A METHOD OF HARDWARE
QUALIFICATION FOR FLIGHT
BY ANALYSES, SIMILARITY
AND INTEGRATED TESTING

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ABSTRACT

This report describes the results of a study on four pieces of flight hardware from the Saturn IU and S-IVB stages to determine whether the objectives of the formal qualification tests on that hardware could have been obtained within that program by methods other than performing the qualification tests. These methods include qualification by analyses, similarity and integrated testing, i.e., distribution of the objectives among the other tests in the program. The intent of the study was to define a method to obtain hardware qualification for flight without utilizing the usual qualification tests. In addition to determining whether an actual program could support this general thesis, it was desired to develop a method for maintaining visibility of the qualification status (referred to as scorekeeping) during a complete program time period and to establish the requirements for implementing this concept on a space vehicle program.

It was found that it is feasible to delete the requirements for formal qualification testing provided that it is accomplished early in the program to allow adequate planning for accomplishing the qualification objectives by other means. Additionally, a scorekeeping system was defined that is simple, straightforward, easy to implement. This scorekeeping system provides complete visibility of equivalent qualification status at any point during the program. A set of groundrules for implementing this study was established as a result of findings on the specific items of hardware studied.

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I. INTRODUCTION

1. PURPOSE

The purpose of this study was to investigate the following:

a. Methods of accomplishing qualification test objectives on selected flight hardware without conducting a formal qualification test program.

b. A scorekeeping system that provides quick visibility of the equivalent qualification status of the piece of hardware at any time if a suitable method is determined in a.

c. Requirements for implementing a. and b. above into the overall program plan.

2. BACKGROUND

On previous programs, the qualification test requirements for flight hardware have resulted in extensive and expensive testing on costly flight identical test units. As a result of these tests, extensive data have been accumulated on testing of parts, materials, subassemblies, and assemblies. Investigations are currently underway within NASA toward accomplishing the intent of qualification testing with a "certification" program that utilizes the results of previous tests, flight demonstrations, qualification by similarity and qualification by analyses. The following definitions are presented.

a. Hardware Qualification

Hardware qualification is a "guarantee" that flight hardware has been examined in a technically thorough manner such that it can be expected to survive the stresses it will encounter and to properly perform its assigned mission.

b. Qualification Tests

Qualification tests are performed on not-for-flight flight-identical hardware to expose it to mission stresses and demonstrate that it is capable of performing its intended function in the appropriate (before-during-after) time relationship to both the stresses and the mission sequence of events.

c. Qualification by Comparative Analysis
The comparative analysis, or "similarities" concept, utilizes data from previous programs to prove that the new design is capable of performing its intended functions. In this case, it is necessary to show the physical and functional similarity to other hardware that has been tested to the required environments and stresses.

d. Qualification by Analysis
This approach represents an additional step in the analysis performed during the design phase of a piece of hardware. Qualification by analysis is a technical in-depth examination and justification to satisfy the same ends as flight qualification testing without actually performing an actual test. When this method is used to satisfy qualification test objectives, the results of the analytical tasks must be documented and presented for approval at Preliminary and Critical Design Reviews in lieu of qualification tests results

This study was conducted to determine whether the intent of qualification testing could be accomplished in a systematic manner without conducting formal qualification tests.

3. STUDY APPROACH

The first task of this study was to determine the various methods and techniques that could be used to delete or reduce the requirements for formal qualification testing. The approaches considered are summarized in Exhibit I-1 along with the advantages and disadvantages of each. These advantages and disadvantages are subjective considerations compared to the usual method of hardware qualification, i.e., by formal qualification testing. Based on these results, the combination of analyses and integrated testing (Approach No. 4 of Exhibit I-1) was selected as being the most promising to study in more detail.

APPROACH	ADVANTAGES	DISADVANTAGES
1. Use pure analytical and similarity techniques to demonstrate hardware qualification.	a. Deletes the requirements for formal qual test procedures, reports, etc. b. Insures complete analysis of design prior to release to manufacturing c. Does not require a flight identical qualification test unit d. Does not increase the cost of other test phases by adding tests	a. Does not allow use of actual testing to resolve uncertainties b. Requires formal documentation of design analyses c. Can be applied only to hardware that can be quantitatively analyzed d. Increases program risk e. Requires a new method of tracking equivalent qualification status f. Increases program risk in that objectives are not demonstrated by tests
2. Integrate all qualification test objectives into other test phases.	a. Deletes the requirements for qualification test procedures, reports, etc. b. Makes maximum use of test equipment, facilities, etc. c. Could delete the requirement for a qualification test unit d. Assures all objectives are demonstrated by tests e. Minimizes program risk	a. Requires more formal reporting of development tests phases b. In some cases development testing may nearly equal qual tests c. No overall reduction in test time, equipment, etc. since all objectives must be demonstrated d. Requires a new method of tracking equivalent qualification status
3. Continue qualification testing but allow deletion of non-critical objectives.	a. Requires minimum change to existing program requirements, tracking systems, etc. b. Assures that all critical objectives are demonstrated by tests c. Minimizes program risk by demonstration of all critical objectives	a. Requires formal qualification test procedures, reports, etc. b. Requires formal documentation of analytical results proving compliance to non-critical objectives c. Requires flight identical test articles d. Will not significantly reduce cost of qualification tests
4. Use a combination of analytical, comparison and integrated testing techniques to demonstrate qualification. (Combine items 1 and 2 above)	a. Deletes requirements for formal qualification test procedures, reports, etc. b. Insures complete analysis of design prior to release to manufacturing c. Does not require a flight identical qualification test unit d. Makes maximum use of test equipment, facilities unit e. Assures all objectives are met by best method, i.e. test, comparison, or analysis	a. Requires more formal documentation of design analyses and development test b. Requires a new method for tracking equivalent qualification status c. Increases program risk in that objectives met by analysis are not actually demonstrated

Exhibit I-1. SUMMARY OF APPROACHES CONSIDERED TO DELETE FORMAL QUALIFICATION TESTS

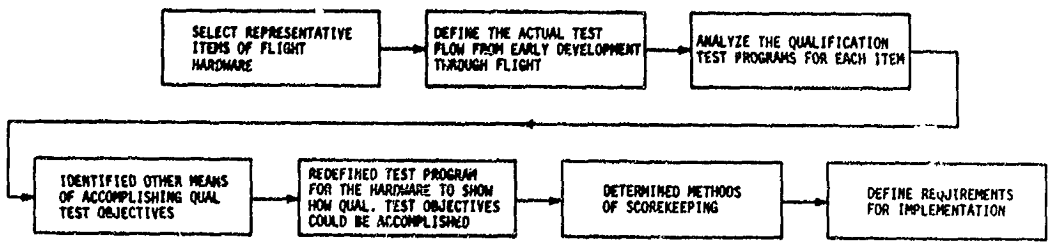

Exhibit I-2. STUDY FLOW

Exhibit I-2 shows the general approach followed during this study. Four representative pieces of flight hardware were selected and analyses of the test histories were performed. The hardware selected from the Saturn V Instrument Unit were the 56-Volt Power Supply, the C-Band Transponder, and the Environmental Control System Primary Coolant Pump, and from the S-IVB Stage, the J-2 Engine Hydraulic Actuator. Each qualification objective, for each item of hardware, was studied to determine if compliance with the requirements could be demonstrated by means other than formal qualification testing. The first approach applied was that of qualifying by similarity according to current rules. This technique was applied at the assembly and subassembly level. In many cases, it was found that the assembly could not be qualified by similarity, although subassemblies were similar to previously used, qualified hardware. For these cases, it was found that certain qualification objectives could be partially achieved by similarity. When similarity could not be used to demonstrate the objective, analytical techniques were investigated. This investigation included identifying analytical techniques and in some cases performing example and sample analyses.

For cases where similarity and analytical techniques could not be applied, other test phases were investigated to determine if the qualification test objective could be fulfilled by integrated testing. It was found that most objectives requiring actual test could be demonstrated by expanding the development testing phase. In some cases this would require the use of flight identical assemblies or subassemblies. It was also found that other tests, particularly RFI and functional capability could be accomplished as part of the test program on higher assemblies. For each item of hardware studied, a re-defined test program was established allocating each qualification test objective to either analytical/ similarity techniques or to some other specific test phase.

Several methods of tracking techniques were investigated to provide visibility of qualification status during the "re-defined" test program for each item of hardware. Of the several techniques conceived and studied only one was found that clearly provided this status while not imposing unacceptable reporting requirements on the contractors and design organizations. This approach is described in subsequent sections of this document.

This study revealed several limitations on the application of qualifying hardware without formal qualification test. These limitations are stated as "ground rules" for implementations and are stated at the conclusion of this section.

During this study, it was assumed that all piece parts were either purchased from a qualified parts list or had been previously qualified for the environment specified. Therefore, no effort was expended on proving the qualification of piece parts. This study addressed the qualification of assembly level hardware only.

4. STUDY SUMMARY

This study determined that the intent of qualification testing can be fulfilled without conducting formal tests. This is accomplished by utilizing an integrated test approach throughout the hardware development cycle and analytical comparison techniques for specific portions of the qualification objectives.

For each of the hardware items studied, the actual test flow during the Saturn program was determined. A typical example of these is shown in Exhibit 1-3.

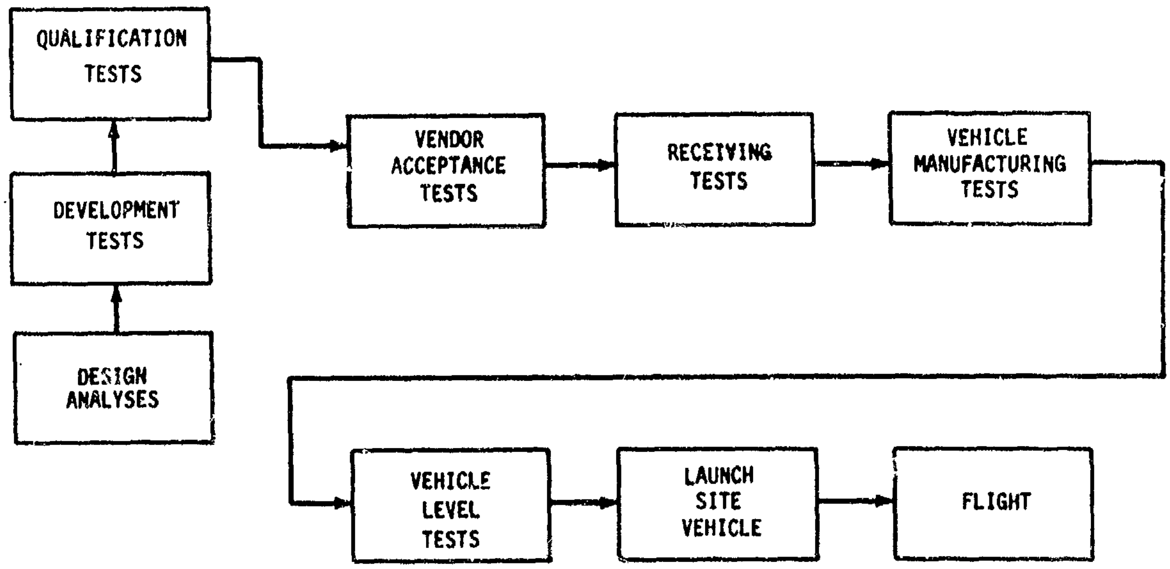

Exhibit I-3. GENERAL TEST FLOW

The test documentation on the hardware was researched and the specific test objectives, requirements, and results were determined for each phase of test. Based on this information, an overall view of the actual test program was obtained and areas of significant repetition were identified.

The qualification test program for each item of hardware was studied in detail to determine the specific objectives. Each objective was analyzed to determine if it could be accomplished without formal testing by analytical demonstration or by integrating the qualification test objective with other phases of tests during the complete development cycle. The resulting test flow for each item of hardware was established deleting formal qualification tests. A typical test flow of this type is shown in Exhibit I-4.

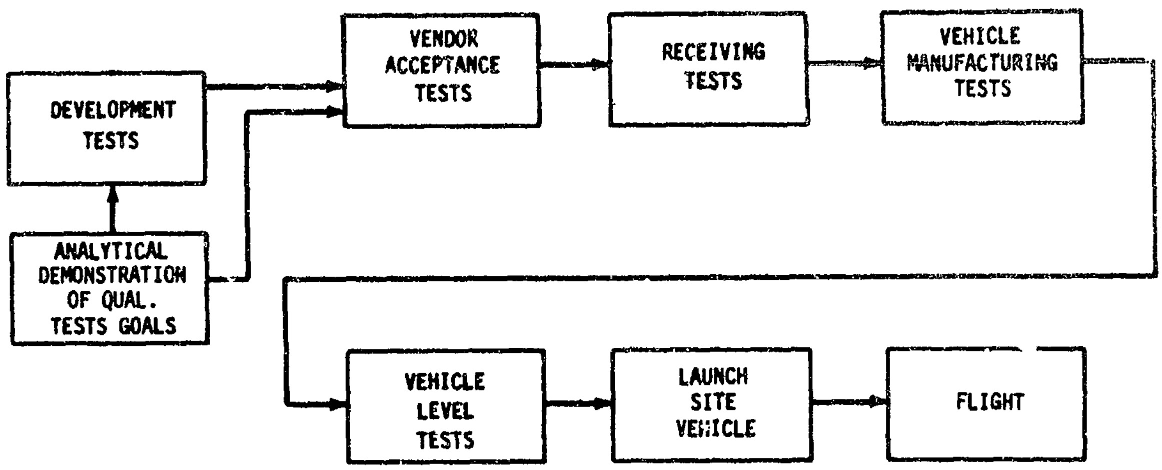

Exhibit I-4. GENERAL TEST FLOW WITHOUT QUALIFICATION TESTS

An overall summary of the findings, listed by typical qualification test objectives, is given in Exhibit I-5. This exhibit depicts the general objective for each type of qualification tests and summarizes the best methods for achieving these objectives without conducting formal qualification tests, based upon the findings of this study.

Of the four items of hardware studied, it was found that three, namely the 56-Volt Power Supply, Coolant Pump, and the C-Band Transponder, could be qualified without formal qualification tests with a reasonable extension of development tests and analytical techniques. If this were implemented in an actual program, it would require more vigorous configuration control during the development test phase to assure the test configuration was identical to the resulting flight hardware. For the S-IVB Hydraulic Actuator, feasibility of achieving the qualification

TYPE OF TEST	OBJECTIVE	FINDINGS
VIBRATION	TO DETERMINE THE HARDWARE IS CONSTRUCTED TO WITHSTAND EXPECTED DYNAMIC VIBRATIONAL STRESSES WITHOUT MALFUNCTION OR DEGRADATION IN THE INTENDED ENVIRONMENT.	VIBRATION WILL YIELD TO A TECHNICAL ANALYSIS, AIDED BY SIMILARITY WHERE APPLICABLE, AND SUPPLEMENTED BY DEVELOPMENT TESTING ON ENGINEERING MODELS. QUALIFIED PIECE-PARTS ARE REQUIRED.
ACCELERATION	TO DETERMINE THE EFFECTS OF ACCELERATION STRESSES ON COMPONENT PARTS AND TO VERIFY THE ABILITY OF THE PARTS TO OPERATE IN THE ACCELERATION ENVIRONMENT.	THE ACCELERATION OBJECTIVE YIELDS READILY TO ANALYSIS AND SIMILARITY. IT INCLUDES: ● SHEAR ANALYSIS ● ELONGATION AND YIELD ANALYSIS ● COMPRESSION ANALYSIS ● CREEP (I.E., TEFLON, ETC.) ● FLUID FLOW ANALYSIS ● SEALS ANALYSIS
THERMAL SHOCK	TO DEMONSTRATE THE RESISTANCE OF HARDWARE TO EXPOSURES OF EXTREMES OF HIGH AND LOW TEMPERATURES AND TO THE SHOCK OF ALTERNATE EXPOSURES.	THERMAL SHOCK CAN BE PREDICTED AT THE COMPONENT LEVEL IF QUALIFIED PIECE PARTS ARE PURCHASED FOR THE ASSEMBLY. TECHNIQUES USED ARE SHOCK ANALYSIS OF MATERIALS, HEAT TRANSFER, EXPANSION AND CONTRACTION OF MATERIALS, AND STRESS ANALYSIS OF RESTRAINED PARTS.
PRESSURE	TO DETERMINE THE HARDWARE IS STRUCTURALLY SAFE TO WITHSTAND THE RANGES OF PRESSURE TO WHICH IT WILL BE SUBJECTED WITHOUT FAILURE OR DEGRADATION.	PRESSURE ANALYSIS MAY BE ACCOMPLISHED ANALYTICALLY THROUGH STRESS ANALYSIS AND SEALS ANALYSIS. THE MATERIALS PARAMETERS MUST BE KNOWN AND PURCHASED TO A COMPREHENSIVE SPEC. DEFORMATION, YIELD, AND RUPTURE MAY BE DETERMINED FROM THE STRENGTH OF MATERIALS CALCULATIONS. THE SEALS MAY BE CALCULATED FOR COMPRESSION, SHEAR, RUPTURE, AND BLOW OUT.
THERMAL VACUUM	TO DEMONSTRATE THE HARDWARE WILL NOT UNDERGO: ● DIMENSIONAL CHANGES ● COMPROMISE OF SEALS ● DETERIORATION OF POTTING ● OUTGASSING ● MATERIALS DEGRADATION ● DIELECTRIC BREAKDOWN ● ARCING ● HEAT TRANSFER PROBLEMS	THERMAL VACUUM MAY BE DEMONSTRATED BY TECHNICAL ANALYSIS AND SIMILARITY WITH PERHAPS SOME SUPPLEMENTARY DEVELOPMENT TESTING AT THE SUB-ASSEMBLY LEVEL. TECHNIQUES ARE: ● MATERIALS ANALYSIS ● HEAT TRANSFER ● THERMAL DEFORMATION ANALYSIS ● STRESS ANALYSIS ● ELECTRICAL ANALYSIS

Exhibit I-5. SUMMARY OF STUDY FINDINGS

TYPE OF TEST	OBJECTIVE	FINDINGS
RFI	THE OBJECTIVE OF RFI TESTING IS TO DETERMINE THE HARDWARE DOES NOT INTERFERE ELECTRICALLY WITH OTHER EQUIPMENT AND IS NOT INTERFERRED WITH ELECTRICALLY TO THE POINT OF PERFORMANCE DEGRADATION.	RFI MAY BE PREDICTED REASONABLY WELL ANALYTICALLY. (IT REQUIRES A DESIGNER-ORIENTED AWARENESS AND TREATMENT FROM THE INCEPTION UNTIL COMPLETION OF SYSTEM LEVEL TESTS.) IT WILL REQUIRE DEVELOPMENT TEST, SUB-SYSTEM AND SYSTEM LEVEL TEST TO ASSURE THE ANALYTICS ARE CORRECT.
SALT FOG	TO DETERMINE THE RESISTANCE OF MATERIALS AND FINISH TO SALT CORROSION.	SALT FOG MAY BE DONE BY ANALYSIS AND/OR SIMILARITY. IT REQUIRES: • MATERIALS ANALYSIS • FINISHES ANALYSIS • COATINGS ANALYSIS • PIECE-PARTS AND MATERIALS (I.E., METALS, COATINGS & FINISHES) FROM A QPL.
FUNGUS	TO DETERMINE (A) THE RESISTANCE OF MATERIALS, FINISHES, AND PIECE-PARTS TO FUNGI, (B) TO DETERMINE THE EFFECTS ON MATERIALS, FINISHES, AND PIECE-PARTS TO FUNGI UNDER CONDITIONS FAVORABLE FOR THEIR DEVELOPMENT.	THE FUNGUS DETERMINATION MAY BE MADE BY: • HANDBOOK DATA • MATERIALS ANALYSIS • DEVELOPMENT TESTING OF UNKNOWN MATERIALS CHARACTERISTICS.
SHOCK	TO DETERMINE (1) STRUCTURAL INTEGRITY OF COMPONENTS, (2) TO DETERMINE SUITABILITY OF SMALL PARTS TO MODERATELY SEVERE SHOCKS.	SHOCK MAY BE MADE TO YIELD TO: • SHOCK ANALYSIS • SIMILARITY ANALYSIS • TRANSIENT VIBRATIONAL ANALYSIS TECHNIQUES • STRESS ANALYSIS • FATIGUE
SAND AND DUST	OBJECTIVE IS TO DETERMINE THE COMPONENTS ABILITY TO RESIST PENETRATION, CONTAMINATION AND DAMAGE BY SAND AND DUST.	SAND AND DUST ARE PRIMARILY A MATERIALS, FINISH, AND SEALS PROBLEM. IT REQUIRES: • MATERIALS ANALYSIS • FINISHES ANALYSIS • SEALS ANALYSIS (1) TECHNICAL (2) SIMILARITY • MAY REQUIRE DEVELOPMENT TEST ON SEALS ONLY
HUMIDITY	TO EVALUATE THE PROPERTIES OF MATERIALS AS THEY ARE INFLUENCED BY THE ABSORPTION OF MOISTURE AND MOISTURE VAPOR AND TO DETERMINE THE DEGREE OF PROTECTION THEREFROM.	EFFECTS OF AND IMMUNITY FROM HUMIDITY MAY BE DETERMINED FROM TECHNICAL ANALYSES AND SIMILARITY. IT INCLUDES: • SEALS ANALYSIS • MATERIALS ANALYSIS • UTILIZATION OF HANDBOOK DATA

Exhibit I-5. SUMMARY OF STUDY FINDINGS (Cont.)

test objectives without formal tests was determined, but it would require an expansion of the development test phase nearly equal the qualification test phase. For items of this nature, it is neither practical nor cost effective to delete formal qualification tests. A good criteria to use when deciding which hardware can be qualified without formal testing is to assess the number and type of objectives that must be integrated with the development tests. If the development test phase must be significantly expanded to include many additional tests on flight identical hardware, it is questionable if this technique would result in any cost savings.

