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DEPARTMENT OF DEFENSE
STANDARD PRACTICE

PRODUCT VERIFICATION REQUIREMENTS

FOR

LAUNCH, UPPER STAGE, AND SPACE VEHICLES

AMSC N/A

FSC 1810

FOREWORD

1. This Military Standard is approved for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, or deletions) and any pertinent data which may be of use in improving this document should be provided by letter addressed to:

   Space and Missile Systems Center, SMC/AXM
   160 Skynet Street, Suite 2315
   El Segundo, CA 90245-4683

3. A verification process is required by this document. The verification process is fundamental in the development of a successful launch or space system. The process involves various tasks performed in different program phases applying a coherent bottom-up building block concept.

4. The fact that most launch and space systems involve flight equipment that is not recoverable and not repairable means that risk management is essential. The cost of a failure may be extremely high due to the loss of mission capability and the loss of equipment. The large number of independent organizations involved and the complexity of equipment and software means that extensive verification of launch and space systems is necessary to reduce the risk of failure. A combination of different verification methodologies (e.g., Test, Analysis, Inspection) at several assembly levels (from units to the overall system) through the various program verification phases (e.g. Qualification, Acceptance, Pre-launch, On-orbit) is cost effective in assuring successful equipment and software design and operation.

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1. SCOPE

1.1 Scope. This document requires that a process be established to develop and manage verification requirements to assure that launch and space equipment can function correctly and withstand stresses it may encounter during its life cycle including end-of-life performance requirements. This document is intended for use in developing the detailed verification requirements for a particular project. The application of these requirements should result in an effective verification process and consequently high confidence in achieving successful space missions.

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3, 4, and 5 of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements documents cited in sections 3, 4, and 5 of this standard, whether or not they are listed.

2.2 Government Documents.

2.2.1 Specifications, standards, and handbooks. The following standards and specifications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation.

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-810	Environmental Test Methods and Engineering Guidelines.
MIL-STD-1522 (USAF)	Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems.
MIL-STD-1541 (USAF)	Electromagnetic Compatibility Requirements for Space Systems.

MIL-STD-1833 (USAF)	Test Requirements for Ground Equipment and Associated Computer Software Supporting Space Vehicles. (Canceled)
MIL-HDBK-340A (USAF)	Volume 1 Test Requirements For Launch, Upper Stage & Space Vehicles - Baselines
	Volume ll - Test Requirements for Launch, Upper Stage & Space Vehicles - Application Guidelines.
MIL-HDBK-343 (USAF)	Design, Construction and Testing Requirements for One Of A Kind Equipment.

(Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Defense Automated Printing Service (DAPS) Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.

Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues are those specified are those in the solicitation.

2.3 Non-Government publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues are those specified are those in the solicitation.

IES-RP-DTE012.1	Handbook for Dynamic Data Acquisition and Analysis.

2.4 Order of precedence. In the event of conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 Part. A part is a single piece, or two or more joined pieces, which are not normally subject to disassembly without destruction or impairment of the design use. Examples: resistor, integrated circuit, relay, roller bearing.

3.2 Subassembly. A subassembly is a unit containing two or more parts which is capable of disassembly or part replacement. Examples: printed circuit board with parts installed, gear train.

3.3 Unit. A unit is a functional item that is viewed as a complete and separate entity for purposes of manufacturing, maintenance, or record keeping. Examples: hydraulic actuator, valve, battery, electrical harness, transmitter.

3.4 Subsystem. A subsystem is an assembly of functionally related units. It consists of two or more units and may include interconnection items such as cables or tubing, and the supporting structure to which they are mounted. Examples: electrical power, attitude control, telemetry, thermal control, and propulsion subsystems.

3.5 Vehicle. Any vehicle defined in this section may be termed expendable or recoverable, as appropriate.

3.5.1 Launch Vehicle. A launch vehicle is one or more of the lower stages of a flight vehicle capable of launching upper-stage vehicles and space vehicles, usually into a suborbital trajectory. A fairing to protect the space vehicle, and possibly the upper-stage vehicle, during the boost phase is typically considered to be part of the launch vehicle.

3.5.2 Upper-stage Vehicle. An upper-stage vehicle is one or more stages of a flight vehicle capable of injecting a space vehicle or vehicles into orbit from the suborbital trajectory that resulted from operation of a launch vehicle.

