable to space, there would be a requirement for making such information more accessible and current. However, the unique training problems posed by space operations are certain to result in a space training technology which is somewhat independent of the larger educational and training technology. This reinforces the need for making current information available to those who are engaged in human factors development for advanced space systems.

It is highly desirable that state-of-the-art information be processed prior to dissemination to be compatible with techniques for relating training supports to requirements (12.5). It is also desirable that the impact of new devices and techniques be assessed in terms of their impact on learning and retention curves (12.6).

Inclusion of training state-of-the-art information both in techniques for improved report dissemination (2) and a data system (3) is desirable.

REQUIREMENT 12.9: A TECHNIQUE FOR DETERMINING PROFICIENCY MEASUREMENT REQUIREMENTS EARLY IN DEVELOPMENT

Delineation

Proficiency measurement is important to advanced space system programs in three ways:

1. Quality control. Proficiency measurement may be considered to be the quality control inspection for the man entering the system. For systems having the component reliability requirements of an advanced space vehcile, such quality assurance of a multi-function component is essential.

2. Development programming. Proficiency measurement can identify trainee personnel who are not fully meeting performance specifications. This can result, as appropriate, in modified training, revised operational planning, equipment redesign, increased dependence on informational job performance aids, and increased functional redundancy (e.g., inspection) of personnel.

3. Mission programming. Performance measurement in-flight can be used as a feedback control loop to determine appropriate training exercises to be accomplished during the mission, and as a basis for selecting alternative operational modes.

The need to identify proficiency measurements early in development stems from two causes. The first is the usually long period of concurrency between system development and training of flight personnel. The second is the probability that proficiency measurement in space will require instrumentation. Requirements for such instrumentation must be included in early tradeoff and design studies to assure optimum design.

Consequences

Failure to allow adequately for proficiency measurement requirements will result in a gamble concerning the human component of the system, and may result in unnecessary degradation of mission performance.

Research and Development

Research and development for proficiency measurement should be aimed at improvements in techniques (Altman, 1960; Glaser & Klaus, 1962) for at least the following:

1. Deciding where in the training and mission cycles proficiency measurement is most needed.

2. Determining the aspects of performance to be measured and the levels to be required.

3. Selecting appropriate methods of measurement.

4. Programming proficiency measurement exercises.

5. Obtaining estimates of the reliability of measurement.

6. Relating individual and crew performance measures to system performance.

Relationship to Other Requirements

The content for proficiency measures should be derived from function and task data (9). Development of proficiency measures for a given system should certainly be dovetailed with human factors evaluation and testing (14) for that system.

REQUIREMENT 13: PROCEDURES FOR INTEGRATING HUMAN FACTORS EFFORTS AND DATA IN SUPPORT OF THE DEVELOPMENT OF JOB PERFORMANCE AIDS

Delineation

Folley and Munger performed a comprehensive review of the literature on design of informational job performance aids in 1961. They found that most of the research had been done prior to 1958 by the former Air Force Personnel and Training Research Center and its contractors. Most of the studies were concerned with development and tryout of sample aids for particular systems or parts of systems, with aids for simplification of troubleshooting receiving most emphasis. Systematic research was lacking on the problems of determining the need for informational aids, evaluating the effectiveness of aids, and coordinating changes in aids with evolution of the system. However, when human factors personnel did make a concerted effort to provide a carefully-developed aid, it generally did cut training requirements and/or enhanced performance.

The current survey yielded little evidence that the situation has changed appreciably in recent years. Although human factors personnel can, and occasionally do, make a useful contribution to the preparation of a special informational performance aid; there is no clearly defined human factors role in this area and no generally available technology for the development of informational performance aids such as manuals, checklists, recorded auditory instructions, etc.

Informational job performance aids have a potentially important role in advanced space systems for at least two reasons. First, the training requirements for crewmen are likely to be prodigious. There can be a tradeoff between training and performance aids, particularly for non-time-critical procedural tasks. Second, appropriately designed informational aids can support performance quality control in lieu of direct supervision, which will be limited for a long space mission.

Consequences

Performance aids of the general quality, typical of today's aerospace systems, will result in an unnecessarily heavy training burden and miss a major opportunity for the enhancement and reliability assurance of flight crew performance.

Research and Development

In conjunction with the development of preliminary procedures for the design of informational job performance aids, Folley (1960; 1961) developed a series of research recommendations. These preliminary procedures were tried out and evaluated by Folley and Shettel (1962) and additional research suggestions were made. It would seem that these procedures and recommendations represent an appropriate point of departure for research and development in support of advanced space systems.

Relationship to Other Requirements

As has already been pointed out, there is a major tradeoff possible between training (12.4) and performance aids. To a lesser extent, there may also be a tradeoff with human engineering (10) and selection (12.2). Function and task data (9) should provide the best source of performance aid content.

Interview Comments	No. of Interviews
There have been some significant improvements in self-instruction books, troubleshooting guides, and similar technical publications. It would be highly desirable to have all technical publications equally well designed.	1
Technical publications is a much neglected area. There ought to be guidance, among other things, on how to use subject testing to improve instructions.	1
During system design, more use should be made of the relationships between human performance and job aids.	1
Organizations which prepare manuals do excellent jobs when human factors personnel are employed.	1
Some type of method is needed to derive the specific tasks which are included in Tech Manuals which is more objective than going back to the PED. PED does not provide information for Illustrated Parts Breakdown or Provisioning Lists.	1
In the Air Force, the efforts in preparation of Technical Manuals are often overly duplicated. A central source of responsibility is needed <u>within</u> the design effort.	1
The best way for manuals to be prepared is for the "expert" to sit down with a tech writer and turn them out. TEA is much too cumbersome a technique for space systems.	1
It is important to develop procedures and languages such that alternative procedures can be considered for system personnel rather than just a direct derivation from equipment. We may note that field personnel typically do develop different procedures from the ones the engineers and human factors people intended. Methods are required for choosing the best procedures as part of the developmental sequence.	1

REQUIREMENT 13.1: DEFINITION OF THE ROLE FOR HUMAN FACTORS DATA IN INFORMATIONAL JOB PERFORMANCE AIDS

Efforts to define a systematic procedure for the design of performance aids (Folley, 1961; Folley & Shettel, 1962) have been based on function and task data as basic input. Insofar as is known, this is entirely consistent with the rationale underlying all function and task analysis procedures and with all of the research on informational job performance aids. Yet, one of the interviewees on the current study commented:

> "The best way for manuals to be prepared is for the 'experts' to sit down with a tech writer and turn them out. Task-equipment analysis is much too cumbersome a technique for space systems."

If this were simply a stray comment, it would perhaps not be too significant, but there is almost a universal non-use of human factors data at the present time in the preparation of informational job performance aids (almost entirely limited to manuals and an occasional checklist).

It would seem then, that there is a major potential use of human factors data which is not being realized. A specific look into the causes for this non-use and identification of possible ways of increasing use seems entirely in order.