The implementation of this qualification method requires a technique of maintaining visibility of qualification status throughout the development program. The "scorekeeping" technique conceived during this study is based on the fact that all of the qualification test objectives will be satisfied by analysis, tests, demonstration or some combination of these methods. Each test objective can be assigned a weighting factor (expressed as a "value" percent of total qualification). This percentage number can then be further subdivided to express how much of the objective will be accomplished in each phase of the program. The results of this planning is documented in the form of a matrix (example shown in Exhibit I-6).

SCOREKEEPING MATRIX

TEST TYPE / TEST PHASE	VIBRATION	ACCELERATION	THERMAL SHOCK	PRESSURIZATION	ALTITUDE	THERMAL VACUUM	ACOUSTICAL NOISE	HUMIDITY	RFI	
% CONTRIBUTION	15	3	18	8	7	15	9	5	20	100
ANALYSIS	15	3	8	2	3	5	9	5	10	60
DEVELOPMENT TEST			10	4	4	10				28
ACCEPTANCE TESTS				2					5	7
RECEIVING TESTS										
VEHICLE TESTS									5	5

Exhibit I-6. TYPICAL SCOREKEEPING MATRIX

This matrix provides complete visibility of the equivalent qualification status at the completion of each phase of the program, i.e. analysis, development test, etc. A detail example of this scorekeeping technique is presented in Section IV.

During this study a number of potential program benefits were identified that can be achieved by application of the qualification methods presented herein. These benefits are summarized in Exhibit I-7.

- CONFIDENCE
  - NO CURTAILMENT OF NECESSARY TESTING
  - PRE-PLANNING OF ALL TESTS FOR REQD CONFIDENCE AND DATA
  - HI CONFIDENCE TESTING REQD FOR HARDWARE IMPACTING LOSS OF VEHICLE OR CREW ONLY
  - UTILIZES DATA FROM ALL TESTING
- COST REDUCED BY
  - FEWER ITEMS OF DEDICATED HARDWARE FOR QUALIFICATION TESTING
  - REDUNDANT TESTING MINIMIZED
  - STREAMLINED DOCUMENTATION AND APPROVAL CYCLES
  - ANALYSIS PERFORMED EARLY YIELDS DESIGN BENEFITS - LATE CHANGES MI[illegible]ED
- IMPLEMENTATION AND CONTROL
  - SHIFT OF TEST EMPHASIS FROM QUAL TO DEVELOPMENT (NET COST OF DEVELOPMENT TESTING WILL INCREASE WITH INCREASED TESTING AND FORMAL CONTROL AND REPORTING)
  - REDUCED PAPERWORK WITH NO LOSS OF INFORMATION, MONITORING, RIGORS, VISIBILITY, OR CONTROL (APPROVALS)

Exhibit I-7. BENEFITS OF QUALIFICATION BY ANALYSES, SIMILARITY AND INTEGRATED TESTING.

However, since this is a deviation to the usual qualification approach, it is recommended that certain ground rules be observed if this approach is implemented. They are as follows:

a. The responsibility for hardware qualification should continue to be assigned to the cognizant design organization. Specific responsibilities will be as follows:
   - o Decide which hardware is to be qualified without formal tests.
   - o Establish detailed qualification test objectives.

- o Integrate qualification objectives into test plans for those objectives to be met by test or demonstration.
- o Perform the design analyses necessary to prove the proposed design satisfies the qualification test objective to be met by analysis. Document the results of these analyses for presentation at Design Reviews.
- o Assign a percentage value of the total qualification test objective to each function.
- o Initiate the scorekeeping matrix and complete all applicable portions through the test phases for which the design organization is directly responsible.
- o Monitor the qualification status via the scorekeeping matrix until all objectives are met.

Where practical an independent assessment of the analysis should be accomplished.

b. This technique should only be applied to hardware with well defined "design-to" specifications. The following should be specifically defined:

- o Reliability Requirements
- o Environments
- o Life Cycle Requirements
- o Operational Limits and Possible Overloads
- o Maintainability and/or Replacement Requirements
- o Tolerances on All Functions

In addition, all "design-to" parameters must be quantitatively described. It is impossible to perform a meaningful analysis if the criteria are not quantitatively expressed.

c. Utilization of "qualification by comparative analysis" should be used to the maximum advantages.

d. Expansion of development testing should be utilized to reconcile any analytical uncertainties or to accomplish qualification test objectives that cannot be otherwise satisfied. Development test configurations and test reports must be maintained in a more formal manner than currently maintained.

e. Utilize only qualified piece parts in the design of hardware to be qualified in this manner. This study addresses the method of hardware qualification for assembly level hardware. One of the assumptions made during this study was that qualified parts were utilized.

5. STUDY CONCLUSIONS

The general conclusions of this study are:

- o It is feasible to delete the requirements for formal qualification testing on selected assembly level hardware provided that it is done early in the program planning phase.
- o A simple, workable scorekeeping system can be applied.
- o The developed approach can only be implemented if well defined "design-to" specifications exist.
- o An integrated or distributed testing approach can and should be utilized to accomplish those objectives that cannot be satisfied by analytical techniques.

II. HARDWARE SUMMARY

1. INTRODUCTION OF HARDWARE

The hardware selected for this study is typical flight hardware from the Saturn program that underwent a usual qualification test program. Electrical, electronic, hydraulic, and mechanical types of hardware were essential to an all-inclusive discussion covering the common types of assembly level hardware.

Specific hardware items chosen for this study include the Instrument Unit 56-Volt Power Supply, the Instrument Unit Environmental Control System Primary Coolant Pump, the Instrument Unit C-Band Transponder, and the S-IVB J-2 Engine Hydraulic Actuator.

The power supply is a power-electronic item, potted, containing parts such as a transformer and filters. The pump is an electrical, mechanical, and hydraulic unit, containing an electric motor, the mechanical driving mechanism for the impeller, and the hydraulic loading on the impeller and pump ports. The transponder is a complex piece of pure electronic hardware containing mounted printed circuit elements and other electronic hardware components. The J-2 engine hydraulic actuator is a heavy piece of hydro-mechanical hardware. It has mechanical and hydraulic stress requirements similar to other types of hardware found in a space vehicle and requires a different consideration than the other three hardware components studied. A descriptive summary of each item is given below.

2. 56-VOLT POWER SUPPLY

The 56-Volt Power Supply converts unregulated 28-volt DC battery power to regulated 56-volt DC for the ST-124M-3 Intertial Platform Subsystem located in the Saturn V Instrument Unit. It is a DC-to-DC converter utilizing a magnetic amplifier as a control unit. The specification number is 50Z60223.[1]

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[1]NASA: Astrionics System Handbook - Saturn Launch Vehicles (NASA/MSFC Astrionics Laboratory, Huntsville, Alabama, 1 Nov. 1968), No. IV-4-401, Chapter 8.

3. PRIMARY COOLANT PUMP

The Primary Coolant Pump is part of the Environmental Control System in the Saturn V Instrument Unit. The pump circulates water/methanol through the thermal conditioning system to maintain the proper operating temperatures on Instrument Unit components. The pump consists of an electric motor and centrifugal pump designed to operate for 1,000 hours. The pump specification number is 20Z42001.[2]

4. C-BAND TRANSPONDER

The C-Band Transponder, Model SST-135C, Specification Number 50M60174, extends the tracking range of the Saturn V ground tracking radar. The transponder receives a coded pulse from the ground station and responds by transmitting back a coded pulse to the radar. The coded pulse allows the ground station to determine the Saturn V range, azimuth, and elevation.[3]

5. S-IVB J-2 ENGINE ACTUATOR

The J-2 Engine actuator assembly is a linear double-acting equal-area electro-hydraulic cylinder incorporating mechanical piston position feedback with an operational pressure of 3650 psig. The actuator body, machined from a 2024-T6 aluminum-alloy forging, is approximately 6-1/2 inches in diameter, providing lightweight construction and good heat-transfer characteristics. The actuator tailstock is machined from a 6AL-4V titanium-alloy forging, and the rod end is fabricated from 6AL-4V titanium.

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[2] IBM Corporation: IU System Description and Component Data (IBM Corporation, Huntsville, Alabama 1 June 1966) No. 66-966-0006, Environmental Control System

[3] NASA: Astrionics System Handbook, Saturn Launch Vehicles (NASA/MSFC Astrionics Laboratory, Huntsville, Alabama, 1 Nov. 1968) No. IV-4-401, Chapter 7

III. HARDWARE QUALIFICATION: TRADITIONAL PROCESSING APPROACH VS. PROPOSED PROCESSING APPROACH

Each piece of hardware was examined in detail in terms of the possibilities for meeting qualification objectives that were established by the prime contractors for this hardware without performing formal qualification testing. Each hardware item test program is flow charted in two forms: (1) the tests as they were actually run and (2) the modified program as it could have been conducted had the objectives been met by analysis, similarity, or integrated testing.

1. 56-VOLT POWER SUPPLY

The normal test flow sequence for the 56-Volt Power Supply is shown in Exhibit III-1a. Tests are classified from development testing through the ultimate test: flight of the vehicle. The development testing shown in the first block is made up of tests to assure the design specification.[1] These tests include circuitry breadboarding test and evaluation to meet environmental and functional requirements. The qualification tests[2] are shown under the qualification block in the figure. There is a slight disparity between the tests actually performed and the tests reported on in the IBM Qualification Test Report and the Qualification Test Plan.[3] This difference occurs because additional tests were performed which were not required by the Qualification Test Plan.

The vendor manufacturing tests, run by the power supply manufacturer assure that each subassembly within the power supply performs properly and the power supply will perform its functions at room ambient temperature in a non-vibrational environment. The acceptance test is run after manufacturing immediately before the power supply is shipped

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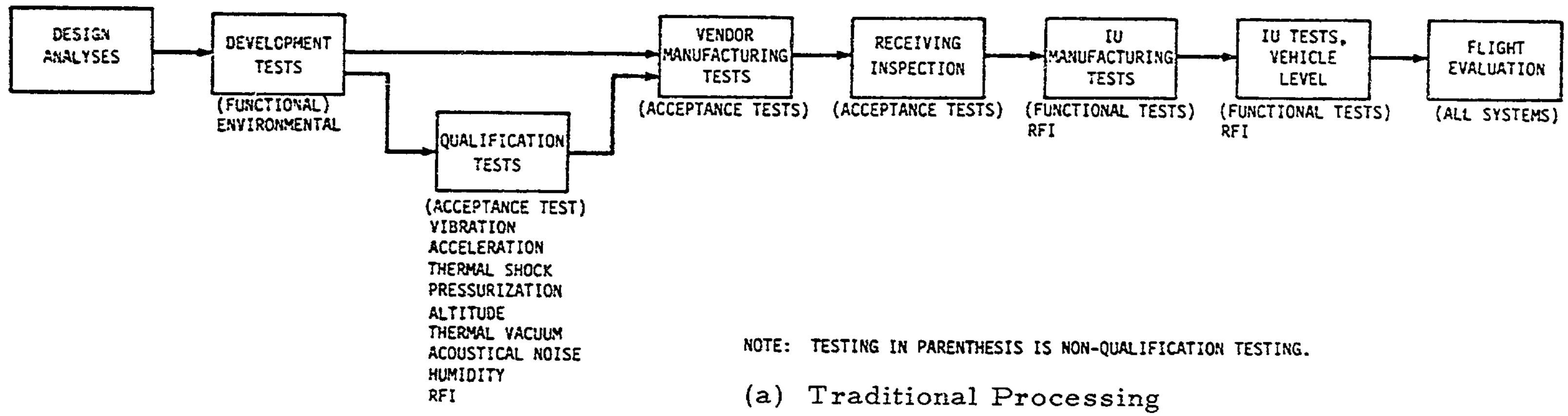
[1] IBM Corp.: Power Supply, Direct Current, 56-Volt, Specification For. (IBM Corp., Huntsville, Ala., February 16, 1971) 50Z60223, Section 3.

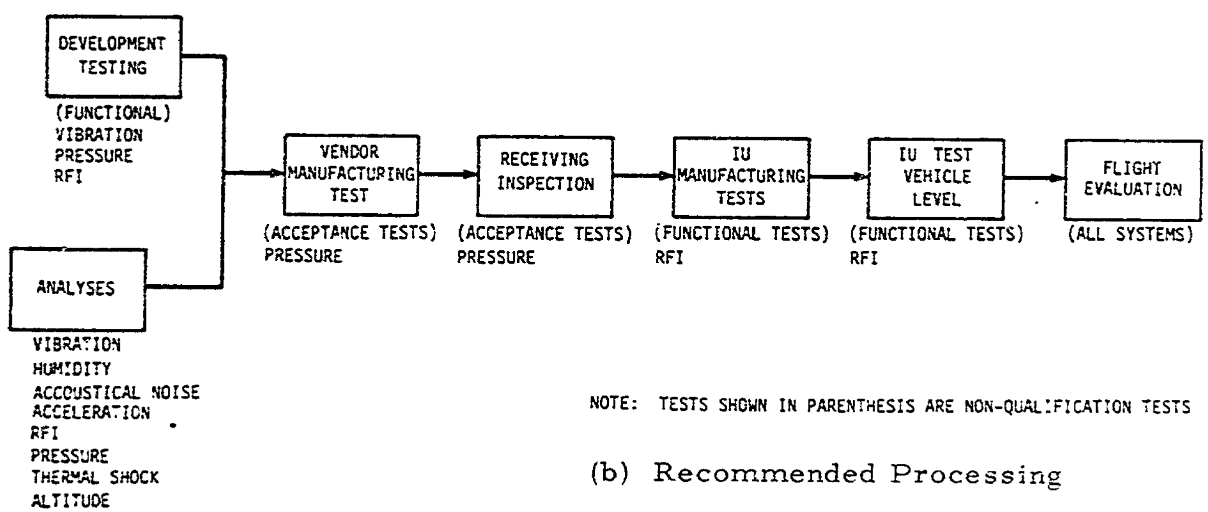
[2] IBM Corp.: 56-Volt Power Supply Qualification Test Report. (IBM Corp., Huntsville, Ala., June 30, 1966) No. 66-226-0015, Sec. 1.0.

[3] IBM Corp.: 56-Volt Power Supply Qualification Test Plan. (IBM Corp., Huntsville, Ala., May 9, 1966), 7907241, Section 4.



NOTE: TESTING IN PARENTHESIS IS NON-QUALIFICATION TESTING.

(a) Traditional Processing



NOTE: TESTS SHOWN IN PARENTHESIS ARE NON-QUALIFICATION TESTS

(b) Recommended Processing

Exhibit III-1. 56-VOLT POWER SUPPLY TEST FLOW to the prime contractor. The Systems Integration Tests - IU[4] are run during the manufacture of the IU at the contractor facility. The Systems Compatibility Tests - Vehicle[5] are run during the erection and pre-launch tests of the entire vehicle.

Exhibit III-1b shows the power supply processing sequence which eliminates the qualification test portion. This modified test flow has expanded the analyses and other test phases to include qualification test objectives.

Functional testing shown under the development testing block in Exhibit III-1b includes all the tests necessary to develop the power supply in terms of performance. Functions tested include input voltage and current, output voltage and current, response times, regulation, ripple, and noise, and other electrical characteristics. In addition, development testing is used to demonstrate the achievement of qualification test objectives not conclusively shown by analysis or similarity.

The analyses block in Exhibit III-1b which parallels the development testing function covers all phases of the analytical design and development of hardware in addition to the required technical analyses to support the demonstration of qualification test objectives.

Individual qualification objectives for the power supply were examined in detail as to how they may be integrated with the other program phases.

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[4] IBM Corp.: General Test Plan, Revision "A" (IBM Corp., Huntsville, Ala., January 23, 1967) 67-257-0001, Table 1, Figure 6-9.

[5] Op cit, Section 7.3 and 7.3.

VIBRATION

The vibration tests are conducted to determine if the equipment will withstand expected dynamic vibrational stresses and to assure performance in the simulated service vibration environment.[6] The test objective is to determine whether or not the power supply will withstand degradation within the vibration environments tabulated below in Exhibit III-2.[7]

MODE	SPECTRUM	COMMENTS
Sinusoidal	5-48 Hz at .318 CM disp. 48-165 Hz at 15 G peak 165-2000 Hz at 10 G peak Sweep Rate 5-2000 Hz 1 octave/minute	3 axis
Random	20-59 Hz at $0.04g^2$/Hz 59-126 Hz at 9.0 db/octave 126-700 Hz at $0.40g^2$/Hz 700-900 Hz at -18.0db/octave 900-2000 Hz at $0.09g^2$/Hz	3 axis

Exhibit III-2. VIBRATION TESTS PERFORMED ON 56-VOLT POWER SUPPLY TO DEMONSTRATE QUALIFICATION OBJECTIVES

Using the vibrational levels and modes from Exhibit III-2 and the analytical methods described below, the design of the power supply was studied to determine if the vibration objective could be proved by analyses.

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[6] USAF: Environmental Test Methods. (Department of Defense, USAF, Wright-Patterson AFB, Ohio, June 15, 1967), MIL-STD-810B, Method 514.

[7] IBM Corp.: 56-Volt Power Supply Qualification Test Report. (IBM Corp., Huntsville, Ala., June 30, 1966), No. 66-226-0015, Section 6.3 and Section 6.4.

