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Test and Evaluation Aspects of the Nimbus II Program Useful to Other Long Life Space Programs

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Summary

The Nimbus II satellite has been in orbit 20 months (to January 15, 1968), operating well within design specifications as a carrier spacecraft for meteorological instruments.

This spacecraft includes a three axis active attitude control system which itself is more complex than many other satellites and their included payloads. An essential element of the total development of Nimbus is the intensive and extensive test and evaluation programs at the General Electric Company, to which the prototype/qualification and flight spacecraft were exposed, coupled with selected design features which contribute to long life. Although a rigid causal relation cannot be established between the programs' administrative and technical activities associated with the design of the spacecraft, integration of payloads and the test and evaluation program, and the long-life on-orbit performance experienced, they are considered important contributing factors. This paper reviews: the essential elements of the General Electric Company's program, long-life aspects of the spacecraft's basic design, the fundamental philosophies which guide the test and evaluation program, the multiple nature of the test and evaluation program, review and analysis of failures encountered in the systems test programs from fabrication to launch and of anomalies encountered in the orbital performance, and some representative lessons learned from the program which can be applied directly to other long life space programs.

I. Introduction

The Nimbus II spacecraft was launched into a near polar orbit in the early morning of May 15, 1966, and has been performing its planned functions well within its design specifications for over 1.6 years at the time of this writing. The Nimbus I spacecraft was launched into a similar orbit in the early morning of August 28, 1964, and lasted for 26 days, at which time the solar array drive ceased rotating and power was depleted. Both spacecraft were unqualified successes in terms of their useful operating life and in terms of the vast amounts of meteorological data acquired by the payload's sensors and collected by the data center. These spacecraft were launched without benefit of prior engineering flight tests to assess potential orbital weaknesses. To what degree is it meaningful to relate

the spacecraft's development history to the on-orbit performance?

The planned life of Nimbus was six months at the time of the start of the program, long by any then-existing demonstrated performance. The payloads were new and at the edge of the state-of-art. Man's knowledge of the space environment was quite meager. As a space carrier for experimental-type meteorological instruments, the life required of the spacecraft should be at least that of the most significant instruments being evaluated. Conversely, to be most effective, a spacecraft capable of a six-month life should carry instruments likewise designed to live for six calendar months. Thus the life requirements and demonstrated performance for the spacecraft and its housekeeping electronics equipment can be treated separately from that of the "passengers".

What constitutes the orbital success of Nimbus II? In-orbit success must be measured only in terms of the performance of the bus. Did the bus function in orbit in a way to allow the payload instruments to perform their intended functions over a time period of at least six months? From the point of view of the research and development mission, the entire Nimbus II orbital program was an unqualified success. To a somewhat lesser degree Nimbus I was almost as successful in spite of its near-one-month life, because in its time environment the total data taking mission was more successful than had actually been anticipated, prior to flight, by those individuals close to the program.

To what factors can the posteriori success of a single long life spacecraft be attributed? Causal relations are hardly likely to be developed between the flight performance of a single spacecraft and planning methods, procedures, tests and evaluations. A more meaningful answer to this question can be had by outlining the activities at the General Electric Company which preceded the successful flight; and relating these to a review and analysis of the failures which occurred during flight. If similar analyses were made with respect to other programs of like complexity, which resulted in long life (greater than one year) orbital performance, and the respective data were examined for commonalities, then perhaps collectively causal relations could be derived.

Constrained by data accumulated from only a single example of a long life complex spacecraft, it is clear a causal relationship which defines a differential sensitivity between What and How things were done and in-orbit performance cannot be established on the basis of scientific, technical, and logical considerations. Neither is it meaningful to dogmatically state and assign requirements for activities which, if conducted, would insure successful orbital performance, with a preassigned numerical assessment of reliability.

*The National Aeronautics and Space Administration, Goddard Space Flight Center, Nimbus Project Office, Greenbelt, Maryland, has Systems Management responsibility for the series of Nimbus spacecraft. Under contract to this group, the General Electric Company, Spacecraft Department, designed and developed the three axis, active stabilization and attitude control system; designed, developed, and fabricated the spacecraft structure, thermal control system, and various components; integrated experiments and meteorological sensors; and tested the complete spacecraft.

II. GE Nimbus Program of Activities

The GE responsibilities as a major contractor to the NASA/GSFC Systems Manager were:

1. Conduct detailed electrical and mechanical design studies.
2. Design, build, test, and evaluate the stabilization and attitude control system to broadly defined goals/specifications.
3. Design, build, test, and evaluate the passive and active thermal control system.
4. Design, build, test, and evaluate the antenna systems, based upon a feasibility study provided by the University of New Mexico.
5. Design, build, test, and evaluate the spacecraft structure to the general outline and systems design provided by NASA/GSFC.
6. Design, test, and evaluate all models, including: full-scale mock-up (pre-prototype); prototype; flight; structural dynamics; antenna; thermal; separation.
7. Integrate all equipments/components into the several models spacecraft (engineering, prototype/qualification, flight), conduct integrated systems level tests and evaluate the performance under a wide range of environmental conditions.
8. Provide the adapter structure to the launch vehicle.
9. Design and fabricate all special test and ground handling equipment for the spacecraft.
10. Integrate the ground stations required to command, test, and evaluate the spacecraft at the plant and in Alaska.
11. Design and provide computer programs for engineering evaluation at the plant and for operational evaluation during flight.
12. Provide operational systems engineering to evaluate in-flight performance from lift-off to completion of in-orbit system checks.
13. Provide launch support services.
14. Establish, staff, and operate the Nimbus Technical Control Center at NASA/GSFC in support of orbital operations.

For a number of reasons, test and evaluation (concept of "test/fix") occupies an essential portion of the activity:

1. Nimbus is a complex spacecraft, having a complex control system and a variety of individual sensor/payloads.
2. Many co-contractors, each an independent contractor to NASA/GSFC, provided equipment and related services to the spacecraft as a total system, but each had no direct contractual responsibility to the integration and test contractor.

3. Mechanical and electrical interfaces were very loosely defined for Nimbus I, but somewhat more tightly for Nimbus II.

4. Sensor/payloads and spacecraft design represented advanced state-of-art, with their understanding and appreciation maturing as the efforts progressed.

5. A comparatively short development time existed, considering the absence of a technical baseline design from which to grow.

The complexity of the control system, with its own composition of basic elements provided by many internal design groups and external vendors, resulted in problems of program management similar to those encountered by the multiplicity of co-contractors. Supporting the GE in-house efforts was the entire complex of NASA/GSFC, including, but not limited to personnel from groups concerned with: equipment and component design; materials; test and evaluation; reliability; tracking and data systems; and most important, the NASA/GSFC Nimbus Project group itself. The devoted effort of the NASA/Industry team jointly attacking problems as they arose in these sample areas may be considered an essential factor in the resulting long life.