REQUIREMENT 13.2: HUMAN FACTORS CRITERIA FOR INFORMATIONAL JOB PERFORMANCE AIDS

Some work has been done in defining physical and functional characteristics for informational performance aids (Folley & Munger, 1961). Certainly, much more remains to be done for optimum design in support of advanced space systems.

Such work must certainly deal with typography, format, graphics, etc. However, consideration also must be given to storage of job instructions and information in digital computers for those who normally interact with such computers as part of their job, to various means of storing and presenting information on microfilm, and to presentation of job instructions and information using auditory recordings.

REQUIREMENT 13.3: DETERMINATION OF MORE EFFECTIVE METHODS FOR PRESENTING JOB INFORMATION

This represents an extension of human factors criteria for performance aids (13.2) to the more complete realization of criteria through the application of new techniques. Certainly one area of interest is the relationship of auto-instructional or programmed instruction to informational job performance aids. Significant advances in either field are likely to have important implications for the other if, in fact, the two fields don't sometimes merge.

Techniques beyond computer storage and microfilm projection are hard to envision at the present time, but breakthroughs in this area should be actively sought.

REQUIREMENT 13.4: DELINEATION OF A ROLE FOR HUMAN FACTORS PERSONNEL IN THE PREPARATION OF INFORMATIONAL JOB PERFORMANCE AIDS

There seems to be clear evidence that human factors personnel have sometimes made distinct contributions to improved performance aids. However, to date, there has been little formal methodology to support the design and development of informational job performance aids. It remains to be seen what the appropriate role might be for human factors personnel in the application of such a methodology.

This requirement is one aspect of the more general requirement to define the role of human factors in advanced space system development (7.3).

REQUIREMENT 13.5: GUIDANCE ON THE USE OF SUBJECT TESTING IN PREPARATION OF INFORMATIONAL JOB PERFORMANCE AIDS

One of the major blocks to effective communication in this area is that most of the actual preparation of performance aids (although not generally conceived as being primarily this) has been done by technical writers. The research has been done almost exclusively by psychologists. There is a need then to pull information from and disseminate information to both fields.

In particular, it is essential that technical writing staffs receive both general specifications and requirements unique to a given system, at the proper time in the developmental sequence and in a form which can readily be translated into action. This has implications both for the human factors data system (3) and communication between human factors and other program personnel (5).

REQUIREMENT 13.6: INFORMATION ABOUT CURRENT PRACTICES IN THE DEVELOPMENT AND USE OF INFORMATIONAL PERFORMANCE AIDS

One of the major features which has characterized the vigorous growth of programmed instruction is the insistence, on the part of all reputable practitioners of the art, that all materials be subject-tested and revised on the basis of tryout results. An analogous situation has obtained for years in the development of psychological tests. The reasons for such tryout seem no less compelling in the area of informational job performance aids, although real tryout seems to be the rare exception rather than the rule.

It would seem that one step toward the achievement of more effective use of tryout might be to establish specific objectives and methods for tryout that could be applied routinely in the development of informational job performance aids.

REQUIREMENT 14: PROCEDURES FOR INTEGRATED HUMAN FACTORS EVALUATION AND TESTING

Delineation

The Air Force has placed some emphasis on evaluation and testing of personnel subsystems (HIAPSD). A contract has recently been let through the Aeronautical Systems Division of the Air Force (Purchase Request Number AM 4-61186) for a review of available human performance assessment techniques. This contract should make more readily accessible the individual techniques and approaches which have been developed and applied over the last decade and a half.

Human factors evaluation and test have been considered in a variety of contexts. Deutsch (1960) has reviewed maintainability evaluation considerations within the context of a systematic human factors approach to the design of space and weapon systems. Altman (1962) has also discussed evaluation and test considerations relevant to maintenance design. Chase (1961) has presented a chronological systems engineering approach to defining integrated test requirements for the personnel subsystem. Recent compendia by Gagne (1963) and by Morgan, Cook, Chapanis, and Lund, (1963) include evaluation and testing considerations, as do earlier human factors methods reports such as the ones by Van Cott and Altman (1956), Sinaiko and Buckley (1957), and the American Institutes for Research staff (1960).

Shapero, Cooper, Rappaport, Schaeffer, and Bates (1960) have examined system test programs for nine Air Force missiles and developed recommendations for human engineering testing and malfunction data collection in weapon system test programs. Whittenburg (1959) has described methodology used in the development of a model for organizing information on human capabilities in meeting requirements for a man-machine surveillance system. Shearer, Peterson, and Slebodnick (1959) have described a method for systematic evaluation of human factors aspects of prototype special weapons equipment. The American Institutes for Research have extensively documented (1962; 1963a; 1963b; 1964) personnel subsystem testing and evaluation for the Air Force 466L Electromagnetic Intelligence System.

Despite these and many other contributions toward more systematic human factors evaluation and test, it seems fair to say that evaluation and test of human factors for advanced space systems is in a relative state of disarray. There is no authoritative, hard-core methodology to which the human factors person involved in the development of an advanced space system could go for real technical guidance. There is little evidence that major efforts to rectify this situation are underway.

Consequences

Failure of human factors evaluation and testing methodology to keep pace with the increasing complexity of advanced space systems is likely to result in piecemeal efforts to provide minimum support to other aspects of systems testing. The main thrust of the human factors quality assurance program will be dissipated and lost.

Research and Development

Early efforts should be coordinated with the Air Force project (Purchase Request Number AM 4-61186) to collate available human performance assessment techniques. Procedures appropriate to advanced space systems and NASA's special requirements will have to be developed beyond the procedures and techniques which are appropriate to military agencies and programs. An important aspect of evaluating the procedures will be to determine that they are, in fact, practicable for advanced NASA programs.

Relationship to Other Requirements

Human factors evaluation and testing will contribute directly to the definition of selection, training, and proficiency measurement requirements (12). It will also verify all other areas of human factors design or will diagnose change requirements. System, function, and task data (9) will be basic input to evaluation and test. Evaluation and test results should become part of a data system (3).

Interview Comments	No. of Interviews
System evaluation should be supported by operations analysis. It should determine what operations have been implemented by the system, and whether design philosophy has been followed.	1
It is important that the data for evaluation standards be in the QQPRI's and PED's in such a way so as to be useful for evaluation, e.g., worksheets or checklists.	1
A human factors test and evaluation program is needed in parallel with the engineering test programs.	1
A manual, handbook, or other tool should be applied to system evaluation to determine whether the system complies with the appropriate human factors principles.	1
The dynamic characteristics of a system must be simulated during system evaluation.	1
Customer involvement may increase in later stages of test and evaluation. Test small questions early while maximum control is held. Don't ask for customer concurrence in test and evaluation program.	1
A mock-up scheme and data collection procedures should be worked up for system evaluation.	1
Simulated exercises and field testing are extremely valuable in system evaluation. This is much better than lab studies.	1
Guidance on evaluation and testing is extremely important. Definition of objectives and standards is especially important.	1
Evaluation programs must be simplified. For maintenance:	
Identify the critical maintenance problems.	1
Establish a simple and direct validation program for only these critical problem areas.	1
Techniques are needed to identify what aspects of man-machine system operation should be evaluated, since it is not possible to identify all aspects.	2
Improved techniques are required for extrapolating testing procedures and results from one system to another.	1