3.5.3 Space Experiment. A space experiment is usually part of the space vehicle payload and is therefore considered to be a lower level assembly of a space vehicle. However, a space experiment may be an integral part of a space vehicle, a payload that performs its mission while attached to a space vehicle, or even a payload that is carried by a host vehicle but performs some of its mission as a free-flyer. Whether complex space equipment is called a space experiment, a space instrument, or a space vehicle is discretionary and the nomenclature used should not affect the classification of the equipment or the requirements.

3.5.4 Space Vehicle. A space vehicle is an integrated set of subsystems and units capable of supporting an operational role in space. A space vehicle may be an orbiting vehicle, a major portion of an orbiting vehicle, or a payload which performs its mission while attached to a launch or upper-stage vehicle. The airborne support equipment (3.2.1), which is peculiar to programs utilizing a recoverable launch or upper-stage vehicle, is considered to be a part of the space vehicle.

3.5.5 Flight Vehicle. A flight vehicle is the combination of elements of the launch system that is flown; i.e., the launch vehicle(s), the upper-stage vehicle(s), and the space vehicle(s) to be sent to orbit.

3.6 System. A system is a composite of equipment, skills, and techniques capable of performing or supporting an operational role. A system includes all operational equipment, related facilities, material, software, services, and personnel required for its operation. A system is typically defined by the System Program Office or the procurement agency responsible for its acquisition.

3.7 Combined Systems. Combined systems are interconnected systems that are required for program level operations or operational tests. The combined systems of interest are typically the launch system and the on-orbit system.

3.7.1 Launch System. A launch system is the composite of equipment, skills, and techniques capable of launching and boosting one or more space vehicles into orbit. The launch system includes the flight vehicle and related facilities, ground equipment, material, software, procedures, services, and personnel required for their operation.

3.7.2 On-orbit System. An on-orbit system is the composite of equipment, skills, and techniques permitting on-orbit operation of the space vehicle(s). The on-orbit system includes the space vehicle(s), the command and control network, and related facilities, ground equipment, material, software, procedures, services, and personnel required for their operation.

3.8 Airborne Support Equipment (ASE). Airborne support equipment is the equipment installed in a flight vehicle to provide support functions and interfaces for the space or upper-stage vehicle during launch and orbital operations of the flight vehicle. This includes the hardware and software that provides the structural, electrical, electronic, and mechanical interfaces with the flight vehicle.

3.9 Critical Unit. A critical unit is one whose failure can affect the system operation sufficiently to cause the loss of the stated vehicle objectives, a partial loss of the mission, or is a unit whose proper performance is essential from a range safety standpoint.

3.10 Development Test Article. A development test article is a representative vehicle, subsystem, or unit dedicated to provide design and test information. The information may be used to check the validity of analytic techniques and assumed design parameters, to uncover unexpected response characteristics, to evaluate design changes, to determine interface compatibility, to prove qualification and acceptance test procedures and techniques, or to determine if the equipment meets its performance specifications. Development test articles include engineering test models, thermal models, and structural static and dynamic models.

3.11 Reusable Item. A reusable item is a unit, subsystem, or vehicle that is to be used for multiple missions. The service life (3.5.6) of reusable hardware includes all planned reuses, refurbishment, and retesting.

4. GENERAL REQUIREMENTS

4.1 OBJECTIVES OF VERIFICATION

This document outlines requirements for a verification process that shall be developed and used for launch vehicles, upper stage vehicles and space vehicles. During development of a launch vehicle, upper stage vehicle or space vehicle, verification is a fundamental process used to demonstrate that the system design meets applicable requirements and is capable of sustaining its operational role during the life cycle. Verification may be by analysis, test, inspection, demonstration, similarity, or a combination of these methods The verification objectives are primarily:

a. To qualify the design through an analysis, demonstration and test program that verifies that it meets performance and interface requirements when exposed to applicable environments.

b. To verify that the manufacturing process produces products that meet specified design requirements.

c. To ensure that flight hardware and software are free of workmanship and latent defects and are acceptable for flight.

d. To validate equipment and procedures necessary to support ground and flight operations.

e. To predict and confirm vehicle and system integrity and performance during all phases and that it completes its design life cycle including end-of-life performance requirements.

4.2 VERIFICATION ACTIVITIES

To reach the objectives stated in 4.1, verification activities shall be conceived and documented during the design and requirements definition phase. The requirements to be verified shall be analyzed taking into account design peculiarities, candidate solutions, qualification status of heritage units and subsystems, test and analysis methodologies, programmatic constraints, risk management process, cost, schedule, and allowable performance dispersions.