In this case, all parts of the 56-Volt Power Supply were purchased from Qualified Parts Lists (QPL). For this reason, the design was studied from a total assembly viewpoint. Specifically the following design analyses were accomplished:

- o Determined amplification characteristics of the circuit board to arrive at maximum vibration levels vs. frequency. Compared this to piece parts qualification levels.
- o Determined the rigidity of the housing components and evaluated the effects of vibration on the various components.
- o Evaluated the net effects of potting material inside the power supply and determined that it dampens out any amplification at the frequencies of concern.

To accomplish these analyses basic data are required from development test on hardware which is dynamically similar to the flight hardware or from previously qualified hardware which is dynamically similar.

These analyses were cursory and incomplete from a complete design viewpoint but they did show that analysis could verify the qualification of the hardware to the specified environment.

For this reason, the vibration objective was re-allocated to the analyses block of the re-defined hardware flow chart shown in Exhibit III-1b.

The general approach used to conduct the above analyses is summarized below. The first portion of this section presents an approach demonstrating structural integrity of the assembly and the second portion addresses the problem of parts vibration qualification. The described general technical approaches were tailored for the qualification objectives of this report.

Structural Integrity

Dynamics and Loads: Visualize the power supply as the spring mass system shown in Exhibit III-3.

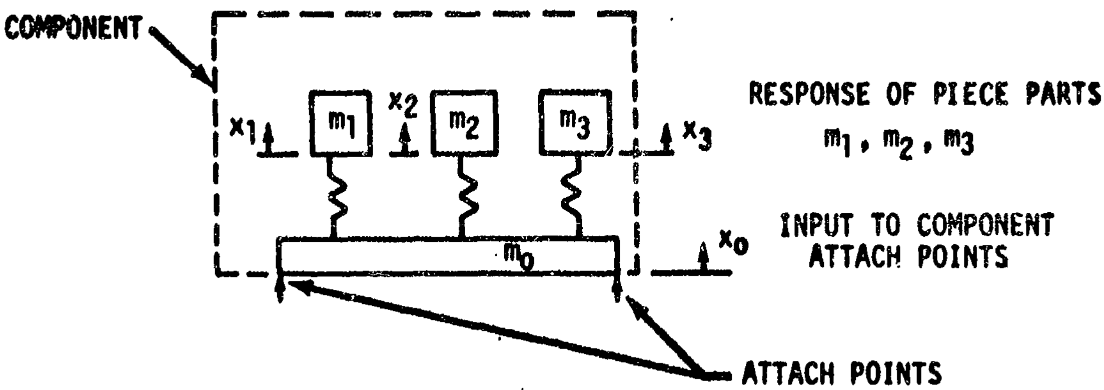

Exhibit III-3. DYNAMIC MODEL OF 56-VOLT POWER SUPPLY

The contents are considered qualified piece parts m_1, m_2, m_3 corresponding to the Choke L1, Choke L2, and transformers T_2, T_3 respectively of the 56-Volt Power Supply assembly. The input random vibration spectrum shown in Exhibit III-4 to which the assembly is to be qualified is applied to the box attach points as shown in Exhibit III-3.

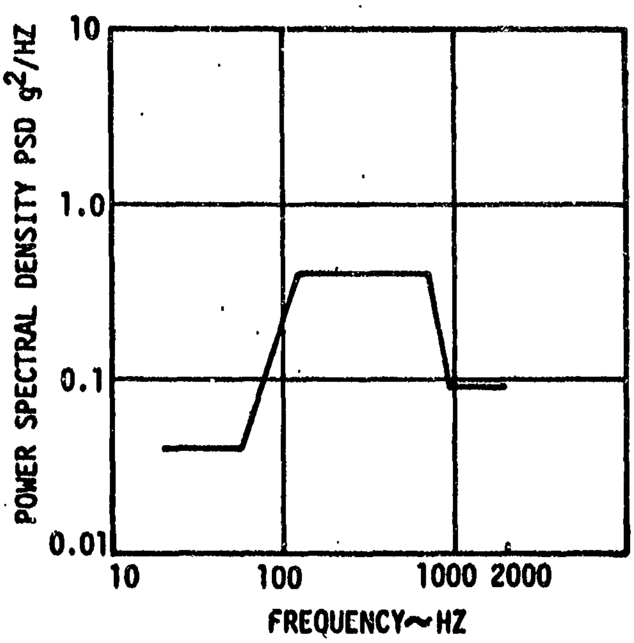

Exhibit III-4. INPUT RANDOM VIBRATION SPECTRUM TO 56-VOLT POWER SUPPLY (PLOTTED FROM EXHIBIT III-2)

The effective mass of the flexible box is designated M_o. The effective spring stiffnesses between the attach points and the piece parts m_1, m_2, and m_3 are designated k_1, k_2, and k_3 respectively.

The basic information for determining both the structural integrity and the vibration qualification level of the 56-Volt Power Supply, is obtained from development test or similarity data. The test specimen must be dynamically similar to the flight hardware and must be extensively instrumented. The objective of the test is to determine the random vibration response characteristics of the parts m_1, m_2 and m_3 due to specified vibration input to the components (M_o) attach points. The response characteristics normally determined from tests are expressed in the form of a transfer function shown in Exhibit III-5. Since actual test data were not available, Exhibit III-5 represents an assumed response used for illustration of the analytical techniques presented.

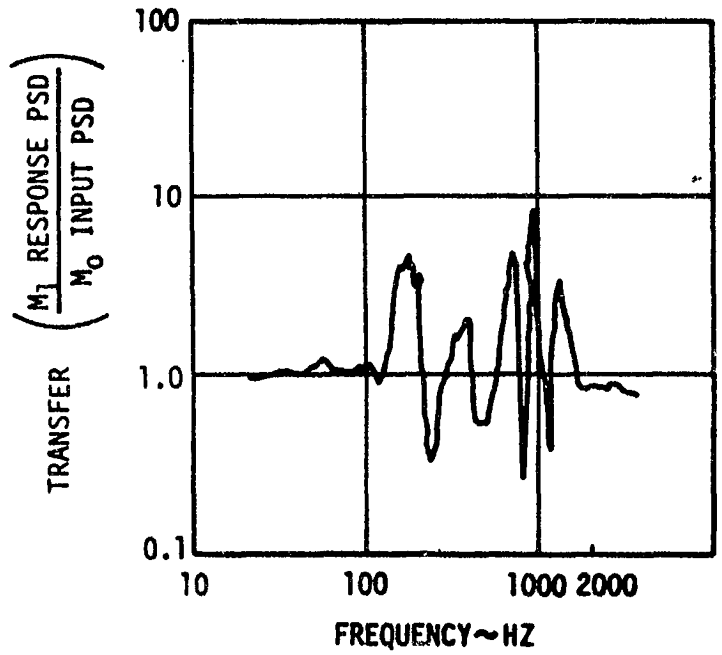

Exhibit III-5. SAMPLE TRANSFER FUNCTION FOR RANDOM VIBRATION

The transfer function is defined as the ratio between the response power spectral density (PSD) of m_1, m_2 and m_3 parts and the PSD of the random vibration qualification level input to the assembly (M_o), expressed as a function of frequency. Knowing the transfer function and the qualification environment PSD, the response PSD environment, Exhibit III-6, of the piece parts m_1, m_2, ... is estimated for the entire frequency range of interest.

$$\text{Response PSD(f)} = \underbrace{\left[\text{transfer function, (f)}\right]}_{\text{From Exhibit III-5}} \times \underbrace{\left[\text{input PSD (f)}\right]}_{\text{From Exhibit III-4}}$$

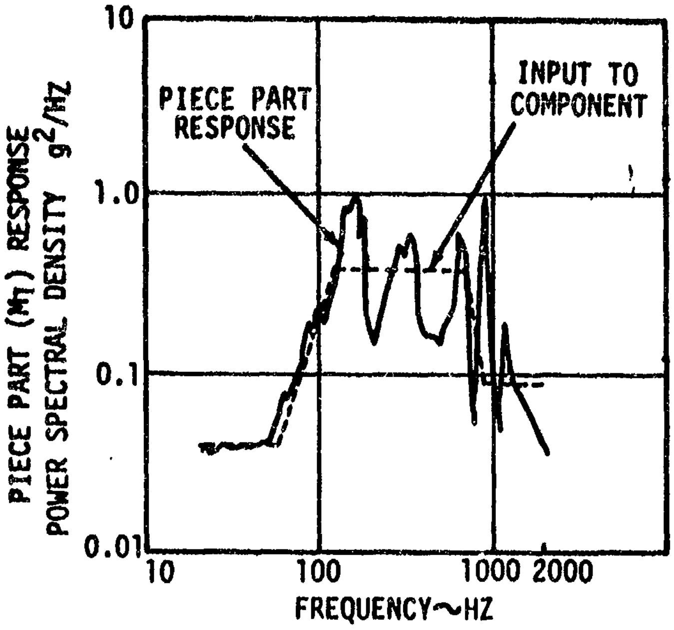

Exhibit III-6. EXAMPLE RESPONSE SPECTRUM RANDOM VIBRATION FOR 56-VOLT POWER SUPPLY

For the sinusoidal vibration qualification requirements, the measured acceleration transmissibility as a function of frequency is used instead of the random vibration transfer function. The sinusoidal data pinpoint significant resonant frequencies. The random vibration transfer function is more practical in computing structural loads due to random environment.

In those cases where development test vibration is different from the qualification environment, transfer functions are used rather than a measured part response to a test input. With the transfer function a new response level can be computed if the qualification and development spectra are different or if the qualification spectrum is updated and modified between the time the development test is conducted and the time flight hardware is to be "qualified." Thus, by using transfer functions, the tests need not be re-run even if the assembly qualification requirement should be modified.

For this example, cross axis coupling has been ignored, but must be considered when cross coupling is significant.

From the response PSD (or by direct test measurement as the case may be), the overall rms vibration level ($\ddot{x}_{1r}$, $\ddot{x}_{2r}$, $\ddot{x}_{3r}$) on each piece part mass is computed. Assuming a normally distributed random function, the maximum 3 σ peak acceleration ($\ddot{x}_{1p}$) in g's is estimated as $\ddot{x}_{1p} = 3\ddot{x}_{1r}$. The maximum load due to m_1 on m_o along the acceleration axis is estimated using the m_1 (Choke L1) mass as .0465 slug and its peak acceleration $\ddot{x}_{1p}$ is 67 g's.

$$l_1 = m_1\,(32.2)\,\ddot{x}_{1p} = .0465(32.2)(67) = 100 \text{ lbs.}$$

Likewise for the other masses, $m_2 = .093$ slugs, $m_3 = .186$ slugs, and $\ddot{x}_{2p} = 57$ g's, $\ddot{x}_{3p} = 29$ g's.

$$l_2 = m_2\,(32.2)\,\ddot{x}_{2p} = .093(32.2)(57) = 170 \text{ lbs.}$$

$$l_3 = m_3\,(32.2)\,\ddot{x}_{3p} = .186(32.2)(29) = 174 \text{ lbs.}$$

These peak loads, l_1, l_2 and l_3 must be suitably applied to the assembly (M_o) container in order to perform a stress analysis on the container. Frequency, amplitude, and phase differences between m_1 through m_3, preclude the likelihood of all three random load peaks occurring simultaneously. The following load combinations (ignoring sign) are assumed.

Case 1	Case 2	Case 3
l_1	$1/2\ l_1$	$1/2\ l_1$
$1/2\ l_2$	l_2	$1/2\ l_2$
$1/2\ l_3$	$1/2\ l_3$	l_3

The load cases are applied one at a time similar to that shown in Exhibit III-7 and stress analysis is performed on the load carrying portions of the structure in the normal manner. With these stress analyses the structural integrity of the assembly can be determined by checking whether the applied stress is less than the materials allowable stress.

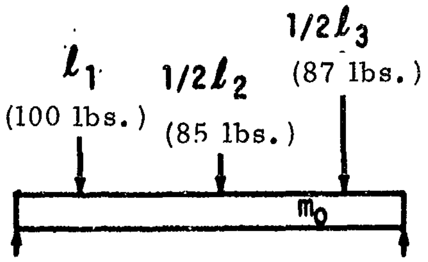

Exhibit III-7. EXAMPLE APPLIED LOAD (CASE 1) TO IDEALIZED MODEL COMPONENT BOX

There are numerous other load case combinations which might be applied. In actual practice, load case selection could be aided by examining the test data from dynamic characteristics peculiar to the hardware under consideration.

Fatigue Life

In qualification by analysis, the fatigue life of the assembly must be estimated and compared to the intended application life. Fatigue life is usually specified as the number of cycles, N, of complete stress reversal ($\pm$ s) to produce failure of a particular structure. The assembly structure is considered qualified if the estimated fatigue life, N, is greater than the required application life, N_A. Normally the classical s-N fatigue curve is based upon the complete reversal of stress of the same peak amplitude, s, being applied each cycle until failure occurs at N cycles. Many materials exhibit an endurance limit stress, s_e, below which fatigue failure never occurs, i.e., $N = \infty$. The stress environment implied by the basis of the s-N curve is more closely approximated by sinusoidal vibration at discrete frequency than by random vibration. In a sinusoidal dwell environment, both the frequency and peak amplitude are constant. Under random loading, the peak amplitude varies with each cycle according to some probability distribution.

The fatigue problem is one of estimating the required assembly application life N_A and the fatigue life N. The example problem is to compute the fatigue life of the assembly structure when exposed to the specified random vibration. The idealized model of Exhibit III-3 is used. Assuming that the piece part m_1 is the primary load contributor to the box structure, the model is treated as a single degree-of-freedom system. Loads due to the other masses are negligible. Also, it is assumed that the stress, s_1, in a critical location in the assembly structure is primarily tension and compression and can be expressed in terms of response acceleration, x_1, of mass m_1, i.e., $s_1 = f(x_1)$. Thus, there is an endurance limit response acceleration, $\ddot{x}_{1e}$ and an rms response acceleration, $\ddot{x}_{1r}$, corresponding to the endurance limit stress, s_{1e}, and rms stress level s_{1r} respectively.

Knowing the equivalent endurance limit acceleration, $\ddot{x}_{1e}$, from stress analysis and the rms response, $\ddot{x}_{1r}$, computed as previously discussed, the assembly fatigue life, N, can be estimated using

$$(1) \qquad N = \left(\frac{\ddot{x}_{1e}}{\ddot{x}_{1r}}\right)^{6.5} \times 3.33 \times 10^{4} \qquad \text{Eq. 24.38}^{8}$$

If the assembly with first resonance, f_{n1}, is to be subjected to the random environment for time, T_A, the minimum required fatigue life, N_A, is approximated by:

$$N_A = T_A f_{n1}$$

The first resonance, f_{n1}, of m_1 is that determined from development tests or similarity data. If N is greater than N_A,($N > N_A$), the assembly satisfies the fatigue life qualification requirements. If N is less than N_A N_A,($N < N_A$), the assembly fails.

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[8] Harris, C. M. and Crede, C. E.: Shock and Vibration Handbook, (McGraw-Hill, New York, N. Y., 1961) Equation 24.38

Equation (1) is the conservatively simplified result of a lengthy analytical procedure. Its use is subject to restrictions resulting from the assumptions and simplifications. Some of the restrictions include:

1) Only applies to single degree-of-freedom (DOF) linearly damped system.
2) Critical stress must be expressed as a function of response acceleration.
3) Assumes random vibration excitation results in primarily narrow band random loading of a single DOF system which can be viewed as sinusoidal loading with varying amplitude.
4) Assumes probability density of peaks in narrow band random vibration follows the Rayleigh distribution.
5) The concept of cumulative fatigue damage due to varying stress amplitude is based upon the classical Miner's rule.
6) The average fatigue property of numerous materials is included in equation (1).

In order to remove some of the conservatism, a more detailed and less restrictive analysis must be performed to determine the fatigue life of a particular assembly.

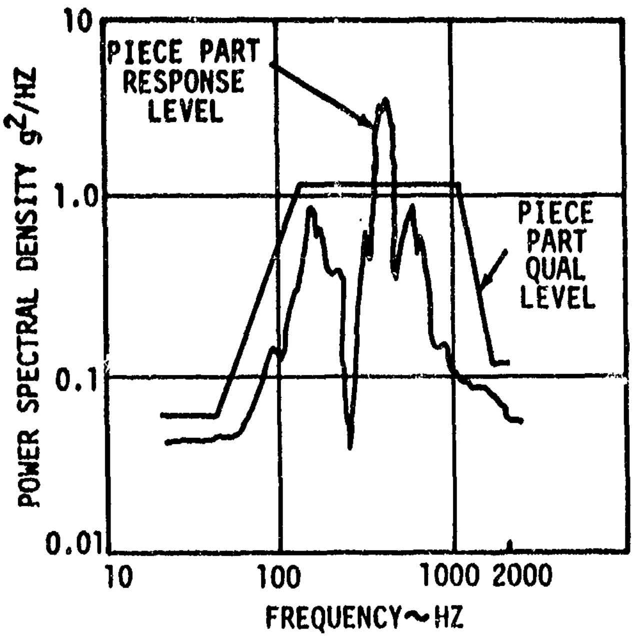
The fatigue life analytical procedure used for example deals with random vibration. A similar procedure for sinusoidal vibration environment is available. Should qualification require survival of both random and sinusoidal vibration, then procedures for determining the combined effect on fatigue life are also available.

Complex multi-degree-of-freedom structures are not often amenable to comprehensive detail fatigue analyses. Should a particular assembly fall into this category, then fatigue test requirements should be included in the development test plan.

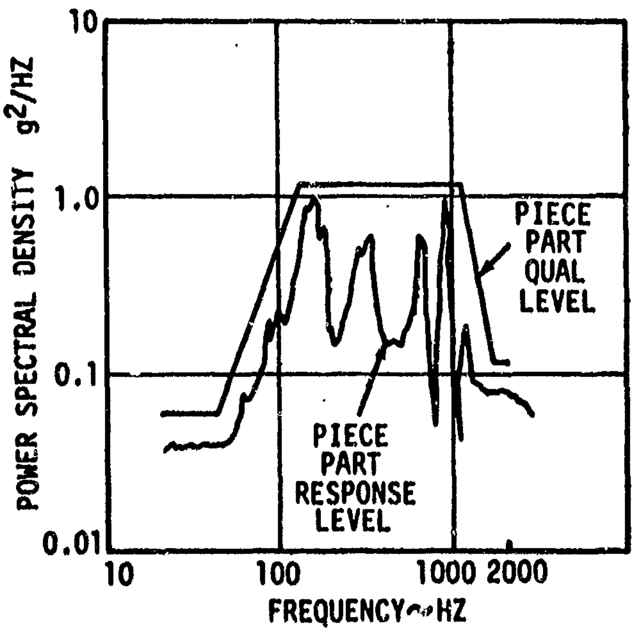
Vibration Qualification

A method is presented for determining whether the piece parts response vibration level is within the qualification vibration level of the part. The transfer functions determined from the development tests on the dynamically similar model are used to compute (if not measured) piece parts response PSD spectrum. The response PSD and the qualification

PSD spectra are compared as shown in Exhibit III-8, a and b. The piece part of Exhibit III-8a does not meet vibration qualification requirements; and that of Exhibit III-8b passes qualification requirements.



(a) Example Vibration Qualification, Failure



(b) Example Vibration Qualification, Pass

Exhibit III-8. PIECE-PART RESPONSE SPECTRUM

For purposes of this analysis and PSD comparison, the piece part (m_1 etc.) is assumed to be a small rigid body. The response measured on the part during development tests is assumed to be that of the part's C.G. and also the part's attachment (input) point. Thus, it is valid to compare the part's computed PSD response with the part's qualification PSD spectrum.