	No. of Interviews
Devices for system evaluation need improvement; meaningful check-lists, observation tools, and questionnaires are important.	1
The current emphasis in evaluation and test is on physiological measures. There is a real need for sophisticated and standardized performance measures. If there were a series of performance measures that were independent of the specific system, they could be run in parallel with simulation of real task performance. For example, it is known that the blocking function of the central nervous system is correlated with fatigue. If appropriate performance measures could be developed which were sensitive to fatigue, the fatigue load of different task requirements could be evaluated and tested.	1
Training efforts should be evaluated during system testing. They should develop a data pool of untrained performance for comparison. Time and motion studies are useful.	1
Psycho-social considerations are most important for evaluation.	1
Evaluation methods are critical. An eclectic approach is best--it can be tailored to specific situations.	1
The methods of psychologists and the information they have are too general to be immediately applied in most situations. They don't have the devices to generate specific needed information.	1
Space suits are not generally designed until after the space vehicle is completed. Generalization of body dimensions is very difficult, especially for dynamic measurements. Perhaps what is needed is a quick method for evaluating new space-suit ideas, followed by more rigorous specific design.	1
All of the answers in system evaluation must eventually come from intimacy with the system.	1
The evaluation team should report human errors in terms of human performance, not equipment damage; i.e., "inadequate information," "poor judgment," "forgetting," etc. Current report forms report hardware problems, not people problems.	1
The prediction of human performance is an important aspect of system evaluation. Operability and maintainability indexes are very useful tools. Models, mock-ups, and simulators should also be used.	1
"Near-misses," as well as errors, should be reported during system evaluation. Reluctance to report such things should be reduced by avoiding penalization for error.	1

	No. of Interviews
Total system operation is the ultimate criterion of system evaluation, but proficiency on specific tasks must be reported for adequate evaluation.	1
The degree of simulation to require for a given human factors test is difficult to determine at the present time.	1
Data on human reliability are needed, but are currently difficult to obtain.	1
Getting the cost down for early simulation and evaluation is a real problem.	2
Why errors are committed needs to be reported; currently only what errors is reported.	1
Alternative display methods should be studied experimentally. The possibility of using untrained operators should be explored. Regular operators resist observation and study by research personnel.	1
System evaluation requires a "push" from the customer. User comments are better received than technical reports from operators.	1

REQUIREMENT 14.1:
DEFINITION OF THE APPROPRIATE ROLE OF EVALUATION VERSUS TESTING

There is no consistent use of terms or concepts in this area. For present purposes, let us use the following definitions:

Assessment: Any process or procedure for determining the adequacy of human factors planning or design for a system.

Evaluation: Assessment not necessarily requiring system exercising.

Testing: Assessment requiring system exercising, either real or simulated.

Unless a distinction between evaluation and testing is maintained and differential roles assigned to each, it becomes very difficult to define a rational and integrated assessment program, particularly since evaluation tends to be much more important early in the development program and testing more important in later stages of development. Evaluation and testing can, of course, be used in a variety of combinations.

REQUIREMENT 14.2: DEVELOPMENT OF A HUMAN FACTORS EVALUATION AND TESTING MODEL WHICH IS DOVETAILED WITH SYSTEM DEVELOPMENT PHASES

A model of system phasing is needed to estimate levels of effort for test and evaluation within the developmental sequence. Procedures are needed to incorporate all kinds of evaluation and test into the developmental sequence. Some of the factors which make phasing of evaluation and testing critical are:

1. There needs to be a direct parallel between the human engineering (10) and evaluation and test programs. In order to ensure parallel effort, the phasing of both programs must be explicit.

2. The availability of system, function, and task data (9) necessarily follows the developmental phasing of the system. Precision of evaluation and test is dependent upon the quality detail of these data.

3. The precision of system simulation and operations analysis increases with development of the system. Human factors evaluation and test should provide a major input to such simulation and analysis, and should also improve in precision as the design evolves.

4. The relative participation of NASA and the industrial contractor is likely to change over the course of development. It is desirable to program these relative roles well in advance.

5. NASA will undoubtedly want to monitor the entire assessment program. Such monitoring is facilitated by advanced programming.

REQUIREMENT 14.3: PROCEDURES FOR ESTABLISHING APPROPRIATE OBJECTIVES, STANDARDS, CRITERIA, AND MEASURES FOR HUMAN FACTORS EVALUATION AND TEST

Evaluation and testing parameters are not clearly defined or used with consistency in the human factors community. For present purposes, let us define the major parameters as follows:

<u>Objectives</u>: The questions to be answered or the purposes to be served by the test or evaluation.

<u>Measures</u>: Classes of information about the system or its human components, obtained for purposes of assessing design adequacy.

<u>Standards</u>: The established levels which measures must reach in order for human factors design to be considered acceptable.

<u>Criteria</u>: Characteristics which the measures must have in order to be considered suitable indexes for assessing human factors design.

<u>Objectives</u>

The objectives of human factors assessment for space systems have not been well defined or generally established. Definition of appropriate objectives, not just in generalities but in specific detail, is a basic step in the establishment of a methodology for human factors assessment in the development of advanced space systems.

<u>Measures</u>

There is no shortage of literature describing measures and measurement methods. In particular, there is an abundance of human engineering checklists. Berkun and Van Cott (1956) developed a checklist of human engineering factors suitable for the evaluation of aircraft drawings and plans. Van Cott (1956) developed a similar checklist for the evaluation of mockup, prototype, and operational aircraft. Krumm and Kirchner (1956) have developed human factors checklists for test and ground support equipment.

Fitzpatrick (1956) presents a checklist of human factors considerations for the assessment of new Air Force equipment during operational suitability tests. He also offers recommendations for planning the operational suitability test in terms of participating personnel and simulating work conditions. He recommends procedures for collecting, analyzing, and interpreting human factors data.

Losee, Buongiorno, Frahm, and Krueger (1960) present a technique developed at Republic Aviation Corporation for the collection of task step descriptions and man-time required in maintenance functions. These data can be collected at early design stages and predictions can be made of the ability of the design to meet maintainability and supportability requirements. Van Buskirk and Huebner (1962) have developed a model which can be used as an aid for determining whether a system conforms to design objectives and for predicting the system's reliability. The primary source of data for the model would be malfunction and failure data obtained during the testing phases of the system's development.

Steinberg and Berliner (1963) present a method and recording form for identifying errors that result in loss of time, equipment damage, personnel injury, or mission failure during operation of a complex man-machine system. The method assigns causation of the error to specific aspects of the environment and permits classification of the error by the kind of activity (i.e., operation, maintenance, transport, etc.).

Krumm, Schwarz, and Fitzpatrick have derived principles and procedures for using pilot opinion as a basis for assessing human factors design. This area is also related to the role of skilled workers in establishing requirements (6).

There are, of course, a number of traditional motion and time measures (e.g., Mundel, 1950) which can be applied to the problem of human factors assessment.