The verification activities are incrementally performed at different hardware and software assembly levels from units to the overall system, utilizing a suitable combination of verification methods. They apply to all project phases through the following main steps of the verification process:

a. Establish all system requirements and allocate to subtier levels.

b. Establish the service life cycle profile.

c. Derive the environmental design requirements.

d. Establish methods for design and process verification (Qualification) and product verification (Acceptance).

e. Prepare for verification activities: e.g.; prepare models, software and databases needed for analyses, prepare plans and procedures for tests, and develop tools and methodologies for inspections.

f. Conduct the verification activities.

g. Evaluate results to confirm verification.

Details of other verification activities required such as for software and for integrated system level requirements are too extensive for inclusion in this document. These omissions should not be interpreted to mean that these verification activities are less effective or less important.

4.3 Risk Management The risk management process is a life cycle process, which periodically reassesses the risk elements; to ensure the programs ability to meet it's cost, performance and schedule goals. The following guidelines shall apply:

a. Design margins shall be a Risk Management Decision,

b. Ensure that risk management decisions do not invalidate the verification objectives,

c. Because space systems / subsystems and launch vehicles are not managed to the same levels of risk. Space risk classification for either hardware class or program class or both should be agreed by the customer,

d. The risk classification of space programs, space vehicles and space experience are defined in MIL-HDBK-343.

5. DETAILED REQUIREMENTS

5.1 REQUIREMENTS ALLOCATION

The system requirements including performance requirements and external interfaces, shall be documented. The allocation of these system requirements to subtier hardware and software shall also be documented as subtier requirements. These system and subtier requirements establish the list of requirements that govern the design process and establish the need for subsequent verification of the hardware and software.

5.2 SERVICE LIFE CYCLE PROFILE

A projection of life cycle events, performance requirements, interfaces, configuration, and associated environmental conditions for an item (unit through vehicle level of assembly) from its completion in manufacturing, through assembly and integration into a flight system, prelaunch, launch and orbital operation shall be documented. The life cycle shall include the various phases an item may encounter in its life, such as: testing, handling, shipping, storage, launch, ascent and on-orbit operations. The combination of environments each item of equipment may encounter at each phase of its life cycle through end-of-life shall be determined. The following factors should be taken into account:

a. Exposure and duration, to launch vehicle, operational and natural environments.

b. Probability of environmental condition.

c. Configuration of the hardware and applicable software.

d. Interfaces with other equipment or software.

e. Other information which helps identify any condition which may influence performance.

5.3 ENVIRONMENTAL DESIGN REQUIREMENTS

Based on the service life cycle profile, the environmental design requirements shall be established for units, subsystems, vehicles and systems. The design requirements shall include sufficient design margin to assure that the capability of production (flight) articles, including manufacturing variables, exceeds the worst case service life environments. Consideration should be given to the following:

a. Probability of environmental occurrence.

b. Effect of combined environments (e.g., temperature, vibration, acceleration).

c. Mitigation of failure modes and effects including propagation and criticality.

d. Effect of equipment performance and criticality to mission success.

e. Experience gained from identical equipment similarly used.

f. Effects of planned acceptance and qualification testing.

5.4 VERIFICATION METHODS

The verification process provides management tools to coordinate the many individuals and activities involved in assuring a successful mission. Generally separate verification activities are implemented for the hardware, the software, and for the integrated system tests. The verification methods shall include the following either singly or in combination:

a. Analysis

b. Test

c. Inspection

d. Demonstration

e. Similarity

Most requirements are verified using a combination of methods such as analysis and test or analysis and inspection. The applicable level of assembly may be the unit level, the subsystem level, the vehicle level, or the integrated system level for prelaunch or on-orbit configurations. The verification activities may be summarized by the preparation of detailed analysis plans, hardware qualification plans and procedures, software verification plans and procedures, hardware acceptance test plans and procedures, and integrated test plans and procedures.

5.4.1 Analysis. Design analysis shall be performed, documented and correlated with test plans and results. Analysis shall include verification of unit, subsystem and system performance over expected life and operating environments.

5.4.2 Test. Testing is generally the method to verify that hardware items meet allocated system requirements during and following exposure to applicable environments. Testing includes an explicit measure of performance during exposure to an applicable environment, or it may be a measurement coupled with an analysis or other demonstration.