III. Basic Design Considerations

A. Design Philosophy

Except for the comparatively simple spin stabilized spacecraft, which have demonstrated extremely long life records, Nimbus has demonstrated the longest life in orbit of the complex spacecraft. To a not inconsiderable extent, this performance may be attributed to the depth to which this spacecraft and its related ground systems were conceived, analyzed, planned, and conceptually integrated before extensive detailed design effort occurred. In essence, Nimbus is well "system engineered", with the system design obviously being the result of thorough consideration having been given to mission objectives and test, qualification and evaluation requirements.

The basic hardware design was planned to provide means for extensive evaluation of the spacecraft through its environmental test program and simulated, operationally-controlled, orbital flights in both ambient and vacuum/thermal environments. Conservatively high estimates of the environmental stresses expected to be encountered by the spacecraft were selected, these being embodied in both the environmental specifications and designs.

The overall system design recognized the dearth of quantitative design data and the preponderance of qualitative design factors. A priori confidence of successful orbital performance was provided to the engineering design with a "test, evaluate, re-design, re-test" or "test - fix - test" philosophy, such that iterative application of these elements would result in a control system and in a spacecraft which would have but small likelihood of failure after launch.

1. Redundancy Practices and Failure Protection - A formal redundancy policy did not exist, nevertheless, functional and block redundancy is

provided as failure protection at the system level in several ways. These can be categorized as being related to the overall aerospace/ground system, the spacecraft and its "housekeeping" systems, and the sensor instrumentation payloads. Figure 1 shows the redundancy built into the stabilization and attitude control system.

The large number of spacecraft operations which are controllable from the ground by command provide a failure protection mode. By ground command all but essential subsystems can be set to their off or standby modes of operation, resulting in a standby mode or minimum spacecraft. This capability has proved to be quite important during all phases of system testing as well as during orbit, when it was important to "sit tight" and reflect upon performance preparatory to issuing commands. The ground command capability, for example, allows selection of different payloads, modes of operation, voltage levels for motors, and redundant elements in the command receiver. It is the key element which allows energy to be managed during the orbit, thus insuring batteries are not discharged at rates higher than or to levels lower than allowed by their design. Most pre-programmed on-orbit operations can be over-ridden from the ground through real time and stored commands.

2. Configuration Management - Formal configuration management was not an engineering design requirement. Following release of engineering data, design change control formally restricted alterations to designs and drawings. A Design Change Control Board met almost daily to review and act upon proposed changes required to continue activity. Normally general improvements in designs were not acceptable reasons for a change - rather changes were authorized primarily because of design errors, manufacturing or materials problems.

3. Interface Controls - General Electric Company practices were followed for defining electrical, mechanical, and thermal interfaces for all components and subsystems provided internally. These were controlled by the documented engineering data multistage release system in effect then.

Interface information necessary for design of mating components and elements being developed by independent internal groups flowed readily from one to the other, allowing changes to be made informally during the formative design period. An extensive and most valuable set of informational drawings were developed, each set devoted to a particular part of design, e.g.: a) signal flow; b) command flow; c) grounding, and d) electric power and distribution. Each showed interfaces in detail, with brief verbal and technical descriptions of the input/output matching stages (voltages, impedances, time constants, etc.).

4. Failure Mode and Effects Analysis - Failure mode and effects analyses were conducted on much of the control system, especially during the early phases of design where its impact was greatest. This technique was just being developed as a design tool in 1960 so its application here was somewhat of a "first". Later this analysis was applied to some of the integration and test effort including the operational programs.

5. Models for Design - Eight model spacecraft or major sections (pre-prototype, antenna and adapter, thermal, structural dynamics, separation, prototype/qualification, electrical systems, flight) were fabricated, tested, and evaluated as parts of the total design cycle. Each is considered to have contributed significantly to the final design, hence their inferred contribution to a long-life design.

6. Piece Parts - The Nimbus spacecraft contains approximately 40300 electronic-type piece parts. The engineering and prototype/qualification models of the control system were built with commercial quality parts (5000). No testing or evaluation of parts was done except for brief testing of functional performance.

The flight model spacecrafts were built with the same commercial quality parts. However, by the time parts were to be ordered and accumulated for producing three flight model spacecraft, NASA/GSFC required power aging (burn-in) of piece parts, especially transistors and diodes.

Occasional circuit failures caused by piece parts occurred, but these elements were replaced during the almost continuous testing to which the control system was exposed. The "make and test" philosophy which was central to the development of the control system served effectively as power conditioning and parts selection controls. The degree to which such activity was "cost effective" is problematical, and was never assessed.

B. Design Features

1. Modular Layout - The mechanical design of the spacecraft provided for two independent structural containers separated by a truss structure, the upper unit being the stabilization and attitude controls, the lower the sensor ring for payloads. The long-life feature of the design is essentially that of freedom - and independent testing which could be done.

The sensor ring itself is of modular design, consisting of 18 bays, allowing equipment to be mounted in each from the top or bottom without removal of cover plates, and from the outside by removal of either a cover plate or a panel on which is mounted a thermal louvre. This design allowed easy removal and installation of equipment, easing problems of maintenance. The modular design also allows extreme flexibility in locating equipment within the sensor ring.

2. Thermal - The spacecraft system design envisaged the sensor ring with its installed equipment to be an isothermal body. Equipment is hard

mounted to the sensor ring framework, with "space grease" at interfaces, providing good thermal conduction, and in a sense leading the heat to be dissipated from the spacecraft to those regions of the ring having either flat panels coated with paint having a specified ratio of absorptivity to emissivity or to panels having venetian blind type louvers. Their slats opened in response to the mechanical motion of a bellows filled with freon which has a large coefficient of thermal expansion. In the event the primary bellows failed, a secondary bellows acted to move the slats to a fixed 30-degree open position. Failure has never occurred.

A truly benign environment was achieved in the sensor ring on both Nimbus I and Nimbus II. Whereas the system design called for a temperature of $25^{\circ} \pm 10^{\circ} \text{C}$, the actual temperature range measured during orbit has been close to $\pm 2^{\circ} \text{C}$. The thermal design for the control system was also extremely conservative. Again passive (paint) and active (louvers) systems were used. The actual temperature range measured during orbit has been close to $\pm 5^{\circ} \text{C}$.

3. Electromagnetic Compatibility Control - Potential electromagnetic interference among the subsystems through conduction and radiation was recognized in the very early phases of system design. However, specifications for the design and performance of subsystems did not include the subjects of limiting the levels of electromagnetic interfering signals within the subsystems nor protection against incoming interfering signals (susceptibility). Only mild requirements were included in the power subsystem limiting the generation of sharp pulses which could be placed on the regulated bus. As a consequence, many electromagnetic interference problems were generated immediately as subsystems were interconnected and during the first series of electrical systems integration tests.

The control system was particularly susceptible to conducted interference pulses propagated on the power bus, generated by switching transients. Most of this susceptibility was eliminated by revisions in grounding and by filtering. Camera shutters introduced substantial transients until the input circuits to the camera subsystems were revised by substituting inductive for capacitive input circuits. Circuits in the clock and telemetry subsystems were also susceptible to power line transients, requiring changes to be made to them.