It is assumed that part vibration internal failure modes are frequency sensitive, i.e., failures are caused by certain frequency excitation. Further, it is assumed that the exact failure prone frequencies for any particular qualified piece part are unknown. Thus, in comparing PSD spectra, the response PSD value must not exceed the qualification PSD values at all corresponding frequencies. This is judged to be conservative criteria, but since the failure producing frequencies are not known, a conservative approach must be followed. Conservatism is attributed to the above criteria because in qualification testing of components, the container box may attenuate its input at the higher frequency range where piece parts may be failure prone. Thus piece parts may endure higher vibration test inputs to the assembly if attenuation takes place at failure sensitive frequencies.

A possible difficulty in comparing PSD levels is that, in actual practice, it may be found that the response PSD level may often exceed the qualification PSD level at some discrete frequencies as shown in Exhibit III-8a. The conservative criteria of the analytical qualification approach may indicate qualification rejection much more frequently than the qualification test approach would.

Threaded fasteners and connectors may loosen under vibration. Analytical evaluation of the self-locking ability of fasteners exposed to vibration has not met much success. The designer must depend upon using qualified and approved fastener parts and proper installation to protect the subassembly against loosening under vibration. The selection of the proper fastener for locking ability in vibration application can be verified in development tests.

Other small mechanical items such as switches and relays are also difficult to qualify by analysis. Those items must be selected by the designer from approved qualified parts lists or must be qualified by tests.

Vibration Summary

Methods have been presented to analytically determine the structural integrity qualification of the assembly and the vibration qualification level of the piece parts. The methods depend upon response PSD spectrum data from development tests of dynamically similar hardware in order to make the pass/fail decision for vibration qualification of the hardware.

ACCELERATION

The power supply must survive a 10-G acceleration in both directions in three mutually perpendicular axes to satisfactorily demonstrate achievement of the acceleration qualification objective.[9] Acceleration testing determines the effects of acceleration stress on component parts and verifies the ability of the component parts to operate properly during acceleration exposure.[10]

The most likely failure modes under conditions of acceleration include piece-part mountings and circuitry (short circuit or open circuit). These failures can occur through compression, tension, or shearing of wires, mounting brackets, or mounting and hold-down screws. To verify that acceleration could be demonstrated by analyses a sample calculation was performed on the mounting of capacitor P/N 7901108. This is a capacitor per MIL-C-11015C, Capacitor, Fixed, Ceramic Dielectric (General Purpose). It has a value of 0.01 fd. + 10% at 1 KHz and 2 ± 0.25 v RMS. Examination of MIL-C-11015C shows that a terminal strength pull test of 5 pounds applied for not less than 5 seconds is required. The specification places no requirements on the capacitor for mass characteristics. The lead wires are required to be 0.64 mm (0.25 in.) diameter, corresponding to AWG No. 22.

It is next determined whether or not the capacitor is capable of withstanding the 10 G acceleration environment. The capacitor weighs 0.5 ounces (.031 lbs) and is supported solely by its leads. This is slanted towards the worst case condition. Force exerted on the leads by the capacitor in a 10 G acceleration is 10(.031) = .31 lbs. in any of three axes. The capacitor leads are capable of standing 5 lbs. stress. This is about 16 times the applied load and the capacitor is expected to remain in place under 10 G acceleration. This approach may be applied to most of the supported piece parts to qualify by analyses for a particular acceleration environment. Piece parts supported or installed in a more

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[9] IBM Corp.: 56-Volt Power Supply Qualification Test Report. (IBM Corp., Huntsville, Ala., June 30, 1966) No. 66-226-015, Section 6.5

[10] DSA: Test Methods for Electronic and Electrical Component Parts. (Defense Supply Agency, Alexandria, Va., September 12, 1963) MIL-STD-202C, Method 212.

complex manner may require more detail analyses on acceleration tests as part of the development tests.

The example analysis above is a worst case condition since in the actual design, the capacitor is mounted on a printed circuit board that is conformally coated and mounted in a potted enclosure. The effects of potting and conformal coating minimize degradation due to the acceleration environment.

Based on this example analysis of the assembly design, the acceleration objective could be demonstrated by analyses. For these reasons, acceleration will be allocated to the analysis function in Exhibit III-1b.

THERMAL SHOCK

Thermal shock testing is conducted for the purpose of determining the resistance of a part, component, or subsystem to exposure at extremes of high and low temperatures, and to the shock of alternate exposures to these extremes.

Permanent changes in operating characteristics and physical damage produced during thermal shock result from variations in dimensions and in other physical properties. Effects of thermal shock include cracking and delamination of finishes, cracking and crazing of embedding and encapsulating compounds, opening of thermal seals and case seams, leakage of filling materials, and changes in electrical characteristics due to mechanical displacement of rupture of conductors or of insulating materials.[11]

Materials respond quite differently under thermal shock conditions from the response under ordinary thermal stresses at much slower application rates. The problem is to show how materials characteristics may be employed to predict how well a given piece of hardware will withstand the rigors of thermal shock.

The thermal shock requirements specified in the 56-Volt Power Supply Qualification Test Specification (No. 7907207) are three cycles of $+85^{\circ}$ C to -40°C with no more than a 5-minute delay in going from the

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[11] DSA: Test Methods for Electrical and Electronic Components, 1963, (Defense Supply Agency, Alexandria, Va., 1963) MIL-STD-202

high to the low temperature and vice versa. The tests of the performance of the power supply to these requirements are reported in IBM Document 66-226-0015, "56-Volt Power Supply Qualification Test Report."

The 56-Volt Power Supply was subjected to thermal shock as follows:[12] The test unit was heat soaked at 85° C for four hours, removed from the heat and within 5 minutes transferred to a chamber of -40° C for four hours. This procedure was repeated three times. After completion of the temperature cycling, the unit was allowed to stabilize for 2 hours at room ambient temperature and a voltage ripple and regulation test were run. (As required in MIL-STD-220, Method 107B, an inspection was made for physical and electrical damage and none was reported in the data sheets from the IBM test reports.) In using an analytical approach to this same qualification problem, two areas must be considered: The electrical/electronic characteristics and the physical characteristics.

First, consider stresses in a mechanical assembly such as a housing found in the 56-Volt Power Supply. Under thermal shock conditions the housing will be subject to deformation or to actual failure of the metal. Utilizing the analytical techniques described by Manson,[13] it is possible to determine the relative thermal shock resistance of the housing assembly.

The next category of problems to be considered is the elongation or shrinkage or materials under the stresses of rapidly applied temperature extremes. For a restrained plate such as the cover plate on the 56-Volt Power Supply or a restrained bar such as may be found in other types of structural members for hardware items, thermal stresses occur, and serious problems can result.

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[12] 56-Volt Qualification Test Report, IBM No. 66-226-0015, June 30, 1966, Huntsville, Ala.

[13] Manson, S.S.: "Behavior of Materials under Thermal Stress," (NASA-MSFC, Huntsville, Ala., July, 1963) Tech Note TN2933

The inelastic thermal stress for the restrained plate (after it is bolted down to the case with cap screws) is shown in Exhibit III-9. The ordinate, x/L refers to the ratio of distance into the plate to the total thickness of the plate. For instance, on the top surface of the cover plate x/L = 1, at the center x/L = 0.5 and through the plate on the bottom x/L = 0. Curves are presented for the elastic and inelastic cases and for creep after 100 hours temperature exposure. The term W is defined as:

$$W = \frac{k}{\rho C_p} \qquad \text{where}$$

k	=	Thermal conductivity, BTU/(hr)(ft)(^{o}F)
ρ	=	Density, lb/in^3
C_p	=	Specific heat, BTU/(lb)(^{o}F)

Temperatures shown are in Fahrenheit and extend to 600^{o} F.

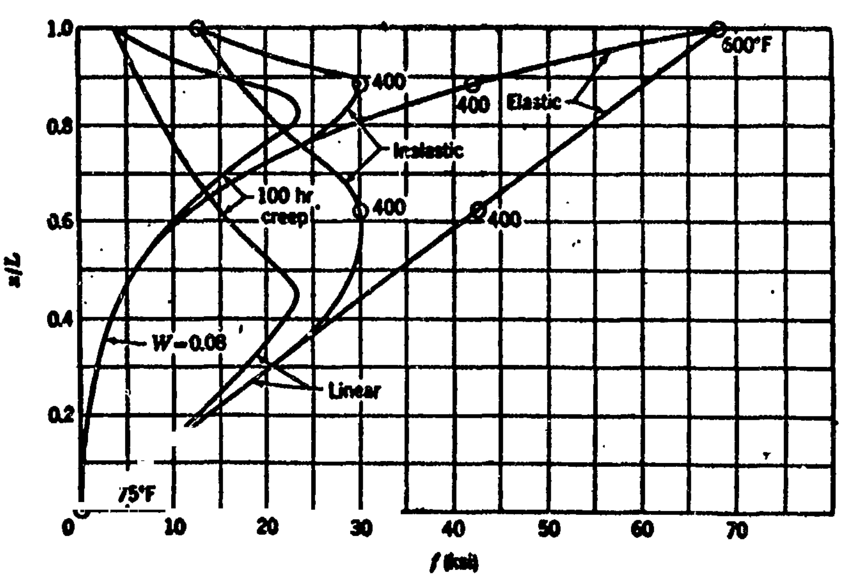

Exhibit III-9. INELASTIC THERMAL STRESSES IN RESTRAINED PLATES

Lateral motion between the container and cover plate due to thermal expansion or contraction is considered unrestrained when mating surface friction is small and screw hole clearance has not been exceeded. When the plate expands or contracts to the point that the screw holes are moved against the hold-down screws, it then becomes a restrained plate. Further expansion or contraction will either deform (elongate) the holes or shear the hold-down screws. Utilizing handbook data this problem can be analyzed to determine if this will occur during operation.

For example, the cover plate, which is 6.0 inches long and 6.0 inches wide, the elongation may be computed for the temperature extremes which the power supply is required to meet as stipulated by the shock testing requirements. These calculations show that the final length of the plate under expanded conditions is 6.0043 inches. From this data it was determined that the hole clearance is sufficient.

Another area to be considered for the power supply is the potting compound inside the unit. The potting compound ideally will have the same coefficient of expansion, A' or A''' (coefficient of volumetric expansion), as does the case metal itself, so that under transient conditions the compound will not create any undue stresses. Knowing the time duration of the thermal shock test and working a heat transfer problem as a function of time, it may readily be determined the degree of thermal shock which the inside of the unit must undergo to exhibit a given shock externally. Then, using the linear and volumetric expansion equations and the stress equations, the movement of "holes" in the potting compound around wires (and other piece parts) may be determined; then the amount of stress which the compound can apply may be determined.

All areas requiring thermal analysis are not covered, but it has been demonstrated that analyses can be done and some approaches to performing such an analysis have been presented.

Because of the above considerations thermal shock is allocated to the analysis function as shown in Exhibit III-1b.

PRESSURIZATION

Pressure testing is one of the simpler tests which must be performed on the 56-Volt Power Supply. The objective is to assure that the power supply will maintain an internal pressurization with dry nitrogen at 25 psig and will leak no more than 0.5 psig in a 24-hour period.[14] This test is a seal test which demonstrates the material properties for the seal.

Conditions which must be met by the materials include temperature, pressure, vibration, moisture, foreign particles, and possibly RFI. It must be shown analytically or by similarity that the materials selected will function properly in these environments without deterioration due to the environments or to the age of the materials. It must be shown that the seal gland design and applied torques to the hold-down areas, in the case of the power supply are not excessive and will not deform the seal material.

The development testing phase can be used to demonstrate adequacy of the seals. These tests must verify the analyses, gland design, and closure techniques from a functional point of view. These tests must be performed in hardware that is physically similar to flight hardware but does not need to include the electronics.

The vendor manufacturing and acceptance testing phases of the program can include a simple pressure test along with the normal acceptance testing activities to verify workmanship and quality control inspection in the application of the seals.

The combination of analyses, development testing and integrating a pressure test into other test phases can conclusively show achievement of the pressurization qualification test objective.

The pressurization qualification objective will be re-allocated to four blocks in the "new" hardware flow chart shown in Exhibit III-1b. These are (1) Analysis, (2) Development Testing, (3) Manufacturing Testing, and (4) Acceptance Testing.

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[14] IBM Corp.: 56-Volt Power Supply Qualification Test Report, (IBM Corp., Huntsville, Ala., June 30, 1966) No. 66-266-0015, Appendix G.

ALTITUDE

The test is required by the "Qualification Test Specification, 56-Volt Power Supply," specification No. 7907207, and may be performed as reported in the 56-Volt Power Supply Qualification Test Report, IBM No. 66-226-0015. Testing conditions require mounting the power supply on a thermal conditioning plate maintained at a constant 69.8° F temperature and evacuating the test chamber to 300,000 feet.

The purpose of this qualification objective is to demonstrate that there is no flashover or arcing between circuit components, no dielectric breakdown,[15] no heat transfer problems, no sealing problems, no materials degradation, and no short circuit problems.[16]

Since the power supply is a sealed unit and will maintain an internal pressure of approximately 10 psia, the only problems associated with this test are the sealing and heat transfer characteristics. The packaging design of the 56-Volt Power Supply is similar to power supplies used on previous space programs. For this reason, the altitude objective can be demonstrated by similarity.

In addition, during pressure tests conducted during vendor manufacturing tests and receiving tests, the delta pressure can be increased to sufficiently prove the ability of the seals to maintain positive pressure in a vacuum environment. The altitude objective is re-allocated to the analyses function of Exhibit III-1b.

THERMAL VACUUM

The objective of thermal vacuum qualification is to identify dimensional changes and resultant damage, opening of seals, deterioration of potting compounds, outgassing and material degradation, dielectric breakdown, arcing, short circuits, heat transfer problems, and overall effects on the electrical functioning of the power supply.

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[15] DSA: Test Methods for Electronic and Electrical Component Parts. (Defense Supply Agency, Alexandria, Va., September 1963) MIL-STD-202C, Method 105C.

[16] USAF: Environmental Test Methods. (Department of Defense, USAF, Wright-Patterson AFB, Ohio, June 15, 1967), MIL-STD-810B, Method 514.

The design of the power supply was analyzed to determine if any of the above areas were likely to cause problems. The results were:

a. Dimensional changes - This was discussed under thermal shock and it was determined that a combined thermal-vacuum environment would have no detrimental effects.

b. Deterioration of potting compounds - As long as the seal remains intact, the potting compound will not be subjected to a vacuum environment. However, as an added measure of assurance, the potting compound could be tested in a thermal vacuum environment.

c. Outgassing and material degradation - The external materials used in the power supply were previously qualified for a thermal vacuum environment.

d. Dielectric Breakdown, arcing, short circuits - The design of the power supply is a sealed, potted and pressurized unit. This assures that the internal electrical circuits are not subjected to a thermal vacuum environment. The pressure tests conducted during development testing proves the integrity of the seals to withstand the pressure differential anticipated when subjected to the operational environment.

e. Heat Transfer - The combination of the thermal and altitude analyses, coupled with similarity data from previously qualified hardware indicates that this will not be a problem.

For these reasons, thermal vacuum qualification is delegated to the analyses function of Exhibit III-1b.

ACOUSTICAL NOISE

Because of the destructive nature of high intensity noise, the power supply must demonstrate its immunity to high intensity noise as a qualification objective. The power supply as discussed here is required to withstand noise up to 148 db and up to 8000 Hz.[17] The noise effects are manifested as mechanical vibrations. The 56-Volt Power Supply is a high density component with small surface area and is not expected to respond significantly when directly exposed to acoustic excitation. The power supply is mounted on a structure which responds to acoustic environment and the environment is transmitted to the power supply as mechanical vibration. Thus, for this particular application, the 56-Volt Power Supply is assumed qualified for acoustic environment if it is qualified for the corresponding predicted mechanical vibration environment of Exhibit III-2.

HUMIDITY

The 56-Volt Power Supply must demonstrate an immunity to humidity as one of the qualification objectives. Humidity testing is an accelerated environmental test, accomplished by the continuous exposure of the power supply to high relative humidity at an elevated temperature. Hygroscopic materials are sensitive to moisture and deteriorate rapidly under humid conditions. Absorption of moisture can result in swelling and cracking with the further result of materials failure.

Humidity applied to the 56-Volt Power Supply will not penetrate beyond the case seals around the cover and connectors. The humidity problem for the power supply must be examined in terms of the seals around external openings.

Demonstration of the humidity qualification objective can be accomplished by analysis of the seal. Since the seal used is qualified for this environment, this objective is allocated to the analyses function of Exhibit III-1b.

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[17] IBM Corp.: 56-Volt Power Supply Qualification Test Report. (IBM Corp., Huntsville, Ala., June 30, 1966) No. 66-266-0015, Appendix J. Figure 1.

RFI

The 56-Volt Power Supply must meet MIL-I-618D for both conducted and radiated interference. Failure to meet these requirements could result in failure of the power supply. During exposure to the RFI environment, the power supply must meet all the requirements of IBM-SPEC-7907207, Qualification Test Specification.

The design of the power supply was studied to determine the best approach to demonstrate compliance with the RFI objective. It was determined that similarity data could not be used except for filter characteristics and shielding and bonding techniques. Based on previous experience, it is believed that some uncertainties concerning RFI characteristics could be resolved by a limited amount of development testing of circuitry and subassemblies. These could verify degree of susceptibility to transits and verify that superfluous noise was not being generated. Based on other tests planned in subsequent test phases, RFI characteristics could be further demonstrated during the IU integration tests conducted at IBM. These activities were actually conducted on the IU[18] and resulted in no significant increase in the amount of testing required.

Considering the above discussion, the RFI objective is allocated to the analyses, development test, and vehicle level test phases of Exhibit III-1b.

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18 IBM Corp.: Summary, IU General Test Plan. (IBM Corp., Huntsville, Ala., 1964) No. 64-208-0007H, Section 4.3

SUMMARY OF 56-VOLT POWER SUPPLY

As a result of this study this item of hardware could be qualified without formal qualification tests. Based on the analyses and assessments of the design that were conducted during this study, each qualification test objective could be met by some means other than by formal tests. To validate these findings, the actual qualification tests results[19] on the power supply were reviewed to determine if any failures or problems were encountered that would not have been detected if the power supply was qualified in the manner described herein. Exhibit III-10 delineates the actual "requirements" and "description of deviations" presented in the test reports in addition to the author's comments.

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[19] 56-Volt Power Supply Qualification Test Report. IBM No. 66-226-0015, dated June 30, 1966.