5.4.2.1 Hardware Qualification. Qualification tests, inspections and procedures shall be developed for hardware ranging from units through integrated systems. In general, the design and manufacturing requirements should be verified at the lowest level of assembly practicable. Requirements affected by integration into higher levels of assembly, such as external system interfaces, should be verified at the highest practical level of assembly. The establishment of effective and optimum test programs is a complex task which can best be accomplished by relying on prior experience. Appendix A provides guidance that may be helpful for defining hardware qualification test requirements for a particular program.

5.4.2.1.1 Qualification Techniques. In general, verification of design and the associated manufacturing processes shall rely on performance of tests except in cases where:

a. Proven documented analysis methods are available for simple designs which have large design margins,

b. A design requirement can readily be verified by inspection or demonstration,

c. Qualifications by similarity shall be shown by analysis and the criteria provided in MIL-HDBK-340A, VOL ll, paragraph 4.4.

5.4.2.1.2 Qualification Test Requirements. Qualification test requirements for design and manufacturing verification shall be developed for units, subsystems and vehicles to assure that products have established and proven design margins of safety. Qualification testing is always required, although, in certain instances, qualification may be established by showing that a product is identical or similar to an existing product that has been qualified using analysis and Qualification by Similarity criteria as discussed in MIL-HDBK-340A, VOL ll, paragraph 4.4. The qualification test program shall assure that a design performance and safety margin exists for any mechanical, electrical or environmental stimuli that the product may reasonable expect to encounter during its service life including:

a. Assembly, integration and acceptance test at the factory,

b. Transportation, pre-mission processing and checkout at the launch site,

c. The mission, including unique characteristics of the launch vehicle, space vehicle, space environment, and age related influences,

d. Other factors as shown in Table A-1.

5.4.2.1.3 Test for Risk Mitigation. In addition to analysis, tests shall be conducted to identify design deficiencies at the unit, subsystem or system level of assembly whenever the program identifies the need to mitigate any of the following product design and development risks:

a. Mitigate technical risk - the program is planning to use new hardware designs or new manufacturing processes that will produce a product that has unproven design margins and unverified performance characterics;

b. Mitigate cost and schedule risk - the program determines that they will not be able to recover, to the procuring agency's satisfaction, from identifying a design or process deficiency late in the product development process, i.e., the cost and schedule required to identify and implement corrective actions during the qualification program would adversely impact the program schedule or the overall cost to develop the product.

See Tables A1, A2 and A3 for factors relating tests to various development and manufacturing process risk.

5.4.2.2 Hardware Acceptance. Acceptance tests, inspections and procedures shall be developed for hardware ranging from units through integrated systems. The verification objective is to demonstrate that flight items are free of defects and integration errors and are ready for operational use. This phase also includes recertification in case the flight configuration is disassembled due to failure or repair actions. Appendix A provides guidance that is intended to help in developing hardware acceptance test requirements for a particular program.

5.4.2.2.1 Acceptance Test Requirements Acceptance test requirements for product verification shall be developed for units, subsystems and vehicles to assure that the delivered product does not have latent material deficiencies and workmanship defects when it is determined that:

a. The product design characteristics are such that there may be hidden or dormant defects that might otherwise surface during testing at higher levels of assembly or during mission operations,

b. Testing is the most appropriate method of surfacing those defects.

5.4.2.2.2 Acceptance Methods. One or a combination of methods shall be selected to assure that accumulated defects of manufacturing and any previous operation or testing have not degraded the capability of the product to perform as designed during the mission life cycle. The selected method(s) shall be capable of surfacing all infant mortality and workmanship induced failures at each level of assembly. In general verification by testing is most efficient when:

a. The design characteristics are sufficiently complex such that non-destructive inspection techniques (visual, x-ray, dye-penetrant, etc.) are not appropriate or cost effective, and other less costly methods are not appropriate or technically sufficient;

b. The product size and configuration is such that environmental test stresses can be effectively induced throughout the product, without concern for overstressing the product.

Programs must be able to prove that there is sufficient remaining useful life after verification testing such that the product can accomplish the mission. The least risk is incurred when this is done by qualification testing of a dedicated test article or when there is a strong and proven product heritage. The benefit that comes with product test verification outweighs the issue associated with proving that there is remaining useful life in a product.