In addition to determining and eliminating the sources and effects of conducted interference, radiated interference existed. Leads and cables had to be re-routed; shielded leads replaced unshielded leads; unbalanced a.c. line pairs which were twisted were untwisted; balanced a.c. line pairs which were not twisted were twisted; many cables were wrapped with metal foil, some grounded; and fine mesh screening was installed around cameras.

An electromagnetic anechoic chamber not being available during systems tests, radiated interference entered the antennas, energy being reflected from the laboratory's floor and walls.

Hoisting the spacecraft and locating it approximately 15 feet from a reflecting surface minimized this type of interference.

Had electromagnetic susceptibility requirements been placed on the engineering design and performance specifications for each subsystem, most of the noise sensitive problems encountered during the electrical systems test would never have occurred nor would the flight data exhibit the degrees and kinds of interference which they do.

4. Maintainability - Two features of the conceptual design characterize the consideration given to maintenance. The first of these has already been noted, namely, the modular design of the sensor ring, the standardized sizes of enclosures and the placement of connectors on hardware allowed easy removal and replacement of components during the integration test and evaluation activities. The high degree of selective redundancy allowed alternative operating modes thus minimizing down-time during tests and what is, of course, most important, failure of the mission in orbit.

An important feature of the Nimbus design not to be overlooked is the inherent capability which exists for remote "maintenance and repair" while the spacecraft is in orbit. The capacity of the command system, directed from the ground, to accept many alternative directions and orders, coupled with the data relayed through the telemetry system, provided a total maintenance capability which has proven most effective during the life of Nimbus II. This concept of in orbit maintenance and repair through cooperative ground activity should be expanded and applied as part of the engineering systems design of new spacecraft.

5. Command - The large number of commands capable of ordering functions on the spacecraft provided the flexibility necessary for alternative selection of operating payloads and orbital management of energy. The system allowed 128 coded and 4 uncoded (emergency) commands. Sixteen of the coded commands could be stored in a memory, to be actuated at specified times during a given orbit. These commands could be revised once each orbit. This large number allowed equipments to be turned on or off individually and to select among the redundant alternative modes of operation, as noted earlier. It is clear, had this capability not been available to the Nimbus II spacecraft, little likelihood exists it would have remained as useful a spacecraft for the long period it has.

6. Telemetry - Several references already have been made to the role of the telemetry system and its alternative modes of operation as contributing factors to the long life of Nimbus II. In spite of the failure of the telemetry system's tape recorder several months ago, almost the full status of all subsystems can be monitored nearly continuously through the real-time telemetry transmissions. This mode allows reception of status information by only those properly equipped receiving stations in the tracking network. Without them real-time data energy management would have been impossible and the entire spacecraft would have failed at the time the telemetry system's tape recorder failed.

An essential feature of the Nimbus spacecraft is the total dependence on the telemetry system for all systems testing, countdown, launch and orbital phases. Although provision was available for transmitting telemetry data through hard-wire connection to a telemetry interfacing connector, except during the earliest periods of testing this method was not used. To provide a more realistic situation, all telemetry data were transmitted through radiation from the telemetry system's quadrupole antenna system, the data being picked up by a receiving antenna(s) connected to the ground station's telemetry receivers. This allowed assessment of the full telemetry system under all conditions including the time when the spacecraft was undergoing environmental tests in the vacuum/thermal chamber.

IV. Philosophy of the Nimbus Test and Evaluation Program

A. General Philosophy

Any effective test and evaluation program is the fulfillment of a logically planned effort, the conduct of which is traceable to some underlying philosophy. The Nimbus test and evaluation effort, as actually conducted, is the eventual realization of a set of guidelines established by NASA/GSFC prior to 1962. It is understood these have not changed materially in the intervening years.

Designing and manufacturing a complex spacecraft is more of an art than a science, and subject to a large number of alterations and constraints representative of many unknown factors and inter-relations which become apparent during the development period. A complex spacecraft is a good example of a system which usually is not fully operable upon "rolling off the end of the production line" - the whole is not the sum of its parts. The performance of a spacecraft, be it an engineering, prototype/qualification or flight model, must be evaluated empirically. Performance of each model must be demonstrated under simulated conditions representative of the environmental stresses expected. In essence, tests must supplement analyses.

This point of view is particularly applicable to a space program which is essentially research and development in nature, and especially so in a program which features a spacecraft of unusual design and equipment which pushes state-of-art. Conventional approaches to establishing reliability and confidence levels, based upon measurements made on a relatively large population, simply do not pertain. Evaluating the performance of the completed spacecraft, however, must not be an isolated activity; it must be viewed in the context of the activities of a total program, i.e., test and evaluation activities should not be isolated from other activities. Accepting this premise leads to considering test and evaluation requirements very early in the planning stage of the total program.

A basic philosophy to guide test and evaluation activities, especially at systems level, can be expressed in seven brief statements.

1. Very conservatively define the total environment and the stress levels expected to be experienced by the subsystem and/or system (the spacecraft). Include as environments: manufacturing, ambient, laboratory, handling, shipping, storage, launch, space.

2. Separately qualify each prototype subsystem and sensor/instrument payload before installing it into the spacecraft. Study of available specifications indicate for some subsystems loosely defined demonstrations of performance were acceptable evidences of qualification. Further, individual subsystems were not required, at the time of their initial development, to adhere to the same single set of evaluative tests to demonstrate qualification of design for space use. Some subsystems required engineering development beyond their anticipated scheduled completion dates, resulting in fully qualified hardware not being available for installation into the spacecraft at the times planned. The GE-operated bench acceptance test activities screened some malfunctioning equipment, but it also allowed other marginally-performing equipment to be installed into the spacecraft.

3. A prototype/qualification spacecraft, complete with identical equipment and payload sensors as will be incorporated into the final flight spacecraft, and in full operating condition, including electro-explosive devices, as required, should be tested in a series of environments simulating those anticipated, augmented by appropriate safety factors as noted in 1. above. The time duration of testing in a vacuum/thermal environment should be two weeks. The conservative assumption is made that a spacecraft whose design is to be evaluated which could not survive these tests is poorly designed and is not suitable for a space program. Obviously all components and subsystems, even those whose orbital lifetimes are short, must survive the test period and not constrain the tests.

4. Separately expose to vibration and vacuum/thermal acceptance tests each flight subsystem and sensor/instrument payload before installing it into the flight spacecraft. For the most part, equipments destined for flight use were exposed to the environments noted and to full acceptance tests. The problems and failures encountered during the integrated systems level tests indicated even these tests were not, in many cases, effective means for screening potential failures. It is presumed, where opportunity existed, equipment intended for Nimbus II was tested to a better degree than similar equipment which was incorporated into Nimbus I. This trend is continuing for successive Nimbus spacecraft.

5. Similarly, each flight spacecraft should be tested to a set of environmental stresses which define an acceptance test. Obviously, to conduct such program requires the spacecraft: to be amply provided with command capability to allow it to be thoroughly exercised during the environmental tests; to be amply instrumented with telemetry to allow rapid assessment of performance of subsystems; and to communicate between the ground control reception point and the spacecraft through only a radio link

(no hardware). The Nimbus spacecraft is designed to allow testing to be so accomplished.