If one takes any or all of the measures which have been delineated to date, he is still a long way from an exhaustive and consistent array of measures which is adequate to the assessment needs for human factors in advanced space systems. Some of the following are reasons that there is an important requirement for an improved definition of measures for human factors assessment:

1. Increased sophistication in predicting long-term adjustment of the space crew is required.

2. A much clearer delineation of the relationship of human factors and total system performance is essential to a realistic priority scheme for measures.

3. With the high reliabilities that will be sought in advanced space systems, it will be important for tendency toward error as well as actual error commission to be measured.

4. Information about error causation will have to be much more precisely diagnostic than is currently the case.

5. The correlation between work load and physiological stress is generally not well established, with the result that operators are often badly and sometimes dangerously overstressed. If there were sophisticated and standardized measures having known sensitivity to degrees of stress, they could be used in parallel with simulation of real tasks as one basis for determining fatigue and stress load of real tasks.

Standards

General standards for measurable characteristics of human factors design have not been established. Techniques for establishing specific standards for a given system have not been well delineated. Both would contribute significantly to the effectiveness of human factors assessment.

Criteria

General criteria such as validity, reliability, objectivity, sensitivity, practicality, cost, and interpretability are relatively common and well known. Methods for effectively applying these criteria to specific measures have not been well established.

REQUIREMENT 14.4: GUIDANCE CONCERNING APPROPRIATE EVALUATION AND TESTING COSTS

Evaluation and test need to simulate the environment and dynamics of new systems and to project the man into the operational situation. Achieving satisfactory simulation for reasonable cost is a big problem. Appropriate guidance concerning evaluation and testing cost tradeoffs would help to achieve a balanced program.

REQUIREMENT 14.5: FURTHER DEVELOPMENT OF OPERABILITY AND MAINTAINABILITY INDEXES

It was found in the current survey that the Operability Index (Payne & Altman, 1962) is being used for a variety of purposes at the present time throughout the aerospace industries. Basic to this technique is a central store of human performance estimates (Altman, 1964) which can be updated as new information becomes available. The store is available in a manual and in computerized form.

Irwin, et al, (1964) used the Operability Index data store in establishing a similar store for behaviors relevant to selected aspects of missile maintenance. Rook (1962) and Swain (1963) also used the data store from the Operability Index in developing quantitative techniques for reliability analysis of human task performance.

The Operability Index seems to be a rudimentary technique having potential as a basic evaluation tool for advanced space systems. However, further development is desirable along the following lines:

1. Inclusion of more discriminating performance information concerning refined categories of mental processes.

2. Expansion of the technique to cover all maintainability design features (Munger & Altman, 1959) and maintenance behaviors.

3. Definition of more precise scale factors between laboratory and operational performance.

4. Inclusion of environmental effects as modifiers of performance estimates.

5. Inclusion of differences in individual ability as well as average performance in the data store.

6. Inclusion of information about the effects of training and performance aids on each aspect of behavior.

REQUIREMENT 14.6: GUIDANCE CONCERNING THE SELECTION OF HUMAN FACTORS ASPECTS FOR TESTING AND EVALUATION

Practical necessity frequently requires that human factors assessment be limited to selected aspects of design. It is desirable in such cases for the assessment to emphasize those aspects which are most critical to successful mission performance. Formal techniques are almost entirely lacking to aid this selection process. They should be developed and made available.

REQUIREMENT 14.7: GUIDANCE ON THE QUALIFICATION TESTING OF HARDWARE DEVELOPED BY HUMAN FACTORS GROUPS

Human factors groups are receiving increasing responsibility for the hardware development of life support and related items in space systems. Human factors personnel are generally not well versed on standard testing of hardware, and there is not yet well established a set of specialized principles for qualification of human factors items. It would be desirable, therefore, for qualifications testing on existing and immediate programs to be closely monitored from a research point of view as a basis for developing guidance on the qualifications testing of human factors items.

REQUIREMENT 14.8:
DEFINITION OF THE ROLE OF OPERATIONAL EQUIPMENT, PROTOTYPE EQUIPMENT, SYSTEM SIMULATORS, AND MOCKUPS IN HUMAN FACTORS TESTING

The basic uses of the various devices for human factors testing seem to be relatively widely and well understood. There does not seem to exist, however, the definitive information about the capabilities and limitations of the various classes of devices which would help to obtain maximun benefit from the various devices.

Another area where codification of existing knowledge would be valuable is in multiple, and sometimes simultaneous, use of devices. In addition to human factors testing, these uses might include:

1. Research
2. Training
3. Engineering test
4. Proficiency measurement

THE SYSTEM DEVELOPMENT CYCLE AND HUMAN FACTORS INFORMATION REQUIREMENTS

Introduction

Relationships between human factors information requirements and different phases of the system development cycle have been pointed out earlier in this report only where some particular point has been associated in some unique respect with a given requirement. In this section the relationships of human factors information requirements to the system development cycle are summarized in a somewhat more comprehensive and organized fashion. It should be noted that the available data do not support an exhaustive analysis of the complex of relationships between requirements and system development. Consequently, the comments presented here concerning these relationships represent largely the author's best judgment. They do not emerge inevitably from the data which generated the statements of requirements.

A schematic of a generalized system development program is presented in Figure 2. It is grossly simplified to provide a manageable framework within which human factors information requirements might be discussed. Development alternatives and decision points, even major ones, are not included in the general framework; but they are discussed in relationship to particular information requirements where there appears to be a strong association. The general framework also avoids differential development specialties and functional areas since these are the subject of the next section of this report.

Each major phase of development is described briefly below. Following these descriptions is Table I. In it the implications of progress in each human factors information requirement area for development phases are briefly summarized. For purposes of this table, information areas have been grouped as follows:

1. Basic data generation and dissemination. This area includes a cluster of four general requirements: basic data concerning selected aspects of human functioning (1), improved reporting (2), a human factors storage and retrieval system (3), and definition of the tradeoff between existing research results and initiation of new research (4). The main objectives of this area are to identify and encourage the most needed research and to maximize the accessibility of needed data--as they exist and as they become available.

2. Definition and control of the human factors process. This area includes the general requirements of improved communication between human factors and other personnel (5) and definition of the appropriate role of the skilled worker