SUMMARY OF 56-VOLT POWER SUPPLY QUALIFICATION TEST DEVIATIONS

Specification Requirements	Description of Deviation	Author's Comments
1. "The thermal vacuum cold cycle shall be performed before the thermal vacuum hot cycle."	"The thermal vacuum hot cycle was performed before the thermal vacuum cold cycle. It was determined that this reversal in the order of performance was necessitated by time considerations. Unless a period of approximately twelve hours were allowed for restabilization at ambient temperature, water vapor in the steam lines to the thermal shroud would immediately condense and freeze when the steam was introduced following the cold cycle."	This problem was a test procedure problem rather than a hardware problem.
2. "After pressurization to 273 $\pm$ 7 KN/m^2A (25.0 $\pm$ 1.0 psig) with dry nitrogen and maintained for a 12-hour period at 25 $\pm$ 2C(77 $\pm$ 3.6F), the pressure shall not decrease more than 3.45 KN/m^2 (0.500 psi)."	"Following removal for the thermal vacuum test, the pressure relief valves on both specimens were replaced hand tight, according to IBM instructions. The specimens were pressurized to 51.00 in. Hg gage (25.0 psig) at 76°F, 29.55 in. Hg barometric pressure. After 12 hours, the pressure in S/N 00011 read 48.55 in. and that in S/N 00013 read 49.45 in. Hg gage, at 76° F and .69 in. Hg bar. press. This indicated the following losses in pressure: S/N — In. Hg — psig — KN/m^2 — KN/m^2-hr 00011 — 2.31 — 1.135 — 7.84 — 0.653 00013 — 1.41 — 0.693 — 4.79 — 0.399"	This problem would have been detected during the pressure tests conducted during vendor acceptance tests and IBM receiving inspections.
3. "There shall be no mechanical or electrical deviation as a result of thermal vacuum tests of 6.0 $\pm$ 0.1 hours duration, vacuum of 1 x 10^{-4} $\pm$ 10 percent mm Hg, thermal conditioning panel temperatures 80.6 $\pm$ 3.6F (hot cond.) or 59 $\pm$ 3.6F (cold cond.), and thermal shroud temperature of 171 $^{+0}_{-5.4}$F (hot cond.) or -320 $\pm$ 9F (cold cond.). During the final hour of each six-hour period, the output voltage ripple shall not exceed 0.25 VPP with 28 $\pm$ 4 vdc input voltage and load current of 3.0 $\pm$ 0.5 adc and the output voltage shall measure 56.0 $\pm$ 3.5 vdc with a load current of 10.0 $\pm$ 0.5 adc."	"In cold condition, output voltage was 51.0 vdc with 24.0 vdc input voltage. In hot condition output voltage was 47.5 vdc with 28.0 vdc input voltage and 44.0 vdc with 24.0 vdc input voltage. In addition, during the hot condition run, the specimen case temperatures measured unusually high (see data sheets). It was suspected that input voltage was low due to voltage drop in long lines from high currents."	This problem proved to be the result of the test setup, not hardware failure.

Exhibit III-10.

SUMMARY OF 56-VOLT POWER SUPPLY QUALIFICATION TEST DEVIA ONS (Cont.)

Specification Requirements	Description of Deviatio	Author's Comments
4. "NASA 50M71810 Procedure II (for simulated I. U. thermal conditioning panels) requires panel surface temperatures of 59 ± 3.6° F (cold condition) and 80.6 ± 3.6°F (hot condition). IBM Specification Number 7907207 requires thermal panel coolant outlet temperatures of 55 ± 2°F (cold condition) and 75 ± 2°F (hot condition) for a flight-type thermal panel."	"The test was performed using a simu ed I. U. thermal conditioning panel with surface temperatures of 55 ± 2°F (cold condition) and 75 ± 2°F (hot condition). It should have been performed with thermal panel temperatures of 59 ± 3.6F (cold condition) and 80.6 ± 3.6F (hot condition)."	This problem resulted from improper test setup - not a power supply failure.
5. The thermal conditioning panel coolant inlet temperature in 'Preliminary Astrionic IU Environmental Qualification Test Criteria' and Procedure I of NASA 50M71810 (for flight-type thermal panels) as well as the above referenced specification is required to be 59 ± 2° F. However, Procedure II of NASA 50M71810 (for simulated thermal panels) specifies a panel surface temperature of 69.8 ± 3.6° F.	The st was performed with a thermal panel surface temperature of 59 ± 2°F rather than 69.8 ± 3.6°F.	This deviation resulted from conflicting requirements. There was no failure in the Power Supply.
6. "After pressurization to 273 ± 7 KN/m²A (25.0 ± 1.0 psig) with dry nitrogen, the pressure shall not drop more than 3.45 KN/m² (0.500 psi) during a 12-hour period."	'Specimen No. 00011 decreased in pressure by 3.90 KN/m² (0.56 psi) and Specimen No. 00013 decreased in pressure by 4.24 KN/m² (0.614 psi) during the 12-hour period.	This problem would have been detected during the pressure test integrated with other test phases. (Refer to Deviation 2 above.)

Exhibit III-10 (Cont.)

2. PRIMARY COOLANT PUMP

Exhibit III-11a presents the test flow sequence for the Instrument Unit Primary Coolant Pump, Part No. 20Z42001. The development testing phase of the pump encompasses testing assuring the pump will perform to requirements specified in the specification, 20Z42001, which defines qualification objectives. The requirements are tailored to the requirements of 20Z42212, "Requirements, IU Environmental Control System, Specification For."

The qualification tests are specified in the test plan.[20] The vendors' post-manufacturing tests are specified in the Hydro-Aire test procedure TP 60-657B.[21] Upon demonstrating satisfactory performance in the tests shown in the flow chart, Exhibit III-11a, the pump is cleaned and installed in the Instrument Unit Environmental Cooling System. During the IU manufacturing process, the ECS is subjected to subsystem checkout to verify hardware compatibility and operability.[22] During this phase of subsystem testing, the pump is leak checked, functionally operated, and monitored for RFI.

Following the IU manufacturing tests the vehicle level tests are conducted to mate the IU to the rest of the vehicle. These tests are similar to the IU manufacturing tests in that they leak check, functionally check, and monitor for RFI on the total systems level. These tests are required by the IU test plan, Section 7, referenced below. A survey of the Flight Data Review reports for the past 14 Apollo missions reveals no malfunctioning of the Primary Coolant Pump in the IU on any flight.[23]

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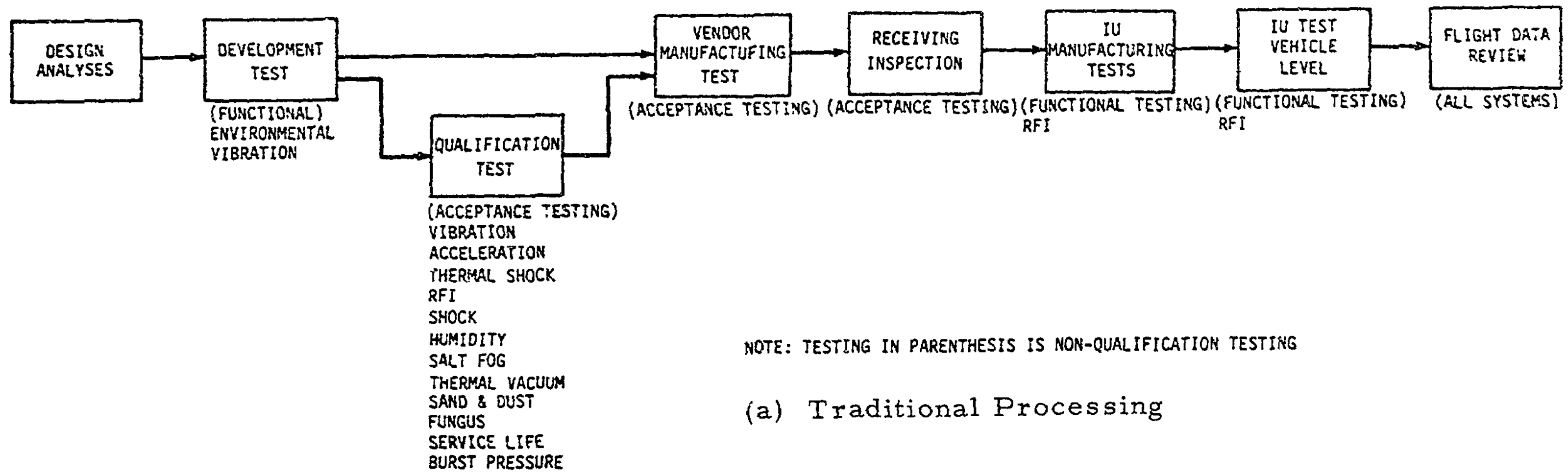
[20] IBM Corp.: Coolant Pump Assembly, Instrument Unit, Qualification Test Specification, (IBM Corp., Huntsville, Ala., Oct. 14, 1966) 7907994, Sec. 3.8.

[21] Clark, R.: Test Procedure TP 60-657B (Hydro-Aire Dev. of Crane, Co., Burbank, Calif., July 12, 1967)

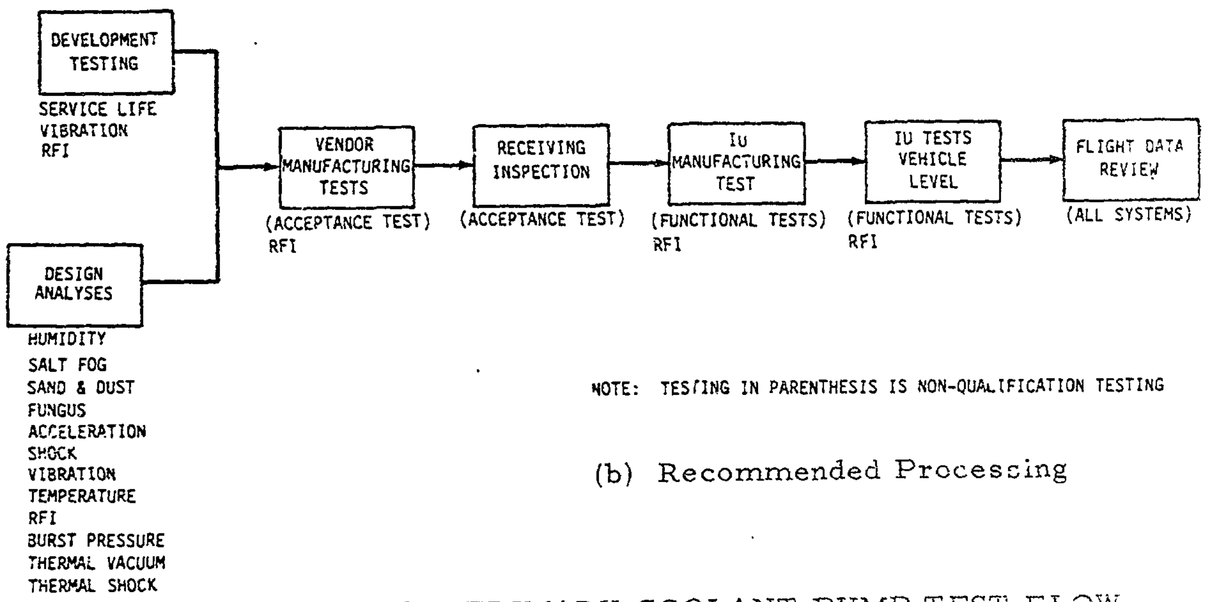
[22] IBM Corp.: General Test Plan, Rev. A, (IBM Corp., Huntsville, Ala., Jan. 1967) 67-2 57-0001, Sec. 6 and Fig. 6-9.

[23] Teasley, R. B., Personal Interview and Flight Data Reports Survey, Apollo 1 thru Apollo 15, NASA-MSFC, S&E-CSE-L, Jan. 14, 1972 (1.5 Hrs.)



NOTE: TESTING IN PARENTHESIS IS NON-QUALIFICATION TESTING

(a) Traditional Processing



NOTE: TESTING IN PARENTHESIS IS NON-QUALIFICATION TESTING

(b) Recommended Processing

Exhibit III-11. PRIMARY COOLANT PUMP TEST FLOW

Exhibit III-11b shows the hardware processing defined in this study.

Accomplishment of the qualification test objective for the primary coolant pump by means other than formal qualification tests are discussed below.

SHOCK

The objective of shock is to demonstrate structural integrity and satisfactory performance in the service use, transportation and handling environment.[24] The shock requirement is for the pump to successfully survive three 20-G peak shocks for 10 milliseconds in each of three mutually perpendicular axes in each direction. This demonstrates seal and seal gland integrity through non-deformation of the materials in the housing; the resistance of the motor shaft to bending which could cause misalignment of the impeller; the ability of the impeller itself to withstand the shock stress without fracture or deformation; and the integrity of the electrical portions of the pump. The primary qualifications that must be met in the motor are positive brush contact, non-deformation of the windings, and no damage to the insulation.

Shock is related to the transient motion caused by suddenly-applied forces or by abrupt changes of direction. It is possible to identify the natural periods of the piece parts by analysis, then to apply the 20-G forces for the 10 millisecond period, and estimate the acceleration responses, loads, deformation, and stresses that may result.

The design of the coolant pump was studied to determine if analytical techniques could demonstrate the qualification test objective. To demonstrate this objective analytically the following must be considered.

- o Seal and seal gland integrity through non-deformation of the materials in the housing.
- o Resistance of the motor shaft to bending which could cause misalignment of the impeller.

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[24] USAF: Environmental Test Methods (Department of Defense, USAF, Wright-Patterson AFB, Ohio, June 15, 1967), MIL-STD-810B, Method 516.

- o Ability of the impeller to withstand the shock stresses without fracture or deformation.
- o Integrity electrical portions of the pump such as positive brush contact, non-deformation of the windings, and no insulation damage.

Analytical techniques are available to adequately demonstrate these requirements. In accordance with these considerations, the shock qualification test objective is allocated to the analysis function of Exhibit III-11b.

VIBRATION

The objective of vibration analysis is to determine whether the pump is constructed to withstand expected dynamic vibration stresses and that performance degradations or malfunctions will not be produced by the vibration environment.[25] Effects of vibration include loosening or relative motion of parts, wear, physical distortion, fatigue and failure.[26] The vibrational objectives for qualification of the pump are specified in the qualification test specification.[27] These objectives are shown in Exhibit III-12.

Mode	Spectrum	Comment
Sinusoidal	5-20 Hz @0.10 D.A. disp. 20-50 Hz @ 2-g peak 50-85 Hz @0.016 in D. A. disp. 85-2000 Hz @6.0-g peak	3-axis
Random	20-120 Hz @ 3db/octave 120-500 Hz @ 0.03 g^2/Hz 500-600 Hz @ -12 db/octave 600-2000 Hz @ 0.01 g2/Hz	3-axis

Exhibit III-12. VIBRATION TEST OBJECTIVES FOR PRIMARY COOLANT PUMP

[25] USAF: Environmental Test Methods, (Department of Defense, USAF, Wright-Patterson AFB, Ohio, June 15, 1967), MIL-STD-810B, Method 514.

[26] DSA: Test Methods for Electronic and Electrical Component Parts, (Defense Supply Agency, Alexandria, Va., Sept. 12, 1963) MIL-STD-202C, Method 201A.

[27] IBM Corp.: Coolant Pump Assembly, Instrument Unit Qualification Test Specification, (IBM Corp., Huntsville, Ala., Oct. 14, 1966) 7907994, Section 3.8

The design of the pump was assessed to determine the best way to prove that each of the detrimental effects will not occur. The results of these assessments are:

a. Loosening or Relative Motion of Parts

The only positive manner to verify that this will not occur is to perform vibration testing on a dynamically identical model. These tests could be conducted during development testing without the use of a flight-identical test unit.

b. Physical Distortion

Since this is a characteristic of the material used and assembly techniques it was determined that this could be resolved by use of qualified materials and comparison to previously qualified hardware.

c. Fatigue and Failure

The analysis technique described in Section III-2 could be used on this item in conjunction with data acquired during development testing. In addition, comparison to previously qualified hardware could be used.

For these reasons, the vibration qualification objective is allocated to the analysis and development test functions of Exhibit III-11b.

ACCELERATION

The acceleration requirement for the Coolant Pump specifies that the pump demonstrate only in the -Z direction a capability to survive a linear 10-G acceleration.

The objective of the acceleration qualification requirement for the pump [28] is to demonstrate structural soundness and satisfactory performance in an environment of steady state acceleration other than gravity. [29]

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[28] USAF: Environmental Test Methods (Department of Defense, USAF, Wright-Patterson AFB, Ohio, June 15, 1967), MIL-STD-810B, Method 513-II.

[29] IBM Corp.: Coolant Pump Assembly, Instrument Unit Qualification Test Specification. (IBM Corp., Huntsville, Ala., Oct. 4, 1966) 7907994, Section 3.8.8.

The pump must not undergo any deformations in the materials or piece-parts that could affect its normal operation. The primary factor that the qualification objective determines by requiring acceleration in the -Z direction only is that the pump motor will continue to function. The failure modes for the pump motor under these conditions are (1) the end retaining bearing for the armature would have to yield to compression and cause the armature brushes to lose contact or to make a faulty contact causing excessive arcing and loss of RPM; or (2) the impeller blade would have to bind against the housing due to deformation or rearward movement of the armature. The possibility of cavitation and the resultant loss of flow must also be considered.

To demonstrate this objective by analyses, it is necessary to determine the forces in the -Z direction which are exerted on the pump and to examine the compressability of the materials in the housing and bearings and seals to show analytically that the pump will function as designed. Analytical techniques are available to accomplish this.

Under these conditions this objective can be demonstrated by analyses and is allocated to that function in Exhibit III-11b.

THERMAL VACUUM

Thermal vacuum is required by the qualification specification, IBM-SPEC-7907994, Sect. 3.8.9. The objective of the thermal vacuum requirement is to assure that no seal failures, no materials deformation and no heat transfer problems occur at ambient (58°F, 25°F, and 100°F) for the service media (water methanol) at a 7800 lb/hour minimum flow rate and ambient pressures of 5×10^{-5} to 5×10^{-4} mm Hg for 12 hours.

Due to the similarity of design in the areas affected by thermal vacuum environment, it is felt that comparisons could be made of the material, seals, thermal characteristic, and functional capability to demonstrate this objective by analyses. For this reason, this objective is allocated to the analysis function of Exhibit III-11b.

RFI

The requirements of MIL-I-6181 define the RFI qualification objective for the Primary Coolant Pump. A pump such as this is relatively immune to most levels of RFI which might be experienced in the IU. However, the effects it could have on other hardware items, particularly from the conducted RFI caused by arcing brushes, could be very significant.

As previously discussed RFI cannot be analyzed to the degree required to verify compliance to requirements. For this reason the RFI objective is allocated to the Analysis, Development Test, and System Level Tests phases of the test program as shown in Exhibit III-11b.

The Bunker-Ramo report[30] describes an RFI problem that became evident during the development testing phase of this pump.

Per the discrepancy report[31] no corrective action[32] was taken and the pump failed the qualification test for RFI. This failure illustrates that qualification test objectives can be satisfied during development testing if proper follow-up action is implemented.

BURST PRESSURE

The Burst Pressure Qualification Objective is defined in the qualification test specification, IBM-SPEC-7907994. The requirement states that the pump will withstand 180 psig for 3 minutes without damage.

The purpose is to determine the integrity of the housing materials and the seals used in the pump. The design of the pump was assessed and it was determined that this objective could be adequately demonstrated by stress analysis and comparison to previously qualified hardware.

The burst pressure qualification objective is placed under the analysis and development testing categories in Exhibit III-11b.

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30 Bunker-Ramo: Report ENV-R-2221, (Bunker-Ramo Corp., Jan. 1969, Canoga Park, Calif.) Section 2.5.1

31 Hydro-Aire: "RFI Discrepancy Report No. 528" QR-60-657B, Burbank, Calif., Hydro-Aire Division, Crane Co., Oct. 18, 1967

32 IBM Corp.: Coolant Pump 7914878-1 Qual. Test Report, (IBM Corp., Huntsville, Ala., 3 Dec. 1969) 69-K84-0004, Vol. I, Sect. 9.5.1.

SALT FOG

The objective of the Salt Fog demonstration is to confirm that the pump will not be corroded due to the salt environment.[33] The corrosion problem must be considered carefully and a finish or coating must be applied which will protect the pump against salt. This qualification objective can be satisfied by demonstrating analytically, through handbook data or through similarity data, that the pump is immune to corrosion damage by salt. This qualification objective is allocated to the analysis function of Exhibit III-11b.

THERMAL SHOCK

Thermal Shock Analysis is conducted to determine the effects on equipment of sudden changes in temperature of the surrounding atmosphere. Cracking or rupture of materials due to sudden dimensional changes by expansion or contraction are primary considerations of the thermal shock analysis.[34] The thermal shock objectives for qualification are given in the qualification test specification, IBM-SPEC-7907994. The requirement is that the pump meet the requirements in MIL-STD-810.