6. A strong policy should be followed minimizing the replacement or removal of any equipment from the spacecraft between the start of flight acceptance tests and launch. Access to, adjustment, or disassembly of the spacecraft or its subsystems should be discouraged. The system should remain intact and last-minute changes avoided. Make no hardware changes at the launch site.

7. Prior to start of the actual test and evaluation program, the participating active ground equipment, facilities, handling mechanisms, detailed test procedures, and test conductors and supporting personnel should, in a sense, be "qualified".

B. Functions of the GE Test and Evaluation Program

The primary functions of the GE Test and Evaluation Program can be summed as:

Estimate orbital environments

Establish and prepare general, specific, and detailed test specifications and procedures

Conduct subsystem tests for equipment provided by GE

Conduct systems test and evaluation using antenna, structural, thermal, electrical, prototype/qualification, and flight models

Redesign or recommend redesign, as required, based on results of the test and evaluation program

Provide certified personnel, procedures, and facilities for all tests except the acceleration test

Subsystems were intended to have been evaluated prior to their integration into the spacecraft for system level tests, to the same regime as planned for the system, i.e., engineering, prototype/qualification or flight acceptance test levels to their own specific set of specifications. Detection of marginal performance conditions, early wear-out and failures were the primary results to be achieved from a strong subsystems test program.

Notwithstanding the detailed overall program planning to have available for systems level testing fully qualified, ready to use subsystems, schedule changes in various parts of the program resulted in some co-contractor's equipment being delivered to the General Electric Company in a not-fully performance-evaluated condition. Each piece of co-contractor's equipment or sensor payload was to have passed its prototype/qualification and/or flight acceptance tests before delivery for incorporation into the spacecraft. Any undetected failure or out-of-specification condition which passed these co-contractors' screens theoretically would be picked up in the acceptance tests for government-furnished equipment or in the systems level tests.

It was therefore necessary to institute a vigorous and carefully documented acceptance test program for all equipment provided by co-contractors, with product assurance controls patterned somewhat after those required by the total spacecraft. This program only allowed either acceptance or rejection of the elements of or a complete subsystem, based on functional performance tests in an ambient laboratory environment. Based on accumulated experience, it is postulated many functional performance problems which were encountered during the systems test program would never have occurred had each of the subsystems been operated under appropriate environmental stress conditions for a time duration sufficient to establish little further likelihood of additional failures.

V. Test and Evaluation Programs

A. Basic Considerations

To a great extent high emphasis was placed on the spacecraft's system level test and evaluation program ("----design-test-fix-test-fix----") because it served as an overall screening function, to detect and indicate corrective actions which had not previously been indicated in the individual subsystems because of the limited testing to which they had been exposed. System level testing, however, should not be considered as an isolated activity; its role must be part of a comprehensive test and evaluation program.

A structural concept of the test and evaluation program for Nimbus (and one which is also applicable to other programs) is shown in Figure 2. Each level of testing is designed to discover weaknesses, anomalous behavior and failures which passed through a lower level testing, and those similar characteristics of performance which may be generated by interactions created by the functional/physical forms associated with that level.

Theoretically, if a sufficiently comprehensive and effective test and evaluation program had been consummated at Level 1, failures in testing at Level (i+1) should not be anticipated as coming from Level i, but rather as coming from unanticipated causes peculiar to the total environment associated with Level (i+1). Corrective action could therefore be localized and minimized.

Levels 1 to 4 pertain to the design, test, and evaluation of subsystems. They are designed to demonstrate: achievement of design goals, performance, structural and functional integrity, and assurance particular pieces of hardware are in fact of sufficiently high quality to be incorporated into a flight spacecraft. Presumably, if the flight acceptance test program at subsystem level does realistically take into account anticipated environmental stresses, and if the subsystem has been tested for a time period to have eliminated infant mortality failures, testing at systems level should encounter problems principally attributable to integrating subsystems.

Level 5, Systems Testing, encompasses a wide spectrum of testing activities on the Nimbus program since it includes evaluation of a large number

of special-purpose spacecraft models. Final verification of the adequacy of design of the spacecraft (as a bus) and its complete integrated payload was demonstrated by the performance of the prototype/qualification spacecraft under extreme environmental stresses. Exposing each flight spacecraft to a flight acceptance test program wherein it must perform while subjected to environmental stresses similar to those expected during and after launch is the ultimate means for instilling confidence it is ready for launch.

Level 6, Flight Readiness Testing, demonstrates no degradation to have occurred during transportation from the factory to the launch site, no short-term degradation to have developed during the conduct of the launch-site activities, concluding with the final checking of the spacecraft's critical parameters as part of the launch countdown prior to lift-off.

In spite of differences which may in reality have existed between what each level of test should have accomplished and what it did in fact accomplish, including both depth and time duration of testing, the Nimbus I and II spacecraft were exposed to a more comprehensive and longer series of tests than any other spacecraft developed under the aegis or at the Goddard Space Flight Center. As noted earlier, although causal relations cannot be established, the fact the Nimbus II spacecraft has demonstrated exemplary in-orbit performance is sufficient for other spacecraft programs to consider Nimbus' test and evaluation program as a model for planning purposes.

B. Test Procedures and Plans

The complex nature of the Nimbus spacecraft and the many alternative modes of operation possible with the housekeeping and sensor/payload subsystems preclude leaving to chance its operation and control. This is especially so during the initial system level integration tests when test conductors and supporting personnel are becoming acquainted with the expensive spacecraft and supporting test facilities. Careful pre-planning of all factors of the test and evaluation program is essential. Simultaneous with intensive reviews of the first drafts of documents within the General Electric Company, representatives of NASA/GSFC, and to some extent co-contractors, reviewed plans. These were comprehensive and in step-by-step detail to insure little likelihood of errors of omission and/or commission during the test program. The reviews were not infallible; corrections in test plans still had to be made during the conduct of the tests. Following review and approval by NASA/GSFC representatives, the procedures and test plans were the guiding documents for the actual conduct of systems level tests.

Several auxiliary advantages result from the preparation of these plans. Their value as educational and training aids is unquestioned. Each participant having a defined responsibility for part of the test program is forced to pre-plan his activities and to consider the impacts and implications of his activities on those of other subsystems. Close working relations developed

between the systems test personnel and the co-contractors' representatives. Existence of formal procedural documents forced consideration to be given to the exact environments to be simulated and to the specification of criteria for evaluating performance of the individual subsystems and the total spacecraft as an integrated system.

C. System Test Program Plan - Nimbus II

The Test Program for the Nimbus II satellite was based upon the wealth of experience accumulated by its predecessor program, Nimbus I. A full flight spacecraft acceptance test program at flight environmental levels was conducted as were environmental qualification tests of new subsystem designs. A full spacecraft qualification program was carried out for Nimbus I, but not for Nimbus II.

The complete Nimbus II system test program constituted four stages:

A prototype test program - intended primarily to complete the design development and system integration.

A sensory ring test program - intended to integrate all flight quality subsystems within the sensor ring and essentially subject this identifiable, major part of the spacecraft to flight acceptance testing.