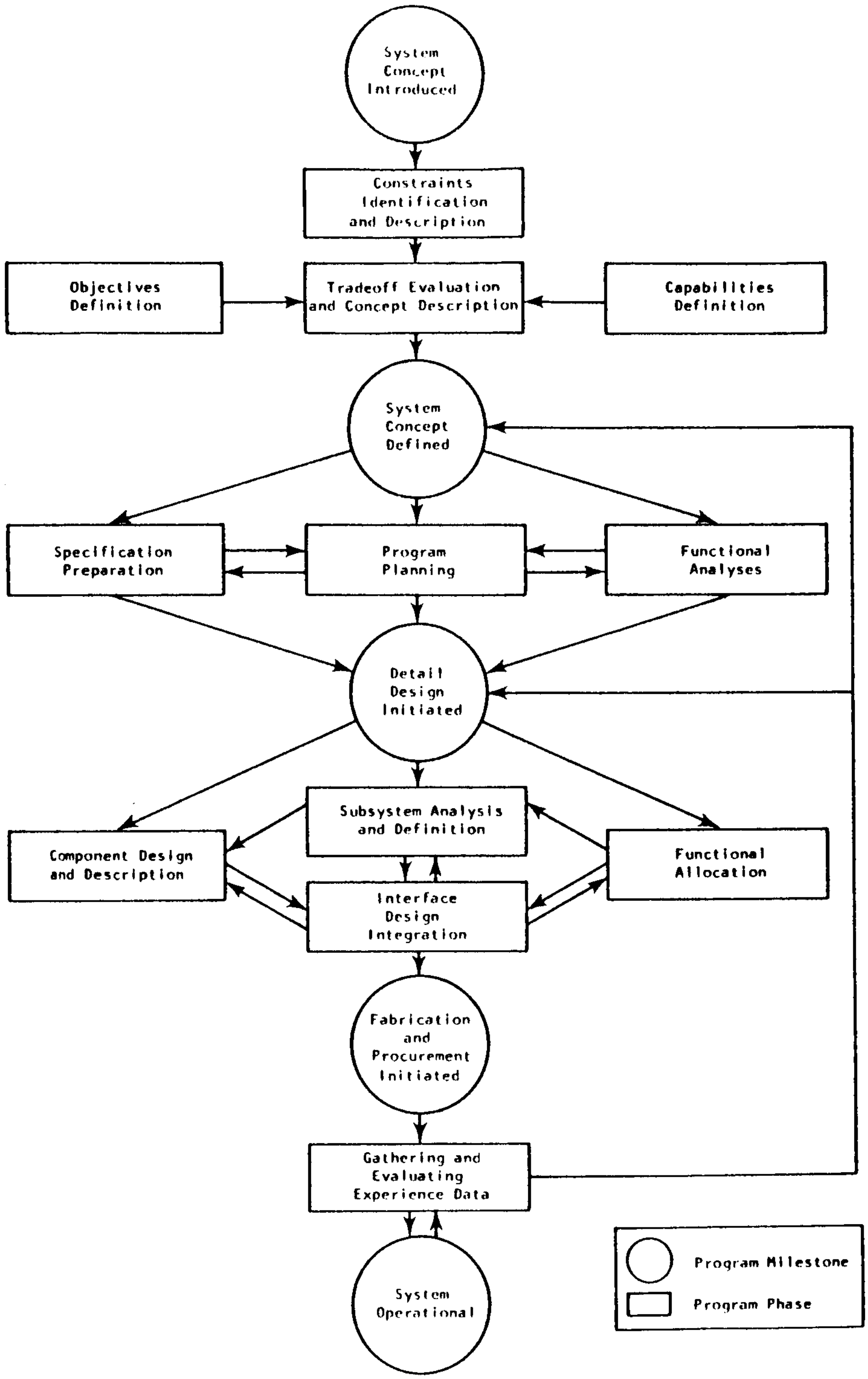

Figure 2. Simplified Schematic of a System Development Program

in establishing requirements (6). It also includes all of the specific requirements relating to integrated procedures for human factors program planning and control (7). The main objective of this area is to define and support an appropriate role and contribution for human factors in advanced space system development.

3. Function description and processing. This area includes all of the requirements relating to function allocation (8); system, function, and task analysis (9); and job design and personnel forecasting (11). The main objective of this area is to ensure that human functions in the system are appropriately identified, described, analyzed, allocated, grouped, and advertised.

4. Human factors design. This area includes all of the requirements relating to human engineering (10); selection, training, and proficiency assessment (12); and informational job performance aids (13). The main objective of this area is to ensure that human functions are adequately supported by skills, equipment, and information.

5. Design assessment. This area includes all of the requirements relating to human factors evaluation and testing (14). Its purpose is to ensure that human factors program objectives are appropriate and are met.

Because it requires explication, the development phase of "Objectives Definition" is treated in narrative form where it is initially described and is not included in Table I.

Objectives

Inherent to the introduction of a new system concept is a set of implications for objectives. To be worthy of serious consideration, a proposed system must potentially solve some identifiable problem, meet significant needs, or serve useful purposes. For complex, costly, and multi-purpose space systems the identification, definition, and organization of objectives may require a substantial and sophisticated effort. Although such definition is a logical first step in system development, objectives may be subject to further definition and modification throughout the developmental cycle.

The human factors discipline has two different kinds of potential contributions to make to the definition of system objectives. The first concerns human research objectives which can be met with a proposed system. The second concerns assistance in the identification of objectives which are not necessarily related to human data which can be provided by the system. The information requirements which can enhance human factors contribution to the establishment of human research objectives for space systems are relatively obvious. A more adequate body of organized knowledge concerning human functioning (1), improved availability of this knowledge (2,3) and better techniques for evaluating the adequacy of existing information (4) will all contribute materially to the rigorous identification and priority-rating of human research objectives for space systems. Improved communications between human factors and other personnel (5) will enhance the identification and evaluation of objectives which have both human research and other aspects. Better techniques for using skilled operators to generate human factors requirements (6) will more accurately focus system objectives on the resolution of critical problems of space operations.

No requirements were suggested by either interviews or literature which relate in any substantial way to a human factors contribution to system objectives other than human research. In fact, there was no clear reference to such a human factors contribution to space systems at all--either adequately supported by existing information or requiring additional information. Yet, despite the lack of popular support for such a role, the broader potential contribution of the behavioral sciences part of human factors to the establishment of space system objectives may be worth some consideration. The impetus for human factors as a formal discipline has come in major part from the problems of military systems development, particularly military aeronautical and missile systems. The requirements for such systems can and have been established in a relatively direct way. The need for improved weaponry is a pervasive and constant fact in the existence of military operating elements. The coalescence of system requirements awaits only a degree of technological advance which will justify the costs of developing and acquiring a better weapon. This situation may be contrasted with the context in which consumer psychology developed. The vendor of consumer products might well have technology available for greatly improved products, but unless he carefully studies the needs of a complex consumer society, his new product lines may ruin him financially.

It is clear that advanced space systems are not directly analogous to either military systems of the 1940's and 1950's or to consumer products. However, the following propositions seem to be worth consideration:

1. Given the military tradition out of which human factors has grown in large part, it is not surprising that behavioral sciences methods have played only a minor role in establishing system objectives.

2. Existing methods of defining user populations and samples, interviewing, and data analysis may well be inappropriate to the exploration of the needs and purposes of the scientific, technological, economic, and political communities. Almost certainly, a naive application of such methods without adequate attention to the special problems and constraints of advanced space systems would have unfortunate results.

3. Advanced space systems of the United States do not have narrow and institutionalized military objectives. They

have broad and diffused scientific, technological, economic, political, and social implications. Many persons may have informed and useful contributions to the definition of system objectives. Properly tailored and applied, the methods of survey research should be useful in the gathering and organization of information for the top-level planners who will ultimately establish objectives.