The design of the pump was assessed and it was determined that this objective could be demonstrated by comparison to previously qualified hardware. The major areas of concern are rupture, electrical opens and shorts, and deformation that could cause mechanical interference. It was concluded that this pump was similar enough to previous designs to allow use of the similarity technique. Therefore, the thermal shock qualification objective is allocated to the analysis and development testing function of Exhibit III-11b.

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[33] USAF: Environmental Test Methods, (Department of Defense, USAF, Wright-Patterson AFB, Ohio, June 15, 1967) MIL-STD-810B, Method 509.1.

[34] Op. cit., Method 503.1.

HUMIDITY

The qualification objective of humidity is imposed on the pump through the qualification test specification, IBM-SPEC-7907994 and stipulates Method 507.1 of MIL-STD-810. Humidity is an accelerated environmental test, accomplished by continuous exposure to high relative humidity at an elevated temperature. These conditions impose vapor pressure on the pump, causing migration of moisture through any improperly mated or sealed surfaces.

The humidity testing objectives are to evaluate the properties of materials as they are influenced by the absorption and diffusion of moisture and moisture vapor.

Some of the combined effects of temperature and humidity are:[35]

- High Temperature and Humidity - High temperature tends to increase the rate of moisture penetration. The general deterioration effects of humidity are increased by high temperatures.
- Low Temperature and Humidity - Humidity decreases with temperature, but low temperature induces moisture condensation, and, if the temperature is low enough induces formation of frost and ice.
- Low Pressure and Humidity - Humidity increases the effects of low pressure, particularly in relation to electronic or electrical equipment. However, the actual effectiveness of this combination is determined largely by the temperature.

The effects of moisture on the pump may include corrosion, hygroscopic action and resultant swelling and rupturing, and short circuits in the electronics. The seal is capable of shutting out the moisture and preventing internal damage.

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[35] Theiss, et al: Handbook of Environmental Engineering (McGraw-Hill, New York, N.Y., 1961) Section 3-48

The design of the pump was assessed to determine if this objective could be accomplished by analytical or similarity techniques. It was concluded that analytical techniques could prove that the pump materials are corrosion resistant to moisture and that any hygroscopic materials are adequately protected by moisture-resistant coating.

In consonance with the above discussion, the humidity qualification objective is allocated to the analysis function of Exhibit III-11b.

SAND AND DUST

One of the most devastating environments for moving parts like the motor-driven pump is sand and dust. Therefore, one of the qualification objectives that must be demonstrated for the pump is its ability to successfully resist penetration at any point by sand and dust. Sand and dust can act as abrasives and could rapidly erode the bearings in the motor, causing pump failure. Sand can penetrate under the motor brushes, causing excessive arcing at the brushes. This arcing can lead to intermittent, erratic, and inefficient operation, and ultimately can cause motor failure.

To meet the qualification objective imposed on the pump by the qualification test specification, IBM-SPEC-7907994, Section 3. 8. 3, the requirements of MIL-STD-810, Method 510.1 must be demonstrated. The sand and dust problem as discussed above, is primarily one of adequate seals.

The design of the pump was assessed and it was determined that this objective could be accomplished by use of qualified seals and comparison to previously qualified hardware. For this reason, the sand and dust qualification objective was allocated to the analysis function of Exhibit III-11b.

FUNGUS

The qualification objective for the pump is to pass the test specified in MIL-STD-810B, Method 508.1, Procedure I.

The effects of fungus on the pump can impair its efficient operation, or, in the extreme case, can cause pump failure. Fungus will manifest itself in many ways, depending on the conditions present.[36] These conditions are primarily high humidity, water atmosphere, and presence of inorganic salts.[37] Because of the possible detrimental effects of the fungus the pump is required to demonstrate as a qualification objective an immunity to fungus growth.

The areas of the pump which are most likely to be attacked by fungus include the seals, the wiring insulation, the solder joints, and the housing and impeller materials. The effects of fungus and fungus erosion on electrical connections may create open circuits due to eroded solder joints or weakened connections which cannot withstand the design point vibration or the shock environment. The effects of fungus on the housing and impeller parts may be to weaken the parts enough over a sufficiently long period of time, as in dormant storage, so that rough surfaces may even lead to clogging or to markedly slowing the pump operating speed.

The design of the pump was assessed to determine if this objective could be accomplished by analyses and comparison to previously qualified hardware. It was concluded that handbook data could verify the adequacy of coatings, impregnations, finishes and fungicides. Therefore, the fungus objective is allocated to the analysis function of Exhibit III-11b.

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[36] Theiss, et al: Handbook of Environmental Engineering. (McGraw-Hill, N.Y., N.Y., 1961), pp. 5-49 to 5-55.

[37] USAF: Environmental Test Methods, (Department of Defense, USAF, Wright-Patterson AFB, Ohio, June 15, 1967), MIL-STD-810B, Method 508, Section 1.

SERVICE LIFE

The objective of the service life test on the pump is to demonstrate the durability of the bearings in the motor and the capability of the motor to perform at rated load for a minimum of 500 hours. The service life test requirements are given in the qualification specification, IBM-SPEC-7907994, Section 3.8.11.

The pump design was assessed to determine the best technique to meet this objective. Even though analytical techniques and comparison to previously qualified hardware could be used toward this goal, it was concluded that actual tests must be conducted on critical portions of the pump. It is not necessary to have a complete flight identical assembly to prove the service life of the critical elements of the pump. Based on these conclusions, the service life objective is allocated to the analysis and development test functions of Exhibit III-11b.

SUMMARY OF THE PRIMARY COOLANT PUMP

The coolant pump could be qualified without formal qualification tests. To validate this finding the actual qualification test results[38] on the coolant pump were reviewed to determine if any failures or problems were encountered that would not have been detected if the coolant pump were qualified in the manner described herein. Exhibit III-13 presents the results of this review.

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[38] Coolant Pump Qualification Test Report. IBM Document No. 69-K84-0004, dated December 3, 1969.

SUMMARY OF IU COOLANT PUMP QUALIFICATION TEST DEVIATIONS

Specification Requirements	Description of Deviation	Author's Comments
1. "There was to be no damage caused by the fungus test which would effect the operation of the unit. The unit was required to meet all functional test requirements after fungus test."	"After the first fungus test, examination revealed corrosion due to improper covering of the electrical receptacle. D.R. 608, page 380, was written. During investigation it was found that the insulation resistance was caused by water entering the motor stator through the stator liner. Holes were found in the liner which were caused by corrosion. A design change was made changing the liner material to an alloy which would not corrode."	This failure would not have occurred if the electrical receptacle would have been properly covered. In addition, handbook data is available to determine if the material used for the stator liner is corrosion resistant. It is felt that if this analysis was conducted on the original design, this problem would not have occurred even though the receptacle was improperly protected during test.
2. Reference Paragraph 3.8.7 of IBM Spec. 7907994: "a. The test unit was not to be damaged by the vibration tests. b. The unit was required to operate at rated conditions and 40% minimum efficiency throughout the tests. c. The functional test requirements were to be met after the vibration tests."	"The flow and efficiency dropped off during the vibration test, after an axis change was made. Investigation revealed the discrepancy was caused by improperly bled pressure pickup flex hoses. There was no malfunction of the test unit. The Qual Test was continued with no penalties required."	This deviation resulted from an improper test setup - not a hardware failure.
3. "a. The test unit was not to be damaged by the acceleration test. b. The test unit was required to operate at rated conditions throughout the test. c. The functional test requirements were to be met after the acceleration tests."	"During the functional test after acceleration the pump did not meet the minimum flow requirement of 17.4 GPM minimum at 28 psid. ... The low flow was caused by improper setting of the inverter frequency during assembly of the pump. ... The inverter was set at the correct frequency per HS 2001-11." The acceleration test was rerun with no discrepancies noted.	This problem did not result from the accelerated environment. No design analyses can detect poor workmanship during assembly.

Exhibit III-13.

SUMMARY OF IU COLLANT PUMP QUALIFICATION TEST DEVIATIONS (Cont.)

Specification Requirements	Description of Deviation	Author's Comments
4. Same as 3 above. (This failure occurred on a second qualification test unit.)	"a. The electrical receptacle broke off of the pump after the first acceleration test. The cause of the discrepancy was due to improper assembly techniques used during the attachment of the receptacle to the motor housing. b. During the (acceleration) test it was noted that the current recorded on the visicorder was erratic. Investigation revealed the test had been conducted at 20 G's instead of 10 G's."	There were no design problems detected during these tests. Item a. above was caused by poor improper workmanship and item b. caused by test error.
5. a. "Interference during the conducted and radiated tests... was required to be within the limits specified in MIL-I-6181D." b. "No change in indication, malfunctioning or degradation of performance of the unit was to occur during the tests."	"Interference during the conducted test ... was within the limits of MIL-I-6181D except as follows: (a) On the negative lead, interference was above limits in the frequency range of 1.0 to 2.20 mc. (b) On the positive lead, interference was above limits in the frequency range of .90 to 2.0 mc. (c) On the switch lead, interference was above limits in the frequency range of .90 to 5.5 mc. While the pump did not meet the RFI test criteria, the deviations noted are not considered significant or detrimental to performance."	This problem was not considered significant and the design was not corrected. Analyses would not have detected this problem. During the actual test program this deviation was noted during development testing. No corrective action was taken.

Exhibit III-13 (Cont.)

3. TRANSPONDER

The actual test flow sequence for the transponder is shown in Exhibit III-14a. This covers all testing from development testing through flight testing. Development testing, shown in Exhibit III-14a, includes all of the engineering modeling and testing, and materials compatibility testing and evaluation required to prove an operable and producable transponder which will meet the design specification.[39] The next block shows the qualification testing performed on the transponder. In-process testing (Manufacturing, Exhibit III-14a) is performed on the sub-assembly level throughout the manufacturing process. The objective of this testing is to assure that the hardware is within specification limits such that it will meet the acceptance test requirements[40] before delivery to the next point in the cycle (i.e., subcontractor to contractor). The objective of the acceptance test is to assure the receiving organization that it is accepting a quality product per specification No. 7907826 (IBM). The Instrument Unit manufacturing tests shown in Exhibit III-14a, are conducted when the transponder is installed in the IU. The transponder is subjected to a full functional test immediately prior to the time it is installed in the IU subsystem.[41] After installation, the transponder receives a full operational test[42] to verify operability and subsystem compatibility. RFI is also monitored during these tests. The next block in Exhibit III-14a

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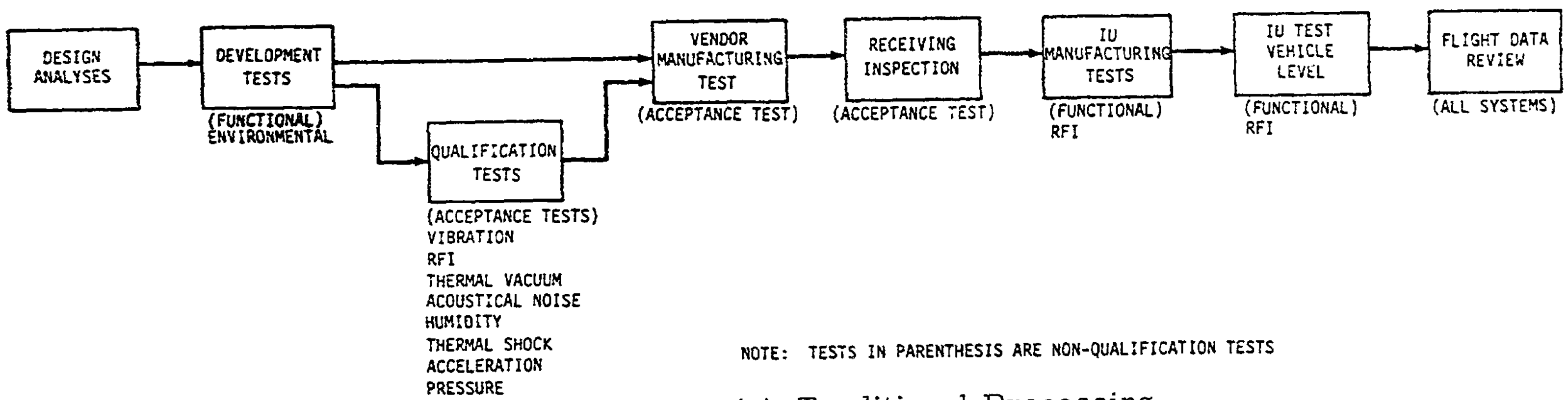
[39] IBM Corp.: Transponder, "C" Band, Radar, Specification For No. 60091332. (IBM, Huntsville, Alabama, Dec. 13, 1967)

[40] IBM Corp.: C-Band Radar Transponder SST-136C, Acceptance Test Specification For. (IBM Corp., Huntsville, Ala., Dec. 13, 1966)

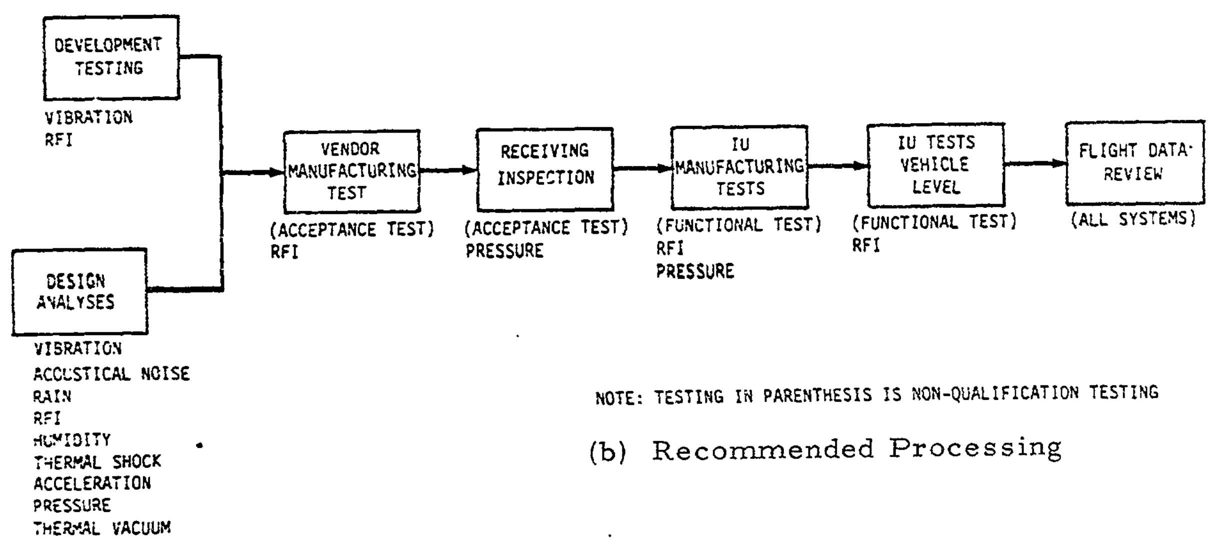
[41] IBM Corp.: Instrument Unit General Test Plan, (IBM, Huntsville, Ala., 1964), No. 64-208-007H, Sec. 4.2.4.

[42] IBM Corp.: General Test Plan, Rev. A, (IBM, Huntsville, Ala., 23 Jan. 1967) No. IBM 67-257-0001, Sec. 6, Fig. 6.9, Block 28-29.



NOTE: TESTS IN PARENTHESIS ARE NON-QUALIFICATION TESTS

(a) Traditional Processing



NOTE: TESTING IN PARENTHESIS IS NON-QUALIFICATION TESTING

(b) Recommended Processing

Exhibit III-14. C-BAND TRANSPONDER TEST FLOW shows the vehicle level tests[43] run on the transponder after the IU has been mated to the balance of the launch vehicle. These tests verify total systems compatibility and monitor for RFI problems that might occur. The last block shown in Exhibit III-14a is the flight test portion in which the transponder actually flies the intended mission. A survey of the Flight Reports for the vehicle reveals no in-flight failures of the transponder have occurred to date.

Exhibit III-14b shows the new hardware processing flow proposed as a result of this study. The "qualification test" block no longer appears; instead, the analysis function is expanded to "qualification by analysis" effort.

Each qualification test objective referenced[44] will be examined for placement under analysis, development testing, or one of the other applicable functions shown in Exhibit III-14b. Since there are similarities between the qualification test objectives for the transponder and the power supply discussed previously, reference will be made to the applicable section when appropriate.

HUMIDITY

The transponder is required by the qualification specification, IBM-SPEC-7907526, to demonstrate an immunity to high humidity at elevated temperatures. Humidity imposes a pressure on the housing seals that can cause water vapor to penetrate the housing and seep into the electronic parts, as was previously discussed for the 56-Volt Power Supply. For the same reasons discussed in Section III-1 this function will be allocated to the analysis function of Exhibit III-14b.

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[43] IBM Corp.: Saturn V, S-IU-504 and Subs. Test and Checkout Requirements Specifications and Criteria for Use at KSC. (IBM Corp., Huntsville, Ala., Jan. 21, 1969) No. 7916404, Sec. 3.2.4.2.

[44] IBM Corp.: Qual Test Specification, C-Band Radar Transponder, (IBM Corp., Huntsville, Ala., May 21, 1968), No. 7907526, Sec. 3.7.

THERMAL SHOCK

The transponder must demonstrate an immunity to thermal shock as required by the Qualification Specification, IBM-SPEC-7907526. The requirements for adequate demonstration of immunity are given by MIL-STD-810, Method 503.1, Procedure 1. The objective of thermal shock testing is to demonstrate the resistance of parts or materials to alternate exposure to extremes of high and low temperatures. The temperature levels required for qualifying the transponder are +85° C to -40° C.

The design of the transponder was assessed and it was determined that this objective could be fulfilled by analyses and similarity to previously qualified hardware as discussed in Section III-1. The thermal shock objective is allocated to the analysis function of Exhibit III-14b.

VIBRATION

The vibration levels and frequencies required for transponder qualification are identical to those required for qualification of the 56-Volt Power Supply discussed previously in this section. Requirements the transponder must meet to achieve a vibrational qualification objective are given in IBM-SPEC-7907526.

The design of the transponder was assessed and it was determined that the same techniques described for the 56-Volt Power Supply (reference Section III-1) could be applied. The vibration objective is allocated to the analysis and development test functions of Exhibit III-14b.

ACOUSTICAL NOISE

Acoustical noise is one of the qualification objectives imposed by the Qualification Test Specification, IBM-SPEC-7907526, Section 3.7.4.

The design of the transponder was assessed and it was determined that the technique described for the power supply could be used. This objective is allocated to the analysis function of Exhibit III-14b.

ACCELERATION

The transponder must exhibit an immunity to the stresses of a 10-G acceleration[45] along three mutually perpendicular axes in both directions to satisfy the qualification objective. The purpose of acceleration qualification is to determine the effects of the acceleration stress on component parts and to verify the ability of the component parts to function in an acceleration environment.[46] (See also the discussion for the 56-Volt Power Supply analysis; it is directly applicable to the transponder.)

Because achievement of the acceleration qualification objective may be demonstrated by analysis and similarity techniques, it is shown in the analysis function in Exhibit III-14b.

THERMAL VACUUM

It must be demonstrated analytically or by similarity that no structural deformations which could cause seal leakage, electrical problems, or which could compromise general structural integrity will occur due to thermal conditions. Possible detrimental thermal effects might include warpage of the transponder cover plate, causing pulling on the screw holes great enough to tear the metal; or the plate might warp upward and rupture the seal.