A spacecraft test program - intended to integrate all elements of the complete spacecraft and subject it to flight acceptance testing.

A launch test program - intended to prepare the flight spacecraft for launch.

1. Prototype Test Program Plan - The prototype/qualification spacecraft from the Nimbus I program was updated to the Nimbus II design configuration. It served also as the initial means for integrating subsystems, the composite resulting in the Electrical Systems Model for Nimbus II. This spacecraft was used for electrical, electromagnetic compatibility control, mechanical and interference testing. Following its use within the test program, the prototype spacecraft was exposed to the launch test program in-house and at the Western Test Range.

2. Sensor Ring Test Program Plan - Following physical installation of flight quality hardware into the sensor ring, the subsystems were energized to form an operating system. Electrical testing eliminated technical discrepancies, interferences and incompatibilities not previously encountered in the prototype test program. Following the electrical testing, the sensor ring as a major subassembly was subjected to an acceptance test program designed as a prelude to a similar program for the entire spacecraft.

3. Flight Spacecraft Test Program Plan - The flight spacecraft was subjected to a comprehensive acceptance test program, including vibration testing at levels for the Thrust Augmented Thor-Agena launch vehicle (Nimbus I was placed in orbit by the Thor-Agena vehicle) and thermal

vacuum conditions. Briefly, the attitude control subsystem (the upper section of the spacecraft) was mated to the sensor ring, and the spacecraft's electrical and mechanical integrity was established. Significant performance characteristics are measured before and after each major environmental exposure. Tuneable antennas were adjusted prior to shipment to the Western Test Range.

4. Launch Test Program Plan - The launch test program included a series of pre-shipment tests, tests after receipt at the Satellite Assembly Building (SAB/WTR), and tests on the launch pad after the spacecraft was mated to the launch vehicle. Pre- and post-shipment tests were preceded by a low-level (workmanship) vibration test to insure the absence of extraneous or loose parts.

D. Aspects of the Qualification and Flight Acceptance Test Programs

1. Prototype/Qualification Test Program - The concepts developed for evaluating the performance of the complete Nimbus spacecraft represented a substantial departure from those applied to other spacecraft developed in the same time period. Even at the start of the Nimbus program in 1960 there already had been outlined the basic elements of the qualification test program. These were specifically defined in a set of test specifications which described the five environments and the stress levels to which the qualification spacecraft was to be exposed as part of the systems integration and test program. Four elements pertaining to the specification and the test program should be noted:

a) The purpose of the qualification test program was to discover basic and/or inherent weaknesses in the design of the entire spacecraft packaged in a form which represented the flight spacecraft.

b) The performance of the entire spacecraft was to be evaluated while it was in the operating condition expected during that portion of its flight history being simulated by the environmental exposure.

c) Stress levels for vibration tests were to be set at approximately 150% of those expected by the flight spacecraft (95% level) during launch and placement into orbit. The extremes of temperature were set by specifying an increase of $\pm 10^{\circ}\text{C}$ of those expected during orbit.

d) The order of exposure to the five environments were:

Humidity
Vibration
Acceleration
Pre-vacuum/Thermal
Vacuum/Thermal

As noted earlier, the systems test programs were concerned with evaluating performance of the integrated spacecraft. The subsystems which were provided as government-furnished equipment had completed their own qualification test

programs with the exception of a small number of components. Therefore, the design being qualified by the integrated systems test program was essentially an evaluation of the spacecraft as a bus/carrier and of the mechanical and electrical interfaces among any subsystem and among the subsystems and the spacecraft, created by the installation of the subsystems into the spacecraft.

The purpose of the program specifically was not to evaluate the design of the subsystems, although their performances in the system test program did result in recommendations for the redesign of some of them. The test program neither ascertains the true levels of stresses which result from the exposure nor are the tests made to establish stress levels to failure since only one spacecraft is available and it cannot be tested to destruction.

Realistic simulation of performance of the spacecraft can only be achieved if the spacecraft is in fact energized and operating as it would normally operate in the expected environment. Thus, during the vibration test there were energized the command receiver, the power system on batteries, the telemetry/beacon transmitter, and the drive motor on the High Resolution Infra-red Radiometer. During the vacuum/thermal tests, all subsystems which would normally operate in orbit were exercised as part of simulated in-orbit operations. Commands were received and acted upon, subsystems were turned on and off, measurements were made by sensors activated by appropriate stimulators, television cameras recorded projected test patterns, sensor and telemetry data were stored on tape recorders, and data were transmitted through radio in both the real-time and stored data modes of information transfer.

Exercising the spacecraft effectively implies the existence of two additional necessary factors - instructions and personnel. The qualification test program was conducted in response to sets of essentially step-by-step instructions embodied in written detailed test plans which were continually reviewed and revised. Personnel operating the spacecraft were being trained to be called upon later to operate the flight spacecraft in its acceptance test program and in orbit. Operational systems planning was completed and written in detail. Computer programs were devised for use with the telemetry data to allow its reformatting, special read-outs, energy balance, conversion from binary digital counting to practical engineering units of measure, and other factors as desired. These were all essentially completed and ready at the start of the simulated flight operations tests in the vacuum/thermal test chamber. Similar preparations, suitably up-dated, were made as part of the flight acceptance test program.

The simulated flight tests started with the spacecraft on the launch pad, with appropriate equipment in full operating condition as they would be in truth. At lift off, the pressure in the vacuum/thermal chamber was reduced, simulating the expected change in pressure/altitude. Subsystems were energized (solar paddles were in the unfolded position), monitored, and exercised on a real time basis as they would be in the early and later orbits after several days following launch, all such activity in accordance with the guidelines

and instructions embodied in the operational systems documents. Commands to the spacecraft were generated by the Test Director, written and forwarded to the ground command equipment, and then transmitted via radio to the spacecraft's command receiver. Telemetry and sensor derived data were transmitted from the spacecraft via radio to the ground receiving equipment. Antennas were mounted inside the vacuum/thermal chamber to permit this transmission. Hardwire communications to and from the spacecraft was not permitted. There was no access to the normal test points used in the development or subsystems test programs.

During the several days operation, thermal stress cycling was provided with real time and/or near real-time evaluation of all data transmitted from the spacecraft. All decisions regarding the performance of the spacecraft and its subsystems were made on the basis of data emitted by the spacecraft. It was necessary to rapidly interpret data, and assess whether the test program should cease because of the exhibition of malfunctions, anomalous behavior, or failure. These requirements provided on-the-job training for the test conductor, the entire test crew, the personnel operating the ground equipment, and all NASA personnel who were later to be faced with true situations.