Constraints

The identification and description of system constraints involves the delineation of characteristics it should or must not have and costs it must not exceed. Early in the development cycle constraints tend to be based on the experience accumulated from previous similar systems and to be stated as absolute boundary conditions. As the system concept evolves more fully, constraints tend to be identified and stated in terms of parameters which will degrade the achievement of established system objectives. These later constraints are likely to be based on operational and cost analyses, simulation, and test.

Capabilities

The definition of capabilities involves the extraction from the available body of scientific and engineering knowledge statements of the methods, devices, and skills which can appropriately be used to accomplish system objectives within necessary constraints. In the very earliest part of the system development, capabilities tend to be extracted from the general body of knowledge or are a result of recent successes which provide impetus for the system in the first place. As the system concept progresses, however, capabilities statements result increasingly from analysis, simulation, and test of techniques and devices specific to the system under development.

Concept Description

Description of a system concept involves the statement of a general design framework within which the rest of system development will take place. It involves the priority evaluation and tradeoff among various design objectives, in the light of applicable constraints and capabilities. It may be based on a variety of analytic and simulation studies of optima, feasibility, tradeoff characteristics, and on experimental data. The system concept may be subject to modification throughout much of the developmental cycle, but there tends to be a heavy thread of continuity from the initial formal description of a system concept and the final system configuration.

Specifications

The preparation of specifications involves the translation of objectives, requirements, and operational requirements into engineering terms. Any major space system development will involve an extensive hierarchy of requirements, from very general to extremely specific and detailed. They will also cover a great variety of characteristics and components. Many general Government specifications are almost certain to be referenced as baselines for design. Early in development, specifications generated especially for the system are likely to be essentially translations of the preliminary system concept into somewhat more hardware-oriented terms. As development progresses, they will relate to increasingly specific functional networks and components.

Program Plans

In a sense, program planning is not parallel to other technical development activities. They provide a mechanism by which development can be accomplished rather than contributing directly to the end system. Program planning will necessarily take place throughout the developmental cycle. However, formal planning can be expected to peak at about the period between initial formulation of a system concept and the initiation of detailed design and development. Earlier efforts can be expected to involve relatively small numbers of personnel and less formal organizational structures. Once full-scale development has mounted, the emphasis will shift from initial formulation to carrying out and monitoring program plans.

Functional Analyses

Functional analyses are difficult to separate from other developmental activities since they are closely associated with many other aspects of development. However, functional analysis does represent a somewhat independent activity. The emphasis in functional analysis is on the identification and description of physical and information processes which are required to achieve desired system outputs. Preliminary and general analyses are required for the initial formulation of a system concept. They underlie the formulation of equipment and system specifications, the establishment of effective program organizational shredouts and work flows. They form an important part of the language used and documentation required for detailed design. The focus here, however, is on those formulations of functional flow which take place between the initial formulation of a system concept and the relatively detailed and final establishment of subsystem boundaries.

Functional Allocation

In a very broad sense, functional allocation will begin early in system conceptualization since the mechanisms by which certain general functions will be fulfilled will be obvious. In other instances, feasibility and required trade-off determinations will necessitate assumptions concerning the means by which functions will be achieved. However, it is with the initiation of detailed design that specific and relatively firm decisions have to be made concerning the mechanisms or types of components by which required functions will best be achieved.

Subsystem Analysis

Subsystem analysis and definition involves a formal effort to organize system concepts, initial specifications, program plans, functional networks, and identified end items into a meaningful functional breakdown of the system. It includes decisions concerning the optimum total system configuration, deduction of required subsystem performance characteristics, and establishment of subsystem configurations.

Components

Component design and description involves all of the traditional engineering activities which pre-date the popularity of formal system argot and the complexity of modern space systems. This is the point at which a network, loop, or device has been relatively well delineated in terms of available inputs, required outputs, and engineering constraints. The problem is to generate a mechanism with demonstrated capability to process the available inputs into the required outputs.

Interfaces

Subsystem analysis and component design will emphasize the division of the system into many parts in order to permit the efforts of large numbers of designers to proceed simultaneously. Interface design integration then, involves those efforts to ensure that these individual design efforts dovetail into a compatible system.

Experience Data

Experience data gained throughout design, simulation, fabrication, procurement, testing, and operational use can be used for human factors as well as engineering and production improvement.

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PHASES	BASIC DATA GENERATION AND DISSEMINATION	DEFINITION AND CONTROL OF THE HUMAN FACTORS PROCESS
CONSTRAINTS IDENTIFICATION AND DESCRIPTION	More effective definition of human factors capabilities and constraints in system design by providing appropriate data.	Clarification of the role human factors information and personnel can play in setting limits on system design.
CAPABILITIES DEFINITION		
TRADEOFF EVALUATION AND CONCEPT DESCRIPTION	Better data will support more precise tradeoff.	
SPECIFICATION PREPARATION	More prior specification of the routine and greater focus of creative resources on unique aspects of human factors design.	Improved definition of the role human factors personnel will have in generating, meeting, and monitoring specifications.
PROGRAM PLANNING		Maximum integration of human factors efforts into planning of the total development.
FUNCTIONAL ANALYSTS	A more complete, better organized, more relevant, and more current body of knowledge to draw upon in effectively designing humans into the system.	A more efficient and effective human factors design effort.
FUNCTIONAL ALLOCATION		
SUBSYSTEM ANALYSIS AND DEFINITION		
COMPONENT DESIGN AND DESCRIPTION		
INTERFACE DESIGN INTEGRATION		
GATHERING AND EVALUATING EXPERIENCE DATA		

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Human Factors Information Requirement Areas

progress in the information area have on the phase.)

REQUIREMENT AREAS		
FUNCTIONAL DESCRIPTION AND PROCESSING	**HUMAN FACTORS DESIGN**	**DESIGN ASSESSMENT**
Techniques suitable for early analysis will help to pinpoint the kinds of needed human factors constraint and capabilities data.	Techniques which permit more facile consideration of design alternatives will support a closer approximation to optimum human factors tradeoff and initial conceptualization of man's role in the system.	Better definition of human factors design assessment will clarify the criteria by which early conceptual design should be evaluated.
Better techniques will support more comprehensive and precise consideration of relevant factors in design for the human.		
Early and precise definition of areas requiring human factors specification and programming effort.	Improved human engineering specifications.	Inclusion of appropriate requirements for evaluation and testing of design characteristics affecting humans in the system.
	An improved informational base for human factors program planning.	
More precise definition of human contribution to system functioning.	Better definition of the design assumptions on which functional analysis and allocation are based.	Early examination of the implications of functional assignment for humans in the system.
Closer to optimum use of humans in the system.		
A more firm, detailed, and appropriate system information base on which to accomplish detailed design.	More effective use of human components as a basis for defining subsystems and their relationships.	Appropriate determination of human factors implications at each stage of design.
	Improved detail design for the human.	
	Improved definition and use of man's role as a system integrator.	
	More effective use of experience data in human factors design.	An explicit role for such data in human factors design.