An additional analytical consideration is that there is a parallel between the thermal vacuum and the altitude qualification objectives in that each[47] requires demonstrated immunity from dielectric breakdown; from materials degradation, such as outgassing; from sealing problems; and from heat transfer problems. Specification IBM-SPEC-7907526, Section 3.7.6, requires demonstrating only the fulfillment of the thermal vacuum requirements.

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[45] IBM Corp.: Qualification Test Specification, C-Band Radar Transponder, (IBM Corp., Huntsville, Alabama, May 2, 1968), 7907526, Section 3.7.5.

[46] DSA: Test Methods for Electronic and Electrical Component Parts, (Defense Supply Agency, Alexandria, Va., Sept. 12, 1963) MIL-STD-202C, Method 212.

[47] DSA: Test Method for Electronic and Electrical Component Parts, (Defense Supply Agency, Alexandria, Va., Sept. 12, 1963) MIL-STD-202C, Method 105C.

The 56-Volt Power Supply discussions on "Altitude" and "Thermal Vacuum" are applicable to this item.

Since analytical and similarity techniques may be used to achieve the thermal qualification objective, it is allocated to the analysis function of Exhibit III-14b.

RFI

The discussion of the RFI qualification objective given for the 56-Volt Power Supply is directly applicable to the transponder.

The RFI qualification objective is imposed on the transponder by the qualification specification IBM-SPEC-7907526, Section 3.7.7. The requirements are further specified in Specification MIL-I-6181.

To demonstrate achievement of the qualification objective, development tests on engineering models to determine the effectiveness of the design must be performed. In addition, RFI must be monitored during subsequent test phases to assure that the transponder performs satisfactorily in the operating environment. After the IU is mated to the vehicle, the transponder is monitored for RFI problems and prior to launch is again subjected to a functional test.[48] When the transponder has successfully passed the tests outlined and the necessary analyses support RF compatibility the transponder can be considered RFI-qualified. The RFI objective is allocated to the analysis, development testing, IU manufacturing, and IU/vehicle checkout functions in Exhibit III-14b.

PRESSURIZATION

The transponder must maintain a leak rate of not greater than 0.5 psi in one hour from an initial pressurization of 30 psi.[49] This is primarily a seal test to determine the transponder's capability to retain a dry nitrogen purge for long periods of time at 5 psig.

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[48] IBM Corp.: Test and Checkout Requirements Specifications and Criteria for Use at KSC. (IBM Corp., Huntsville, Ala., Jan. 1969), 7916404, Section 3.2.4.2.

[49] IBM Corp.: Transponder, C-Band, Radar, Specification For, (IBM Corp., Huntsville, Ala., Dec. 13, 1967), 6009132, Section 4.5.4.3.2.

The effect of a leaky seal would be to allow the transponder to lose its purge. This would allow penetration of water vapor and dust into the unit, possibly bringing about a myriad of undesirable effects.

The purpose of the pressurization qualification objective is to establish a reasonable degree of certainty that the transponder seals will remain intact after closure. Attainment of this objective may be demonstrated by analysis, by use of similarity techniques and by development testing on seal closures for a specific closure requiring testing.

It was determined from an assessment of the design that the configuration of the housing and the case could be qualified by utilization of analytical techniques and pressure tests that can be integrated into the Vendor Manufacturing Tests and the Receiving Inspections.

For these reasons, this objective is allocated to the analysis and other test phases as shown in Exhibit III-14b.

SUMMARY OF TRANSPONDER

The assessment of the transponder revealed that it could be qualified in a manner similar to the power supply without formal qualification tests. The qualification test report on the transponder could not be acquired to compare this assessment to the actual test data.

4. HYDRAULIC ACTUATOR

The hardware flow process for the test functions of the hydraulic actuator is shown in Exhibit III-15a. The flow begins at the development testing phase and progresses through a sequence very similar to the sequences followed by the other three pieces of hardware examined in this study.

After undergoing the acceptance testing outlined in the Qualification Test Report [50] and in the general test plan[51] the actuator is installed on the vehicle. Systems testing is then performed both on a subsystems and on an all-up systems level.[52] From the systems test the hardware flow chart progresses to "Flight Test." The Flight Analysis Reports[53] for the last fifteen flights show that no in-flight failures have occurred on this item.

The hardware flow processing recommended by this study is shown in Exhibit III-15b. Each qualification objective is discussed briefly and the easons for its re-allocation as shown in the recommended hardware flow given.

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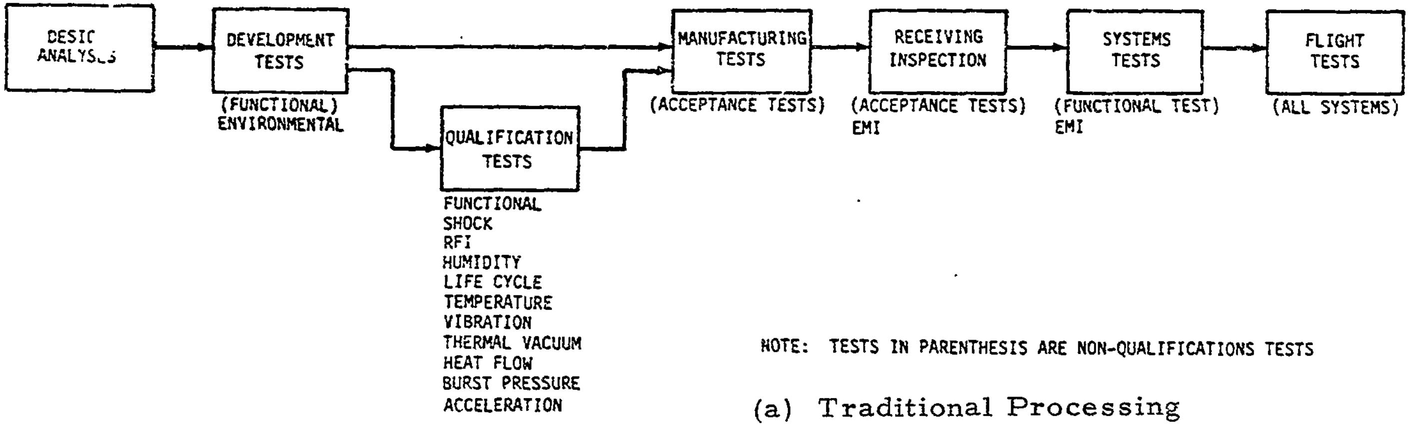
[50] Douglas: Qualification Tests of the Hydraulic Actuator Assemblies, Douglas SCN 1A66248-503 and -505. (Douglas Aircraft Co., Santa Monica, Calif., August 1966), Report No. SM-46580, p. 8.

[51] Douglas: General Test Plan, Saturn S-IVB System (Douglas Aircraft Co., Santa Monica, Calif., 1 Dec. 1967) Report No. SM-41412, p. 97

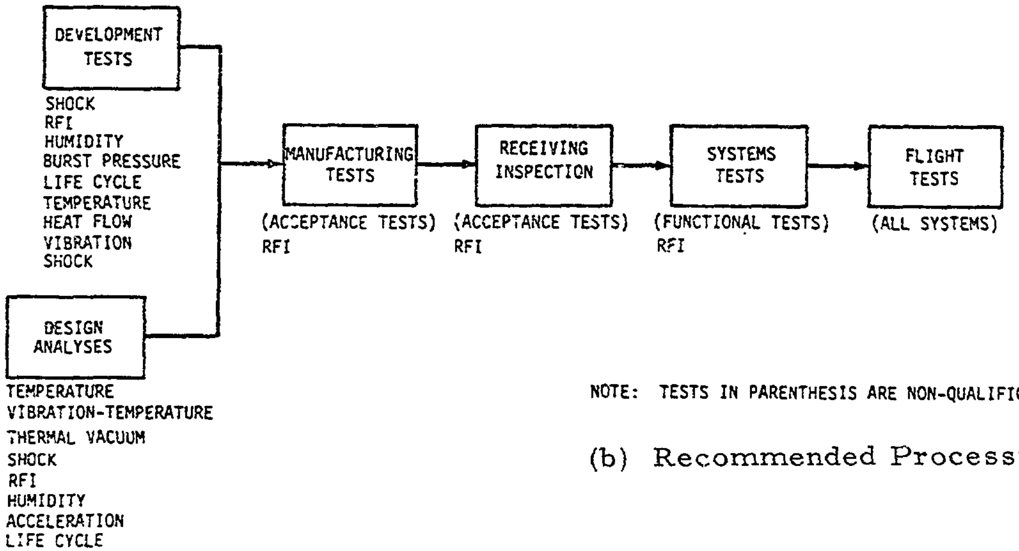
[52] Douglas: Hydraulic Subsystem - S-IB- CL (Douglas Aircraft Co., Santa Monica, Calif., Feb. 10, 1966), Specification No. 1B59485, Section 1.

[53] Teasley, R. B., Personal Interview and Flight Data Reports Survey at NASA - S E-CSE-L (1.5 hours)



NOTE: TESTS IN PARENTHESIS ARE NON-QUALIFICATIONS TESTS

(a) Traditional Processing



NOTE: TESTS IN PARENTHESIS ARE NON-QUALIFICATION TESTS

(b) Recommended Processing

Exhibit III-15. HYDRAULIC ACTUATOR TEST FLOW

TEMPERATURE

The qualification objective for the temperature requirement is to determine no thermal expansion which could cause a malfunction in the actuator. This requirement is imposed on the actuator by the specification, 1A66248, Section 3.10.2. The failures which the requirement is intended to detect include expansion of the piston to a degree that might bind or close the piston-housing clearance, making the piston difficult to operate; and expansion of the valve operating parts to the point that binding or leakage and external or internal seal deformation could occur.

The effects of expansion include leakage of hydraulic fluid internally and externally, slow response, excessive actuation current, and actuator failure. These effects can be predicted utilizing materials and heat transfer analyses.

The design of the actuator was assessed to determine if this objective could be fulfilled by analytical techniques. It was concluded that development testing would be required to verify many of the functions and items of hardware.

This objective is allocated to the analysis and development test functions of Exhibit III-15b.

VIBRATION

The purpose of the vibrational objective[54] is to assure that the actuator is constructed to withstand dynamic vibrational stresses and that performance degradations or malfunctions will not occur while the actuator is operating in the intended environment. Some of the effects of vibration include loosening or relative motion of piece parts, wear, physical distortion, fatigue and failure. The qualification test report

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[54]USAF; Environmental Test Methods (Department of Defense, USAF, Wright-Patterson AFB, Ohio, June 15, 1967), MIL-STD-810B, Method 514.

written by Douglas on this hydraulic actuator reflects two vibrational-operational tests,[55] one at ambient temperature and one at +275°F. While not required by Douglas Spec. 1A66248, the tests were performed to determine whether the actuator would work in high temperatures as well as in ambient temperatures in the vibration environment specified. The high temperature vibrational operation is closer to the actual operating conditions of the actuator than is ambient temperature vibrational operation. The vibration portion of the discussion on the IU ECS Primary Coolant Pump contained in this section is also applicable to this discussion.

Based on an assessment of the actuator design, it was concluded that to satisfy the qualification environment, development tests would be required on a dynamically similar engineering model. With data acquired during rather extensive development tests, analytical techniques could be employed to demonstrate this objective. For these reasons, the vibration qualification objective is allocated to the analysis and development functions of Exhibit III-15b.

ACCELERATION

The acceleration specification objective for the actuator is stated in Section 3.10.8 of Specification 1A66248. The requirement specifically states that the actuator must survive 8 G's along the thrust axis and 2 G's along the two mutually perpendicular axes in both the plus and minus directions in an operating status. This requirement outlines a total of six operational-acceleration situations that must be considered in hardware qualification. It must be shown that the actuator operates satisfactorily in each of the six conditions mentioned and that no structural, seal, or electrical problems will occur. The major problems that may occur during acceleration concern elongation and shearing of parts such as end plate bolts and housings. Seal problems can also occur as a result of piece-part deformation or seal loading due to the mass of the media inside the actuator. The case

[55] Douglas: Op. Cit., SCN's 1A66248-503 and -505, Section 2.2.2.

of a fluid-operated unit such as the hydraulic actuator requires another consideration within the acceleration objective: How well will the unit handle the fluid? Will the fluid move readily through the system? Will it bubble or cavitate?

The design was assessed to determine if these areas could be resolved by analytical techniques. Since many similar items of qualified hardware currently exist from previous programs, it was concluded that these potential problems could be satisfactorily resolved by comparison. For this reason, the acceleration function is allocated to the analyses function of Exhibit III-15b.

SHOCK

The actuator is required by Section 3.10.7 of Spec. 1A66248 to meet a qualification objective of 100 G's shock in each direction in three mutually perpendicular axes.[56] The shock objective demonstrates structural integrity of the actuator in a shock condition. It must be shown that the attach bolts will not elongate or shear, that the end plates or housing will not deform or rupture, that the piston and shaft will not deform or jam, that the seals will remain intact in all areas, and that the electrical piece parts such as the potentiometer and connector will function properly after shock.

The design was assessed to determine if this objective could be accomplished with analytical techniques. It was concluded that analyses would show the design could withstand the shock conditions, but for an items of this mass and complexity, tests must be performed to conclusively demonstrate the objective. These tests could be performed on engineering models during development testing.

For this reason, the shock objective is shown under the analysis and development test functions of Exhibit III-15b.

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[56] Douglas: Actuator Assembly, Hydraulic, Specification For (Douglas Aircraft Corp., Santa Monica, Calif., Jan. 24, 1963) Specification No. 1A66248.

THERMAL VACUUM

The requirements for thermal vaccum qualification are satisfactory operation at -300°F and 1×10^{-7} Torr when the hydraulic fluid is maintained at 100°F in a reservoir and is circulated through operation of the actuator.

The design of the actuator was assessed to determine if this objective could be met by analyses. It was concluded that there were no new or unique aspects concerning the vacuum environment. Provided that adequate temperature tests were conducted during development tests, this objective could be demonstrated by comparative techniques. The thermal vacuum objective is allocated to the analyses function of Exhibit III-15b.

HEAT FLOW

This qualification objective is peculiar to this actuator and to similar pieces of hydraulic hardware. It is actually an extension of the temperature testing discussed previously, intended to demonstrate that no detrimental effects on se... or materials occur while the vehicle holds in the pre-launch condition.

Environmental conditions[57] imposed on the actuator are to maintain the heat-sink temperature at -175°F. Hydraulic pressure is applied at 3650 psig between 10°F and 40°F; and with a neutral command to the actuator (piston centered) the actuator temperature distribution must be determined for the actuator at environmental temperatures of -25°F, -45°F, and -80°F.

To demonstrate this objective analytically it must be shown that there are no temperature gradients or "hot spots" which will cause materials or seals deformations such that the actuator will leak, rupture, or fail to operate properly. The heat gradients between heat sink, environment, and fluid are significant.

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[57] Douglas: Qualification Tests of the Hydraulic Actuator Assemblies, Douglas SCN's 1A66248-503 and -505. (Douglas Aircraft Corp., Santa Monica, Calif., August 1966) SM-46580, Section 2.2.7.1

Differences in the rate of expansion at different points in the actuator must be determined and must be satisfactorily shown to be neutral in detriment.

Based on the complexity of the actuator, it was concluded that tests must be performed during development tests on a flight similar engineering model to conclusively demonstrate this objective. This objective is allocated to the development test phase of Exhibit III-15b.

RFI

RFI is specified in the test plan[58] as a qualification objective for the actuator.

The major problem for the actuator in the area of RFI is the possible conduction of erroneous and spurious command piston signals to the valve control servo electronics system, causing the valve to actuate to these erroneous commands or to chatter due to the RFI transients. During systems tests, the actuator and its associated electronics are monitored closely for RFI[59] problems which may occur at a systems level.

Utilization of analyses techniques, employment of applicable similarity data, and performance of development tests will demonstrate this objective. The development testing can be done on engineering hardware, thus deleting the testing requirement for unique qualification hardware.

These tests are shown in Exhibit III-15b as a part of the RFI qualification objective for the actuator. The analyses, engineering model development testing, and systems tests are shown in their respective positions in Exhibit III-15b.

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[58] Douglas: General Test Plan, Saturn S-IVB System (Douglas Aircraft Co., Santa Monica, Calif., Dec. 1965) Report SM-41412, Appendix 1

[59] Douglas: All Systems Test, Saturn IB, (Douglas Aircraft Co., Santa Monica, Calif.), Specification No. 1B65533 (This number obtained by telecon 1-14-72 from McDonnell-Douglas Aircraft Corp., Sacramento, Calif.)

LIFE CYCLE

The object of the life cycle qualification requirement is to demonstrate the ability of the actuator to perform satisfactorily throughout its period of operation. The moving parts most likely to fail in the actuator are the piston, valve, and potentiometer. The most susceptible parts of the piston are the seals, primarily that around the piston itself, and secondly, those around the tail shaft where the rod end connects. In addition the moving parts of the servo valve are likely to fail.

The life of the actuator is a function of design, workmanship, and inspection. To demonstrate achievement of the life cycle qualification objective for the actuator it must be proven that:

- o All purchased parts and materials are qualified for the intended use;
- o That finish of the bore, tolerances, fits of piece parts, and materials will meet the life cycle requirements in an operating environment.

Based on an assessment of the actuator design, it was concluded that analytical techniques are not available to demonstrate service life. To accomplish this objective without formal qualification tests will require a service life development test on a flight identical unit.

According to these considerations, the actuator life test qualification objective is allocated to the analysis and development testing functions of Exhibit III-15b.

HUMIDITY

The actuator is required to achieve a qualification objective which demonstrates immunity to humidity. The objective required for the actuator to meet is survival in an accelerated environmental situation brought about by elevated temperatures. These temperature conditions impose vapor pressures on the actuator which can cause migration of water vapor through any improperly mated or incorrectly sealed surfaces.

The detrimental effects of water vapor may be corrosion (including rust in some cases); support for fungus growth, associated with the resultant seal deterioration; and short circuiting of the position potentiometer.

To demonstrate achievement of the humidity qualification objective, it must be proven that the materials chosen are corrosion resistant by virtue of handbook data or by similarity analysis. It must also be shown that the temperature extremes required in this objective will not deform the end plates or covers enough to jeopardize seal integrity and that the materials chosen for the seals are not hygroscopic and will not deteriorate under the required environment. This data is available from handbooks and from materials specifications.

Even though a complete analysis could be performed on this objective, it was concluded that for a mechanism of this complexity, there would be enough unknowns and assumptions to justify a humidity test during the development test cycle. For this reason this objective is allocated to the analysis and development test function of Exhibit III-15b.

BURST PRESSURE

The actuator is required to demonstrate a burst pressure qualification objective in excess of 9130 psig at a stabilized temperature of 275°F. The requirement is cited in the S-IVB test plan,[60] applied in the actuator specification,[61] and discussed in the qualification test report.[62]

The object of this burst objective is to determine at what point in excess of 9130 psig the actuator will fail. The actuator could fail in several ways: overstress of the end cover bolts in tension; rupturing around the tail shaft area or around the inlet port area; or by rupturing

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[60] Douglas: General Test Plan, Saturn S-IVB System (Douglas Aircraft Co., Santa Monica, Calif., December, 1965) Report No. SM-41412, Appendix 1

[61] Douglas: Actuator Assembly, Hydraulic (Douglas Aircraft Co., Santa Monica., Calif., June 1963), Specification No. 1A66248, Section 3.7.12.

[62] Douglas: Qualification Tests of the Hydraulic Actuator Assemblies, Douglas SCN's 1A66248-503 and -505 (Douglas Aircraft Co., Santa Monica, Calif., August 1966), Report No. SM-46580

through the side. The end plate bolts' combined tensile strength would probably preclude blowing off the end plate; thus, the most likely failure to occur would be rupturing around the tail shaft or through the side.