When the environmental test specification was written, a comparatively limited amount of data were available regarding the vibration environment during the launch phase. A central problem attendant to an environmental test program is the establishment of appropriate stress levels. The vibration specification was based upon the knowledge available at the time for the Atlas/Agema launch vehicle, updated as more data became available between the time of the initial specification and the time of the tests. The stress level for the vibration test was set to be a 99% probability level, i.e., during flight, there would be only one chance in a hundred the flight spacecraft would experience a vibration environment more severe than that experienced by the prototype/qualification spacecraft in its test program. Assuming a Gaussian distribution of the vibration stress levels, the 99% level is set at the mean level (i.e., the mean vibration level expected based upon actual measurements) plus 1.5 times the difference between the mean level and the 95% level. In essence, the 150% vibration test level is based on the 95% level on a Gaussian distribution of expected stresses not on the 150% of the mean value. Thus, all test levels are far more severe than the average stress level which may be encountered in a flight. The duration of the vibration test was selected to give assurance the flight units would survive the environments imposed both in the acceptance tests and in the actual launch activity.

The temperatures to which the spacecraft would be exposed in orbit, the quality of the thermal design and the temperature regulating system were not known with high confidence. Consequently, in establishing the extreme levels

of stress for these tests comfortable margins of safety were chosen. While inside the "space chamber" for the vacuum/thermal tests, the spacecraft was exposed to radiant heating to achieve the specified profile. All temperatures were measured on the spacecraft's most massive non-heat producing section, part of the sensor ring. The structure had mounted thereon a number of temperature detectors. The lowest temperatures read on the structure was taken to be the level specified as the high temperature, and the highest temperature on the structure was taken as the level specified as the lowest temperature. Temperature readings were made when the pressure was less than or equal to 10^{-5} mm Hg; the rate of pressure change was to be no greater than the pressure/time profile expected in flight. The spacecraft was interrogated bi-hourly, looking for any changes or anomalous performance which would be interpreted as a forerunner of an equipment failure or harmful, but slow degradation or out-of-specification condition.

As data have been accumulated over the past several years, and the skills of spacecraft designers have improved, the needs for these extremes have diminished and tighter tolerances will no doubt be specified.

While the qualification test program pertained specifically to the Nimbus I program, a partial qualification test program was in effect for Nimbus II. The sensor ring with its subsystems/experiments were exposed to a qualification test program, including exposures to humidity, gas leak, vibration, acceleration, and vacuum/thermal.

Two additional factors were necessary before initiating the qualification test program:

- 1) Criteria and/or guidelines to judge whether the spacecraft and its full complement of installed equipment "passed" the qualification test.
- 2) An operating plan to define what should be done in the event of failure of an element during the test program.

Formal and rigid acceptance criteria were not established during the qualification test program. Presumably, the absence of formal technical criteria provided the NASA Project and Spacecraft Managers with more freedom to exercise technical judgments related to program flight schedule, and expenditure commitments. Collective technical judgment is a most important factor and quite correctly should take precedence over detailed formal planning, which should be subject to amendment as the test program proceeds. In a sense, this was acceptable since in many cases quantitative descriptions of performance would not have had firm bases for their specification. For example, although the resolution of the television camera system had been quoted at 800 lines (in one diameter inch tube), this actually pertained only to the central section of the tube. If 700 lines resolution were found in a tube, this would hardly be cause for rejecting the spacecraft. As the test program developed, specific criteria were formulated for some subsystems. The NASA Project Manager relied heavily on the judgment of the members of the Nimbus

Environmental Test Committee, whose membership included NASA/GSFC and GE representatives. This group monitored, reviewed, and recommended changes in the rationale for testing and evaluating test data, and it reviewed all test data and made recommendations to the NASA Project Manager as to whether the spacecraft and its installed equipment met design objectives and was qualified.

The rejection and retest plan was formulated before the start of the program. Its essential features were:

- a) If the spacecraft is rejected before, during, or after an exposure, discontinue the exposure.
- b) Determine the cause of failure, and correct it, including any design defects.
- c) Starting at the event, timing, temperature where the failure occurred, repeat the complete test program until successful.

2. Flight Acceptance Test Program - Little differentiated the flight acceptance program for the Nimbus I and II spacecraft. Basically, the same set of environmental specifications pertained. Whereas the qualification test program searched for inherent design weaknesses, the flight acceptance program could be characterized by the following:

- a) The purpose of this test program was to determine the flight worthiness of the flight spacecraft and to discover workmanship defects and/or errors in use of materials.
- b) The performance of the entire spacecraft, which was to be an exact replica of the prototype/qualification spacecraft, was to be evaluated, in the operating condition expected during that portion of its flight history being simulated by the environmental exposure.
- c) Stress levels were to be set at approximately 100% of those expected by the flight spacecraft during launch and orbit.
- d) The order of exposure to the three environments were:

Vibration
Pre-vacuum/Thermal
Vacuum/Thermal

Since flight acceptance testing follows the qualification acceptance test of a single spacecraft, no prior knowledge has been developed regarding the expected variations among supposedly identical spacecraft. The assumption is made no variation exists, which, of course, is statistically invalid, but economically wholesome. On the presumption that all design defects have been eliminated as a result of the qualification test program, the flight acceptance test program is presumed to screen only for workmanship and/or material errors and defects. That this is not so is ably demonstrated by analysis of the failures encountered during the flight acceptance test programs for Nimbus I, Nimbus II, and many other spacecraft programs for which comparable data have been analyzed.

The stress levels used in the flight acceptance tests were the best estimates of those anticipated in the launch/flight environment. The test levels were to be no greater than those expected in these environments. In the case of the vibration tests, the stress level was set by first assuming a Gaussian distribution of vibration levels (based on accumulated experience). The test level was the 95% probability level, i.e., one chance in twenty this level would be exceeded during the actual launch. The 95% level is the 1.65 σ point.

An innovation introduced into the vibration test program for Nimbus II was the use of notching techniques. The combination of the spacecraft and the drive power/frequency characteristics of the vibration table were such that if the original amplitude/frequency specification were adhered to, the spacecraft structure could be overstressed. Analysis and vibration survey data indicated frequency bands wherein the drive power of the vibration table should be reduced with no resulting deleterious effect on the purposiveness of the vibration test program. These specific notch points were then incorporated as part of the final specification for the vibration tests.

The same rejection and test plan was stipulated for the flight acceptance test program as for the qualification test program, and just as easily interpreted on the basis of program needs as in the earlier tests.

In addition to the systems test program for the entire Nimbus II spacecraft, the sensor ring with all equipment installed was exposed to a flight acceptance test program in all environments, and with its own vacuum/thermal test cycle.

The rejection and retest plan was not followed, in spite of its good intentions. Program management considerations, trading off performance, cost, and schedule factors resulted in continued testing in accordance with the planned profile, following repairs or replacement of failed equipments, rather than recycling the tests.

3. Launch Pad Test Program - The test program at the Western Test Range was conducted to ascertain that the flight spacecraft had not suffered any detrimental damage in being shipped from GE/VFSTC to WTR.

VI. Analysis of Failure Records - System Tests and Flight

A. The Raw Data

Quantitative analyses were made to determine causes of anomalous behavior, out of specification performance, and/or failures of components and subsystems which form the total spacecraft, encountered during the flight acceptance tests for Nimbus I and II and their performances in orbit. All available reports within the General Electric Company pertaining to these system tests were individually examined, including: System Failure Reports; Malfunction Reports; Final Test Reports; and Flight Reports. These data were supplemented by records of in orbit malfunctions as reported in GE-originated reports. Failure data pertaining

to the Prototype/Qualification Test Program were not reviewed at this time.