5.4.2.2.3 Test for Risk Mitigation. Programs shall conduct tests to confirm specification performance and that defects were not introduced by assembling and integrating products in the field, or degraded by unanticipated interaction between those integrated elements, whenever the program identifies the need to mitigate any of the following risks:

a. Mitigate technical risk - the program cannot effectively acquire data at the next higher level of assembly. The program will not be able to prove, by testing at the next higher assembly level, that the integrated assembly is functioning as designed; or the program determines that a failure at the next higher level of assembly may cause damage to other product elements or cause injury to personnel;

b. Mitigate schedule risk - the program will not test the next assembly level in a timely manner. Identification of an assembly error or unfavorable interaction between elements at that later time would adversely impact program schedule;

c. Mitigate cost risk - detection of a failure at the next higher level of assembly would require extensive rework and retest to recover from such a failure.

See Tables A1, A2 and A4 for factors relating tests for various development and manufacturing process risks.

5.4.3 Inspection. The inspection method of verification is usually performed during manufacturing, qualification, acceptance, integration and prelaunch phases. It is used mainly to verify those requirements where physical characteristics (e.g. construction features, finish, identification marking and cleanliness) and interfaces are involved.

5.4.4 Demonstration. A demonstration typically involves the use of actual hardware or software with a simulator or in a simulated operational configuration. For example, validating the ignitor circuitry or the circuitry to a destruct charge on a flight vehicle can best be accomplished by demonstrating that a simulated charge can be fired, rather than an actual charge.

5.4.5 Similarity. Verification by similarity is used usually in combination with analysis to show that an article is similar to another article that has already been qualified to equivalent or more stringent criteria. This verification method consists of assessment and review of hardware configuration, hardware application and prior test data including a comparison of prior test levels with new specific requirements. Differences in configuration, application or test conditions usually require analyses and additional testing to complete verification by the method of similarity.

5.5 Integrated Test Plan. Each program must evaluate and determine the need for and the best test approach for each product level of assembly that the program identifies as being a candidate for verification by test. There are many factors to consider when establishing qualification and acceptance test requirements for a particular program. Table A-1 provides a listing of some of the more pertinent factors that should be considered. Table A-2 provides a summary of the causes and types of failures surfaced during testing of products in previous launch, upper stage and space vehicle programs.

Test requirements shall be established for design, performance and manufacturing verification (qualification) and for product verification (acceptance). A combination of test methods at levels of product assembly ranging from units through the assembled vehicle shall be selected to prove design margins, validate manufacturing processes and verify that products are free of latent defects. The selected methods shall be capable of identifying all marginal aspects of the design and of the manufacturing process. The test plan for a program should be designed to:

a. Identify and correct problems at the lowest level of assembly.

b. Prevent any problems from causing a failure in flight hardware at higher levels of assembly and with the highest assurance of no failure after launch.

5.6 Preparation for Verification Activities.

5.6.1 Preparation for Analysis. For those requirements where analysis is identified as the primary or supplementary method for verification, additional tools, models, software, or databases may be required. These items need to be developed, verified, and made available to meet the needs of the analysis. In some cases the analysis results provide an input to another verification method, such as a test. In those cases, the analysis needs to be scheduled such that the results are available when needed.

5.6.2 Preparation for Test Activities. The test activities and procedures shall be documented in sufficient detail to provide a framework for identifying and interrelating all of the individual tests and test procedures needed to complete the verification process. These activities and procedures shall as a minimum include the qualification (design verification) and acceptance (product verification) test requirements. A general description of each test planned, the conditions of the tests, and the pass-fail criteria shall be documented. The tests should be based upon a function-by-function mission analysis and any specified testing requirements. Test objectives shall be planned to verify compliance with the design and specified performance requirement of the items involved, including interfaces. The overall schedule of tests shall be prepared showing compatibility with program schedules including the availability of test articles, test facilities, special test equipment, and procedures.

5.6.3 Preparation for Inspections. Tools and methods shall be developed to conduct all required inspections. A general description of each planned inspection, and the pass-fail criteria shall be documented.

5.6.4 Preparation for Demonstrations. A general description of each planned demonstration and the pass-fail criteria shall be documented. The simulators, tools, and software needed for any demonstrations shall be developed and made available to meet the needs of the planned demonstrations.

5.6.5 Documentation for Verification by Similarity. Documentation that establishes the basis for verification by similarity shall be identified and reviewed for adequacy.