Burst pressure can be calculated by analytical techniques but the only conclusive method to determine the actual burst pressure is by conducting the test on a flight identical assembly. For this reason the burst pressure is allocated to the development test function of Exhibit III-15b.

SUMMARY OF S-IVB HYDRAULIC ACTUATOR

This study determined that it is technically feasible to demonstrate qualification objectives on the S-IVB Hydraulic Actuator without the conduction of formal tests. However, to accomplish this, it is required that the development tests include a significant number of additional tests on flight identical test units. For this reason it is not intuitively obvious that the approach presented herein would result in an overall cost savings when compared to the usual qualification programs. A detail cost trade should be accomplished to assure that it would be cost effective prior to implementing this qualification approach for hardware of this type.

The qualification test report[63] on the hydraulic actuator was reviewed to determine if any failure or problems were encountered that would not have been detected if the actuator was qualified in the manner described above. Exhibit III-16 presents the results of this review.

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[63] Qualification Tests of the Hydraulic Actuator Assemblies. Douglas Report No. SM-46580 dated August 1966.

SUMMARY OF S-IVB HYDRAULIC ACTUATOR QUALIFICATION TEST DEVIATIONS

Specification Requirements	Description of Deviation	Author's Comments
1. **Vibration:** "There shall be no evidence of damage, malfunction, or performance degradation when the actuator assembly is subjected to the following high-temperature vibration requirements. With the test specimen mounted in the load test fixture, hydraulic fluid at +275°F shall be applied to the actuator at pressures of 3,650-psig supply and 50- to 100-psig return. The test environment shall be room temperature. A triangular command signal of ±30 ma at 1.0 cps shall be applied to the actuator. The actuator cylinder differential pressure shall be 1,200 psid. Under the foregoing conditions, the test specimen shall be subjected to the sinusoidal and random vibration applications .... Hydraulic supply and return pressures, cylinder differential pressure, valve input current, telemetry feedback, and position feedback shall be monitored."	"The post-vibration frequency response test revealed an increase in load/current resonant peaking; .... This implied a reduction in servo system dynamic damping. The DP-F piston and springs were removed from the actuator housing and examined. The piston was free in its bore, and the spring appeared normal with measured rates of 450 to 500 pounds per inch. It was suspected that the change in damping was possibly caused by shifting of the DP-F nozzles. For this reason, the actuator was returned to Moog Servo Controls, Inc., for additional analysis. Since the increased load/current resonant peaking was only slightly higher than the allowable limits, the results of the high-temperature vibration test were considered acceptable without additional frequency response testing."	Since this was an isolated failure for only one unit, it is unlikely that this problem would have been detected if the qualification approach described herein was used.
2. **Mechanical Shock:** "There shall be no evidence of damage, malfunction, or performance degradation when the actuator assembly is subjected to three shocks in one direction along each of three mutually perpendicular axes, a total of nine shocks. The shock inputs shall be 100.0-g peak (half-sine pulse) with a duration of 10±2 milliseconds."	a. "Test specimen No. 3 was shock-tested per the requirements .... The magnitudes of the input shock pulses during the test were 20 to 30 percent lower than the 100 g specified; this difference was caused by the low-volume pressure capacity of the shock-tester gas supply. Based on the extensive vibration testing performed on specimen No. 3, it was decided that the lower levels were acceptable." b. "During shock tests in the thrust direction, small amplitude oscillations were observed on the current trace after the application of the shock. The frequency of the oscillations measured approximately 225 cps. Removal of the electrical connector from the actuator stopped the oscillation. When another servo amplifier was used, the oscillations did not occur. The exact reason for the oscillations is not known but they are believed to have been caused by a faulty component in the dual-channel servo controller, not by the actuator."	Item (a) above was a fault of the test setup and apparently had no adverse effect on the overall test results. Item (b) was an isolated failure. The probability of detecting this type of failure during analyses or development testing is extremely low.

Exhibit III-16.

SUMMARY OF S-IVB HYDRAULIC ACTUATOR QUALIFICATION TEST DEVIATIONS (Cont.)

Specification Requirements	Description of Deviations	Author's Comments
3. Life Cycle (Axial Load): "There shall be no evidence of leakage, damage, or maladjustment when the actuator assembly is subjected to the following series of cycles. a. 5,000 cycles at full actuator stroke, cycling at the maximum hydraulic power output of the servovalve. b. 10,000 cycles at one-half actuator stroke, cycling at half the maximum hydraulic power output of the servovalve. c. 100,000 cycles with constant amplitude signals equivalent to 1 per cent and 25 per cent of the actuator stroke, each amplitude for a duration of 8 minutes at the following frequencies: 0.2, 0.4, 0.6, 1.0, 2.0, 2.5, 3.0, 3.5, 7.5, 8.0, 8.5, 9.0, 10, 12, 16, and 20 cps."	a. "After successfully completing tests 1 and 2, test specimen No. 4 experienced cracking of the titanium end between the electrical connector holes during either test 3 or the post-life-cycle frequency-response test. Additional full-power cycling of test specimen No. 4 beyond the qualification test requirements resulted in complete failure of the titanium end." b. "Both test specimens performed staisfactorily at half- and full-power, tests 1 and 2. There was noticeable flexing of the titanium tailstock in the vicinity of the electrical connectors, but visual inspection of both test speciments, after testing, did not reveal any cracks or failure." c. "Approximately 2 months after completion of the life-cycle testing, the titanium tailstock of test specimen No. 4 was discovered to be cracked between the two electrical connectors. The part had not been tested since the life-cycle tests; examination following life-cycle tests 1 and 2 did not reveal any sign of failure. These facts indicate that the failure occurred during either test 3 or the post-life-cycle frequency-response run. ... It was decided to reinstall the cracked end on the actuator and apply an additional 5,000 full-power cycles to determine if the strength of the part was still adequate. Almost immediately after cycling was resumed, cracks began propagating downward from the connector holes along the radius of the bell-tail intersection. Complete rupture ... occurred at 4,920 cycles.	These deviations could not have been predicted by analytical techniques. However, the development tests recommended in lieu of qualification tests could have detected the failures provided the tests were conducted under similar test procedures on identical test units.

Exhibit III-16 (Cont.)

IV. SCOREKEEPING

1. RATIONALE

Program Management must monitor status of hardware qualification. When hardware is qualified in the usual manner, this is accomplished by monitoring "qualification tests complete" milestones on program schedules. If formal qualification tests are deleted, and hardware is qualified by the manner described herein, other methods of monitoring hardware qualification status at any point in the program must be implemented. A method of "scorekeeping" to accomplish this must be part of the overall management plan imposed on the contractor and subcontractor at the time this method of qualification is authorized for use on a hardware program. This scorekeeping technique must be simple, usable, readily implementable and cost effective.

The method of scorekeeping devised in conjunction with this study satisfies these requirements. It is based on the principle that the hardware must meet all qualification objectives that would be established if the item were subjected to formal qualification tests. This technique is designed according to the concept that qualification objectives serve as monitoring points during the qualification activities, and the completion of these objectives is monitored during the various program phases.

2. SCOREKEEPING IMPLEMENTATION

The steps involved in implementing this scorekeeping system are shown in Exhibit IV-1.

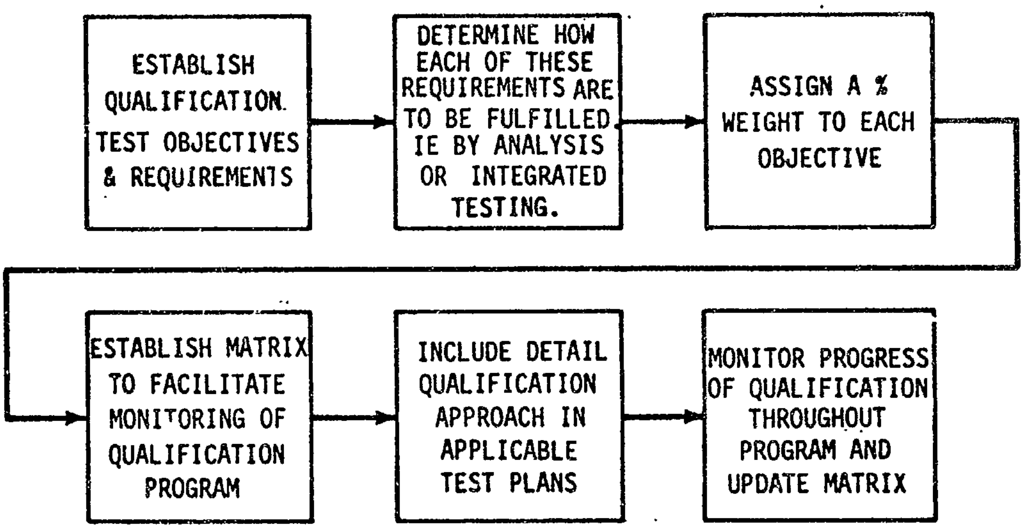

Exhibit IV-1. SCOREKEEPING SYSTEM IMPLEMENTATION

The proper display of the milestones and their percentages will immediately make several different kinds of information obvious to program management. This information includes the total percentage of each milestone relative to the total program effort, the percentage of completion reached at any point by total program or by individual milestones, and the percentage of the total program to be accomplished by analysis, by development testing, by systems testing, or by other activities in the program.

The specific steps required, both for the design organization and program management, are depicted in Exhibit IV-2. A specific example serves to illustrate more clearly the scorekeeping techniques proposed. The example chosen is an application of the scorekeeping technique to one of the four pieces of hardware included in this study, the IU 56-Volt Power Supply.

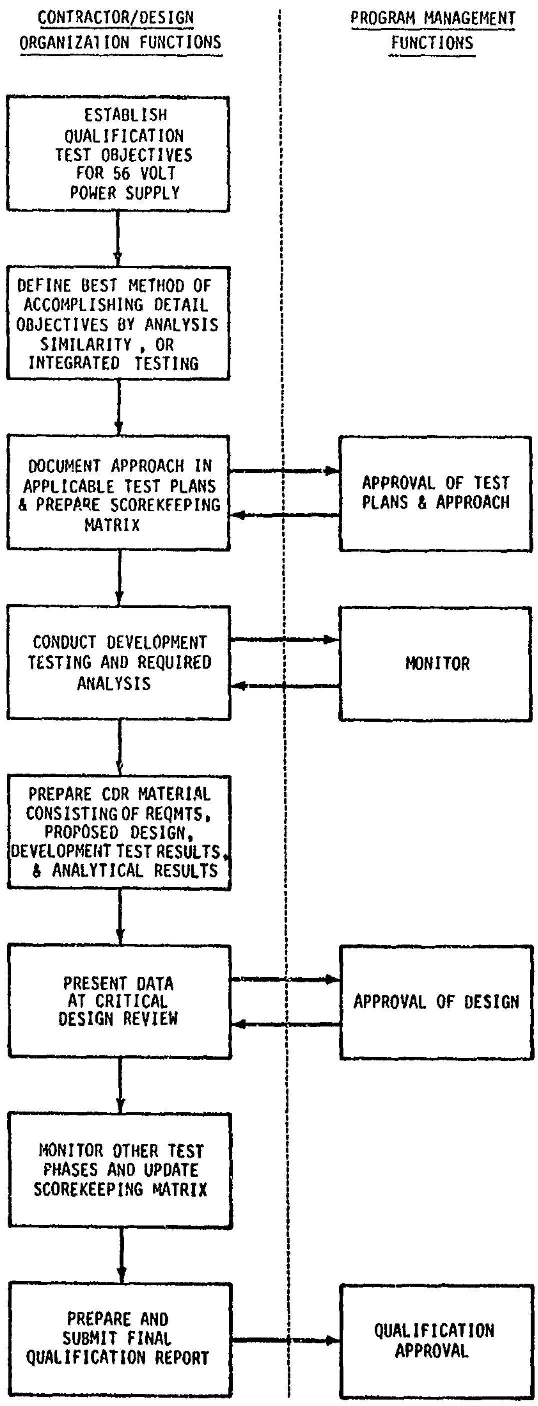

Exhibit IV-2. IMPLEMENTATION OF SCOREKEEPING TECHNIQUE FOR 56-VOLT POWER SUPPLY

An example of the scorekeeping matrix for the power supply is shown in Exhibit IV-3. This example is based on the results of this study on the qualification of the power supply. The weighting percentages used are engineering judgments based onthe detail evaluation of the power supply design and the associated test documentation.

SCOREKEEPING MATRIX

TEST TYPE / TEST PHASE	VIBRATION	ACCELERATION	THERMAL SHOCK	PRESSURIZATION	ALTITUDE	THERMAL VACUUM	ACOUSTICAL NOISE	HUMIDITY	RFI	
% CONTRIBUTION	15	3	18	8	7	15	9	5	20	100
ANALYSIS	15	3	8	2	3	5	9	5	10	60
DEVELOPMENT TEST			10	4	4	10				28
ACCEPTANCE TESTS				2					5	7
RECEIVING TESTS										
VEHICLE TESTS									5	5

Exhibit IV-3. SCOREKEEPING SHEET SHOWING TOTAL AND INDIVIDUAL PERCENTAGE CONTRIBUTIONS TO QUALIFICATION TEST OBJECTIVES - 56-VOLT POWER SUPPLY

The qualification test objectives are listed across the top of the matrix and the program functions are listed vertically. The design organization must determine the percentage weight of each objective and allocate this to the appropriate program phases. As shown in the matrix several of the objectives are allocated to more than one phase, i.e., analysis and test.

This percentage weighting must be based on the designer's best engineering judgment, called from previous hardware programs. For instance, if the designer knows from experience that RFI presented twice the difficulty shown by acceleration on previous hardware programs, this knowledge will be reflected by arbitrarily assigning twice the percentage points to RFI as are assigned to acceleration. The relative weighting and distribution is thus an arbitrary function performed by the designer and based on his best engineering judgment. These allocations are subject to approval by program management.

The scorekeeping matrix delineates the accurate qualification status at all times during the program based on the completion of analyses and test phases. For example, when the analysis portion is completed, the power supply is 60 percent qualified. See Exhibit IV-4 for the distribution of qualification objectives as defined in Section III-1. This is a positive and concise summary of the qualification status of the hardware, requiring only the submittal of one updated sheet to program management. This matrix could be included in the periodic reports required. Once the scorekeeping is established, as described above, it requires only checkoff and updating to keep program management appraised of progress. This gives management visibility of potential problems in qualification.

3. SCOREKEEPING SUMMARY

The scorekeeping technique presented in this section is designed in accordance with the qualification approach proposed by this study. It will allow a great deal of "quick look" data to be readily available for management with very little effort. This technique fulfills the objectives earlier outlined as being required of a valid scorekeeping system; that is it must be simple, it must be usable, it must be readily implementable, and it must be cost effective.

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(SCOREKEEPING EXAMPLE)

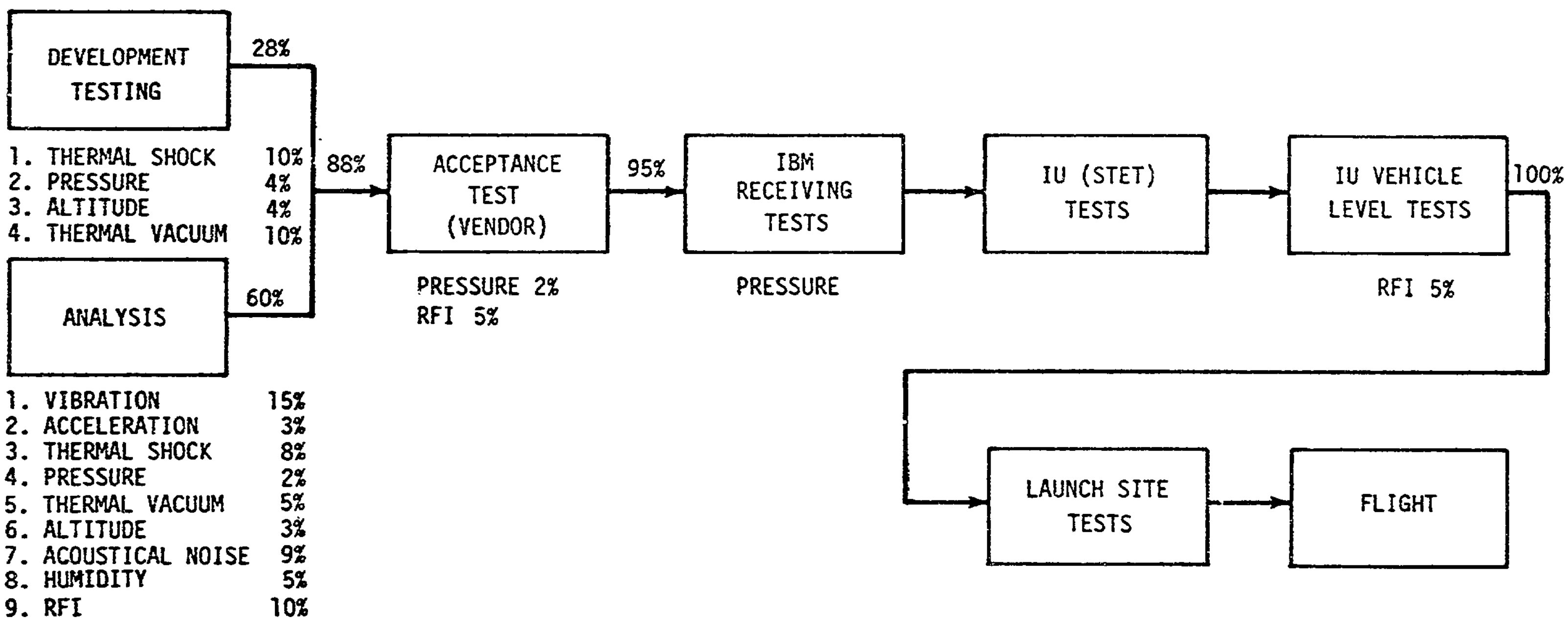

Exhibit IV-4.

V. CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

This study showed that selected items of hardware can be qualified without formal qualification tests. To determine the items of hardware that can be effectively qualified in the manner described herein, the added cost of development testing versus the cost of usual qualification tests must be compared.

The following specific conclusions were reached based on the detail assessment of the four items of hardware. These are:

- Redundant and repeat testing can be minimized by integrating and distributing the qualification test objectives with other planned tests.
- The overall quantity of required documentation for the verification activities can be reduced by deletion of formal qualification test procedures, reports, etc.
- More formal configuration management of development test hardware will be required if formal qualification tests are deleted.
- Design analyses must be documented and results presented in design reviews.
- With the "scorekeeping" technique presented, program management can retain current visibility of the equivalent hardware status.

2. RECOMMENDATIONS

For success of the qualification program defined in this study, management and the design organizations must adhere to a few basic groundrules. These recommendations are presented below:

(a) The design organization must retain the complete and total responsibility for qualification of the hardware. Implementation of new methods or techniques for qualification should in no way suggest that the designer be relieved of the responsibility for qualification.

(b) The implementation of methods outlined in this study requires well-defined "design-to" specifications. The following are therefore recommended to be available to the design organization.

1. Reliability requirements
2. Life cycle requirements
3. Environmental requirements
4. Operational limits and possible overloads
5. Maintainability and replaceability requirements

(c) All piece-parts and materials must be purchased from an approved specification and a Qualified Parts List (QPL). This assures the required parameters.

(d) The design organization must have the option of specifying limited qualification type testing during development testing or during other appropriate test phases. With this option, the design organization has the flexibility to specify the completion of all the qualification objectives in the most cost-effective manner.

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