B. Method of Data Analysis

The principle method of analysis of the raw data is categorization into factors of interest, showing for each classification the absolute numbers of occurrences. The general classifications are by:

1. Importance of the failure to the successful operation of the mission or of the subsystem.
2. Attributed cause of failure.
3. Environment and test activity existing at the time of failure.
4. Level of testing, other than system level, at which the failure could have been detected.
5. Subsystem.
6. Type and complexity of subsystem.
7. Source of hardware.

C. Significant Failures Encountered

The most significant failures encountered during the Nimbus I Prototype/Qualification, Nimbus I Flight and Nimbus II Flight Systems Acceptance Test Programs are shown in Tables 1, 2, and 3.

VII. Lessons Learned and Applied

The experiences encountered during the development of the Nimbus I and II spacecraft may have application to other space programs.

A. Design Practices

Provide extensive alternative modes of functional redundancy as a means of failure protection, thus enhancing long life potential.

Provide an extensive command system with ground command override for programmed functions to effectively use alternative modes of operation.

Fabricate all cables and wire groupings on a full-scale, exact replica three dimensional mock-up model spacecraft. This minimizes stresses and strains in wiring and connectors.

Give most attention in design and test to non-electronic and complex equipments, since most failures and anomalies occur here.

Be wary of all specifications for components and subsystems which contain idealized, "text book" conditions for design, test and performance; e.g., a transmitter designed for a 50 ohm resistive load which actually is to be connected to a transmission line, impedance matcher and antenna.

- Evaluate all equipment under conditions of the total expected environment.

Design a thermally benign environment for all equipment, to the greatest extent possible.

- Provide a structure and heat controlling system having high thermal inertia.

- Provide a thermally conservative design whereby the heat dissipating capability is much greater than the heat producing sources.

- Provide for thermal load sharing in the event of failure or removal of planned equipment.

Long life in orbit may be greatly enhanced by:

- Condition/power-age piece parts before installation into components.

- Specify conservative stress conditions and environments for systems level tests.

- Apply experienced engineers to design, test and evaluate subsystems and the spacecraft.

- Incorporate functional redundancy and an appropriate command system to allow ground control.

- Provide a benign thermal environment to minimize in-orbit thermal stresses.

B. Test Operations

Qualification tests were not made to destruction levels, hence no real measure exists of the degree of conservative design in the spacecraft. There is no way to evaluate the applicability of all tests to which the spacecraft and/or subsystems were exposed.

Operate each subsystem under normal conditions (life-test) after passing its flight acceptance test to discover latent failures. This would reduce failures and anomalies encountered during the more expensive integrated systems test program.

Expose the spacecraft to an orderly planned series of tests, each successively encompassing a larger number of subsystems which require integrated performance.

Plan the test and evaluation activities early in the program, preferably concurrently with engineering design. Potential problems in the conduct of system tests and simulated orbital operations will be exposed early.

The best efforts expended in: conservative design, engineering, management and test practices, selection and training of personnel are still not sufficient to absolutely screen and eliminate all latent failures from individual subsystems or from the complete spacecraft. A strong test and evaluation program helps to isolate these types of failures prior to launch; e.g.,

- The control system on Nimbus I after more than 750 hours of operation, including two weeks of vacuum/thermal testing.

- The (2N768) transistor in the command clock failed after more than 1000 hours of operation, in spite of conservative circuit design and power conditioning of piece parts.

C. Failure Records and Analyses

Report and record all failures and anomalous, out-of-specification performance of components, subsystems and the spacecraft system as soon as observed.

- Provide expeditious diagnosis and determination of the specific reason for the failure.

- Provide closed-loop record of the action taken.

- Analyze and record failures and final actions taken on a near real time basis. Failure records are intended to be used for management control, not for purposes of historical record.

D. Documentation

Write all plans, specifications, requirements and procedures necessary for a test and evaluation program in detail, step by step, before the start of the functional activity.

Focus attention on specific problems as they arise through rigorous use of the detailed test requirements and plans documents.

- Confidence is provided to the Test Conductor and to the Program Manager by isolating activities and problems.

E. Personnel

Define fully all responsibilities and authorities vested in personnel directly handling, working on or operating the spacecraft.

- Do not permit random assumptions to replace such assignment.

- Avoid misunderstandings which can lead to strained inter-personal relations and consequent loss of operating efficiency.

Certify spacecraft Test Conductors as to their ability to operate the spacecraft, to supervise the test program, and to take effective measures should an emergency arise.

- Provide a unique certificate.

Encourage and train all personnel, through direct, conscious management effort, to be performance oriented, technically honest, and to demonstrate integrity.

- Personnel should feel free to expose errors and faux pas without fear of management discipline either to themselves or to others.

Establish a highly disciplined environment for the test and evaluation program wherein each participant knows his job and the personal impact he has on the total task.

Provide long term personnel assignments consistent with separable phases/elements of the engineering, test and evaluation program and the professional interests of the personnel.

- Better use is made of accumulated experience than if frequent training and retraining is required.

- Methods are developed for the expeditious conduct of routine tasks.

- Develops healthy inter-personal relations among members of the project team.

Rehearse all new test activities and phases of the test program using the previously published detailed test plan containing step-by-step instructions.

F. Technical Reviews

Prepare information flow schematics early in the program.

- Show individual schematics for: signal, grounding, power, command, telemetry.

- Very useful in system trouble shooting and planning operational activities.

Require design reviews for all hardware developed.

- The periodic reviews cover activities from the initial concept through qualification testing.

- Personnel responsible for hardware must be made to understand the review is an essential part of the design cycle, intended to help them strengthen the design, and is not a "police" action.

- Technically strong, competent, perceptive personnel should lead design review activities and recommend action.

- All action items resulting from a review are accountable to be accomplished as part of the design effort.

Permanently staff the program with Senior Consulting Engineers. Their need and contributing value were well recognized by the Program Management.

- The Nimbus program had two, one in the area of mechanical engineering, another in the area of electrical/electronic engineering and systems.

- Each had full responsibility and authority for overview of the overall technical performance of the electrical and mechanical systems and to enter into any technical area for analysis/review and to recommend changes to all levels of participating personnel and management.

The GSFC Nimbus Environmental Test Committee provided independent guidance directly to the NASA/GSFC Project Manager regarding: Test Program; Test Levels; Acceptance of Test Results; Re-Test Requirements.

- GE had two members on this committee, the two Consulting Engineers, responsible for the areas of "Electronic Systems" and "Design and Reliability".

A Launch Readiness Review preceded certification of flight readiness of the spacecraft.