DEVELOPMENT FUNCTIONS AND HUMAN FACTORS INFORMATION REQUIREMENTS

Neither a sufficient number nor variety of system development specialists was interviewed to permit a meaningful empirical correlation between human factors information requirements and different development specialties. However, since it may be relevant to an evaluation of the potential importance of the various information requirements, some effort to suggest the relationships of requirements to different development specialties seems to be desirable. In this section, therefore, comments are made concerning the likely principal impacts of various human factors information requirements on different functional areas involved in system development. As with phases of the developmental cycle, the relationships identified here largely represent the author's best judgment and do not necessarily emerge from the data which generated the statements of requirements.

In Figure 3 are presented the principal functions in system development which will be used as a framework for describing relationships to human factors information requirements. Figure 3 is not intended to imply any organization of a development program since such organizations:

1. Are highly variable from one program to another.
2. Tend to change from one phase of development to another.
3. Typically contain complexities which are not cogent to the problem of human factors information requirements.

It may be noted that the breakdown emphasizes generalized functional areas rather than scholastic disciplines since the former are much more relevant to differential human factors information requirements. It may also be noted that human factors is not broken out as a separate development function, although a number of the functions listed have major human factors aspects. The impact of human factors information requirements on any given human factors group would depend upon the particular development functions assigned to it.

The impact of progress in each human factors information requirement area on major development functions is summarized in Table II. The grouping of requirement areas presented on page 151 is also used in this table.

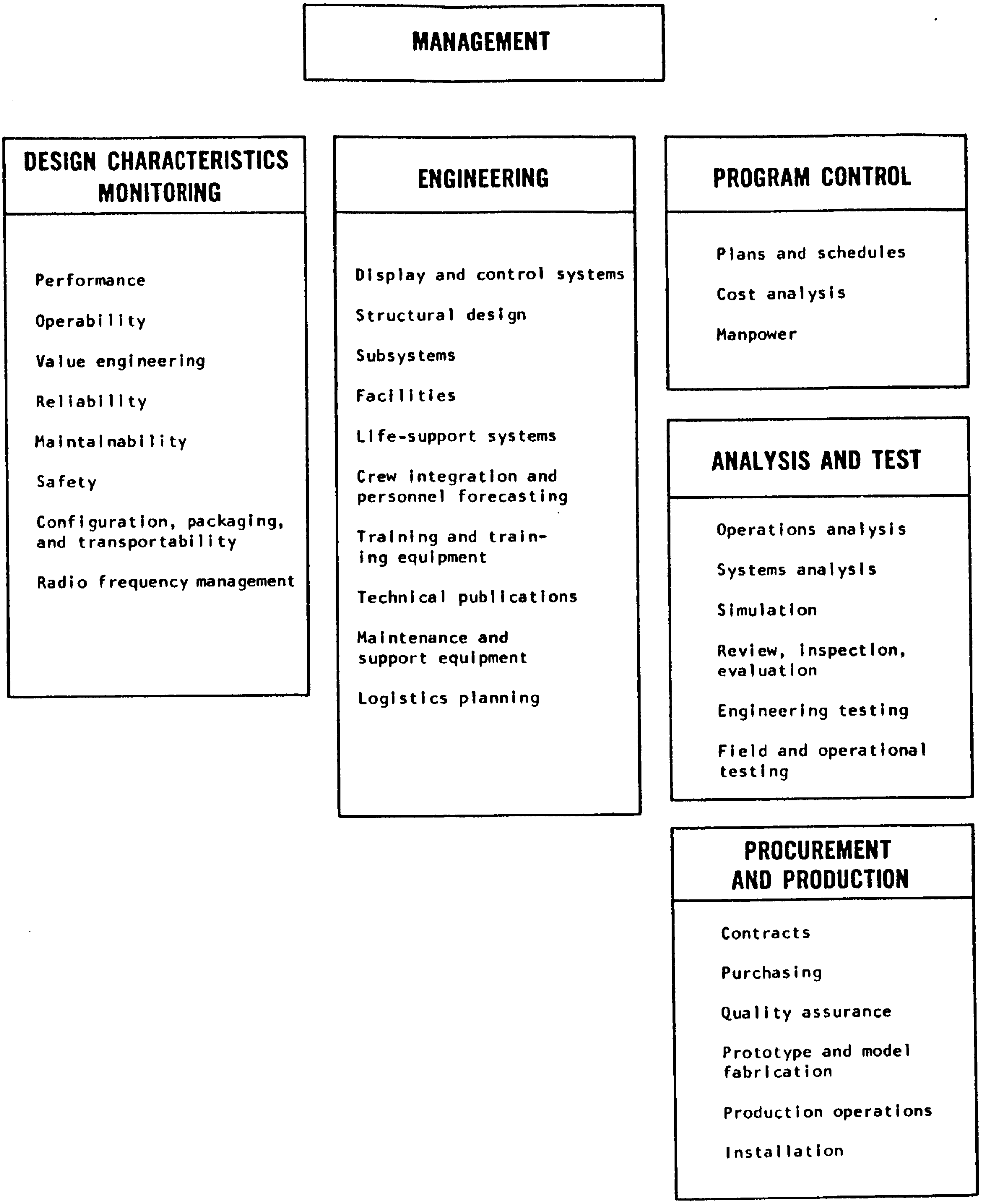

Figure 3. Principal Functions in System Development

Relationships Between Development Functio

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FUNCTIONS	BASIC DATA GENERATION AND DISSEMINATION	DEFINITION AND CONTROL OF THE HUMAN FACTORS PROCESS
MANAGEMENT	Little of direct value, but will support a generally better informed and more effective human factors staff.	Will minimize the necessity for top management to intervene in the human factors program. Will maximize understanding of major decisions to which human factors can contribute information and availability of this information.
DESIGN CHARACTERISTICS MONITORING	Make available to each specialist an improved body of knowledge concerning human functioning which is relevant to his area of specialized responsibility.	Clarification of the role of all design specialists in achieving an integrated human factors design efficiently.
ENGINEERING		
PROGRAM CONTROL	Little direct contribution.	Reduced problems in planning and monitoring one of the more troublesome elements of most major space system developments.
ANALYSIS AND TEST	Improved human data for analytic and simulation models. A better baseline of human data for design evaluation, test planning, and interpretation of test results.	
PROCUREMENT AND PRODUCTION	Information which may be useful in planning production, inspection, and installation job operations and training.	Reduced change order requirements.

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ogress in the information area will have on the function.)

REQUIREMENT AREAS		
INCTIONAL DESCRIPTION ND PROCESSING	HUMAN FACTORS DESIGN	DESIGN ASSESSMENT
Will enhance one of the basic technologies available to management in approaching optimum system design.		
Improved definition of human functioning which requires consideration in tracking the achievement of each major design objective through the development cycle. Optimization of human contribution to each design characteristic.		Improved procedures by which better and more timely data can be extracted from analysis and test for each relevant characteristic and component.
tter definition of the man factors design prob- m for each system element.	Improved support toward the optimization of human factors design for each system element.	
Better definition of processes requiring programming for one of the more garrulous aspects of development.		
Improved definition of the processes and features demanding analysis and test from the standpoint of human components of the system.		Direct assistance in one of the more difficult areas of analysis and test.