TABLE 1
MAJOR FAILURES DISCOVERED DURING
INTEGRATED SYSTEMS TEST PROGRAM -
NIMBUS I PROTOTYPE SPACECRAFT

Subject	Potential Effect on Mission	Action Taken	Attributed Cause of Failure	System Test Related?	Remarks
HRIR Loss of synchronizing signal	Catastrophic to the HRIR subsystem	Mechanical redesign of the mount for the magnetic pulse pickup which moved when vibrated	Functional design	No	
AVCS TAPE RECORDER Shaft of recorder broke in vibration test	Catastrophic to stored AVCS data	Component redesigned	Functional design	No	Failed as a result of extreme tests; failure occurred during a second vibration test at the prototype/qualification test levels.
COMMAND CLOCK One transistor (2N768) exhibited excessive leakage current after more than 1000 hours operation	Catastrophic to total mission	Bought-off. Replaced the piece part with another of the same type.	Parts/material	No	Circuit was very conservatively designed with respect to expected variations in the transistor's parameters. This explains the long time period of operating without failure.
ATTITUDE CONTROL Solenoid valves overheated	Potentially catastrophic to total mission	Replaced overheated solenoids with others of the same type	Test procedure	No	Solenoids had not failed in performance; insulation appeared damaged; replaced to enhance confidence.

TABLE 2

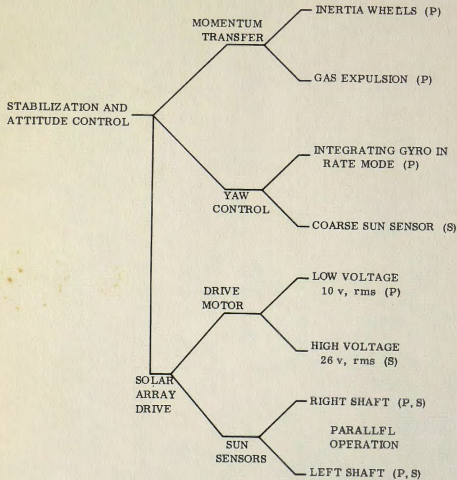
MAJOR FAILURES DISCOVERED DURING
INTEGRATED SYSTEMS TEST PROGRAM
NIMBUS I FLIGHT SPACECRAFT

Subject	Potential Effect on Mission	Action Taken	Attributed Cause of Failure	System Test Related ?	Remarks
CORONA	Catastrophic to the television camera systems. Degraded and reduced performance of the telemetry system	Redesigned television cameras and electric power distribution systems to remove the sources of corona	Functional design	Yes	The redesign of cameras was not to the degree which would allow them to operate in a corona-inducing environment.
ATTITUDE CONTROL AUXILIARY The potentiometer signal to the automatic day/night switch in the television cameras was noisy	The camera systems could be made inoperative by improperly turning on and off their power supplies. Mission operations would have been hampered.	Bought-off, Over-ride command capability controls power to the cameras	Functional design	Yes	
AVCS AND HRIR TAPE RECORDERS Leaks in the pressurized containers	Long term degradation of performance	Leaks repaired but containers were not redesigned	Functional and other design	No	
AVCS S-BAND TRANSMITTER Marginal automatic turn-off signal	Catastrophic to the total mission through consumption of available power.	Redesigned the switching system. Added an alternate command to insure turn-off	Functional design	Yes	
ELECTROMAGNETIC COMPATIBILITY CONTROL Conducted interference through transient pulses on power system caused by switching some equipment	Degraded performance of sensors/payload and telemetry; orbital operations and data interpretation made difficult	Redesign of subsystems; installation of filters in subsystems; redesign and shielding of electric power and signal distribution system	Functional design	Yes	
Radiated interference from sub-system to subsystem	Degraded performance of sensors/payload	Minimized by shielding cables	Functional design	Yes	
APT Microphonics on camera tube	Degraded performance	Redesign; mounting washers (Vion) installed to isolate camera tube component	Other design	Yes	
TELEMETRY TAPE RECORDER HRIR TAPE RECORDER Lubrication failures following vacuum thermal tests.	Degraded performance leading to catastrophic failure of stored telemetry and HRIR data	Recorders were replaced with identical units having fresher lubricant	Parts/material	No	Time/environment-induced lubrication failure
ATTITUDE CONTROL Short circuit of regulated bus power because of failure in insulation	Catastrophic to total mission	Replaced wiring	Other design and fabrication	No	Thermal stress and cold flow of insulation
TELEMETRY Distortion of PCM signal at output of the transmitter	Degraded performance of the telemetry system	Redesign of transmitter to allow wide variation of load impedance at the transmitter output. Redesign of the phasing transmission line to provide more uniform parameters.	Functional design	Yes	

TABLE 3

MAJOR FAILURES DISCOVERED DURING
INTEGRATED SYSTEMS TEST PROGRAM -
NIMBUS II FLIGHT SPACECRAFT

Subject	Potential Effect on Mission	Action Taken	Attributed Cause of Failure	System Test Related?	Remarks
ELECTROMAGNETIC COMPATIBILITY CONTROL Conducted interference from sub-system to sub-system; HRIR/APT/MRIR Conducted interference affecting command clock	Degraded performance of sensors/payload Degraded performance of clock	Redesign of HRIR (internal shielding) and improved shielding of electrical power and signal distribution system Redesigned circuits in clock	Functional design Functional design	Yes Yes	
HRIR TAPE RECORDER Leaks in the pressurized container Failure of relay	Long term degradation of performance Degraded performance	Leaks repaired but container was not redesigned Replaced relay with no other change	Functional and other design Parts/material	No No	
COMMAND RECEIVER Reduced audio output signal level	Lessened margin of safety for receiving commands	Bought Off. Problem disappeared after exposure to vacuum; presumably component dried.	Parts/material	No	
AVCS Halo in pictures generated by Camera No. 2	Degraded performance of Camera No. 2	Replaced the vidicon camera tube	Parts/material	No	
TELEMETRY/BEACON Intermittent operation of the PCM telemetry at +35°C	None since telemetry system does not operate at +35°C; degraded performance would result if the spacecraft would operate at this elevated temperature	Bought-off.	Parts/materials	No.	
ATTITUDE CONTROL Loss of the "A" scanner video signal	Catastrophic to the total mission	Replaced Infrared Scanner Amplifier (IRSA) and Amplifier. The specific cause of failure was not found; the problem was not duplicated	Other design, Fabrication Parts/Material	No	
MRIR Radiometer motor stopout	Catastrophic to the performance of the MRIR sub-system	Motor was re-lubricated No design change although it is known motor is of marginal design for its application	Functional design	No	



P - PRIMARY
S - SECONDARY

Figure 1. Functional and Block Redundancy-Spacecraft Subsystems

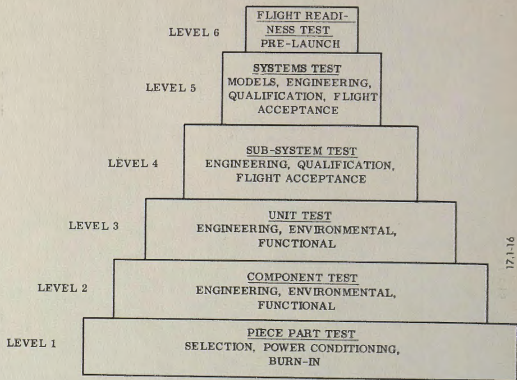


Figure 2. The Test and Evaluation Pyramid