RESEARCH PROGRAM

Specific suggestions for research have, where appropriate, been given in association with the individual requirements. In this section the purpose is to suggest one way in which the various individual research needs can be combined into an articulated long-range program. An overview of such a program is presented in Figure 4.

The study on which this report is based emphasized a series of relatively informal open-ended interviews, mostly with personnel having human factors as their primary professional identity and vocational responsibility. Such a study is useful for preliminary description of the kinds of information needs felt by human factors personnel. However, the open-endedness makes comparability of response from one interviewee to another questionable. The narrowness of the sample leaves many questions concerning the representativeness for any population of major importance. A first step in the formulation of a program for the long-range improvement of human factors information for space system development should be the confirmation, generalization, and priority establishment of requirements as found in this and related studies. This can be accomplished by conducting a survey of space system development personnel along relatively standard lines. It will require the careful translation of results from this and related studies into interview scales which are primarily close-ended, description of the populations which it is desired that the information needs represent, and definition of sampling procedures that will insure representativeness. Interviewing is to be preferred over the use of mailed questionnaires because of the likelihood of serious bias with selective mail returns.

The guidance of a working panel of experts in human factors and space system development will be helpful in designing the survey. Such a panel, however, will have its major utility in deriving objectives for the program from results to date and results of the proposed survey. Once the objectives for an information program have been established, it will be desirable to evaluate in some detail the extent to which each has already been achieved by the existing human factors technology. Here the expert panel can also be of major value by ensuring that staff efforts to summarize the status of the technology is appropriately structured, detailed, and comprehensive.

Once the existing technology has been appropriately summarized and evaluated, it will remain to assess existing plans for research and development which will contribute to human factors technology. Such assessment will permit the formulation of plans for new research and development which are both non-overlapping with existing programs and which maximally dovetail with such programs.

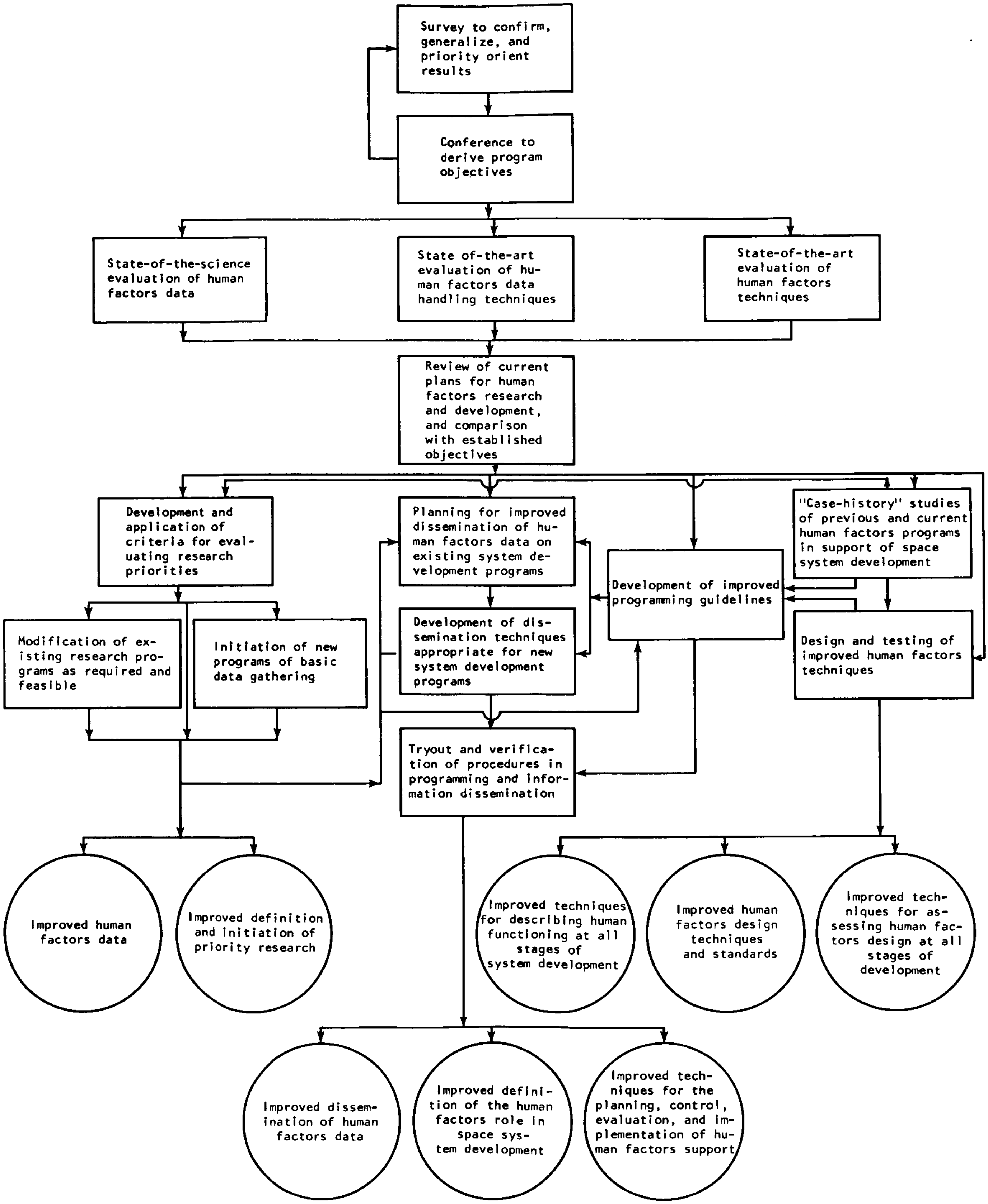

Figure 4.

An Overview of a Long-Range Program to Improve Human Factors Technology for Space Systems

A first step in the establishment of an improved body of organized knowledge concerning human functioning in systems is to develop a set or criteria by which relevance and importance can be established. Such criteria can then be used to modify existing programs to more fully meet priority needs and to initiate new programs aimed at problems not encompassed by existing programs. Criteria for evaluating data needs will undoubtedly derive in large part from objectives as established for the entire program to improve human factors technology for space systems.

Improved dissemination networks for human factors data in space system development can profit not only from tradition and ongoing studies of automating the handling of human factors data, they can perhaps profit even more from an improved definition of the role which it is desired for human factors to play in the development of space systems.

Once the general objectives for a program to improve human factors technology have been established, detailed "case-history" studies of current and previous human factors programs in space system development can serve multiple purposes. They can identify the types of needed human data found to be lacking previously, such identification serving as a basis for selective extrapolation to future contexts. They can serve to put planning for dissemination networks and programming procedures into perspective and help to ensure that initial planning is realistic. Finally, such reviews of specific system developments can help establish desirable characteristics for human factors techniques in all areas of design. The development of such techniques will also, of course, depend upon a continuity with previous efforts along similar lines and upon the general objectives set for human factors as a development tool for space systems.

Programming guidelines are a central aspect of improvement in human factors technology for space systems. They are the media by which data and techniques are melded into an effective design effort. Consequently, the development and verification of major improvements in human factors programming would seem to be dependent upon more sophisticated data and more effective techniques.

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