5.6.6 Process Improvement. In the course of a program, information may be acquired which can help to improve the efficiency and cost effectiveness of the process. The procedures shall indicate data retention and traceability provisions for use in periodically reexamining and revising the process. Since the number of articles for a given program is often small, the results from other similar programs may be considered before major changes are made, for example, adding or deleting a test. As a minimum, plans for verification process improvement shall include criteria that will trigger reexamination of the process.

5.7 Conduct Verification Activities The various verification activities shall be conducted with an accuracy necessary to assure their validity and that the pass-fail criteria have been met.

5.8 Evaluate Verification Results

An audit of all verification results with special attention given to omissions or changes in requirements shall be conducted prior to the launch readiness review.

6. NOTES

6.1 Shared Database

A key to improvement in the design, integration, and test process is the ability to provide product life cycle information to the various technical and management disciplines. Availability of product life cycle data will greatly enhance program performance goals in terms of product improvement, cost savings, and schedule optimization.

Product improvements, test process improvements, and associated cost benefits can only be fully realized if the necessary data are documented in an easily retrievable electronic format. This can best be accomplished by industry support of a common set of data with standardized formats.

The development and use of an industry-wide product life cycle database will reduce the costs of sharing data and provide a means for quantitative test process improvement. A minimum set of data using a common database format is required to accommodate these goals.

The Space Systems Engineering Database at the Aerospace Corporation is an enterprise wide relational information system suitable for management of project data. The SSED data model uses ISO 10303 Standard for Exchange of Product Model Data that provides complete, unambiguous, computer interpretable data for each constituent of a product throughout its life cycle (from conceptual to orbital operation).

6.2 Guidance Tables. Programs may use the programmatic factors listed in Table 1 when establishing testing requirements. Consideration of a test program also incorporates knowledge of the possible failure cause or type. Table 2 contains a comprehensive list of failure cause or type for the various units and subsystems comprising space hardware. Once failure mechanism is determined, the environmental qualification test listed in Table 3 provide means of detecting the defect. The primary acceptance test to precipitate failure mechanisms are given in Table 4.

TABLE 1

FACTORS TO CONSIDER WHEN ESTABLISHING TEST REQUIREMENTS

_ Criticality to mission

_ Sensitivity to environment

_ Severity of environment

_ Knowledge or uncertainty of environment

_ Environmental time profile

_ Similarity to previously qualified articles

_ Ability to analyze vs. design margins

_ Maturity of technology

_ Maturity of production line

_ Level of assembly vs. simulation, e.g. tubing and wiring vibration tested at higher levels of assembly

_ Product complexity

_ Cost of repair and retest for problems found at higher levels of assembly

_ Use of qualification articles for flight-alternative strategies

_ Benefits of dedicated qualification articles

-Fatigue life verification for repeated acceptance test of flight articles

-Available test article to evaluate upgrades/modifications

-Available testbed to evaluate mission anomalies

-Greater ability to prove design robustness

_ Simulation of mission environments

_ Prior experience with statistically significant sample of similar products and their performance variability

_ Training and experience of manufacturing, assembly integration and test personnel

_ Use of automated vs. operator performed manufacturing operations

_ Manufacturing process controls proven to produce defect free products of similar designs and complexity

	Type of Subsystem													
Failure Cause or Type	Electrical and Electronic	Antenna	MMA	Solar Array	Battery	Propulsion	Pressure Vessel or Component	Thermal Control	Optical	Structural	Tubing	Wiring and Connectors	Ordnance	Fluid
• Manufacturing Workmanship														
- Solder Balls/Splash	X											X		
- Solder Bridges	X			X								X		
- Excessive/Insufficient Solder	X	X		X								X		
- Poorly Wetted Solder	X	X		X								X		
- No Solder	X	X		X								X		
- Excessive Heat/Soldering	X	X		X								X		
- Undertorqued Screws	X	X	X			X			X	X				
- Contamination	X		X	X		X	X	X	X			X	X	X
- Loose Parts	X		X			X			X					
- Loose Connectors	X	X		X				X	X			X	X	X
- Excessive Staking	X			X										
- Abnormal Epoxy	X			X				X	X				X	
- Inadequate Bond	X	X		X				X						
- Cold Flow	X											X		
• Defective Parts														
- Pins Wrong Length	X											X		
- Bent Pins	X											X		
- Broken Part	X			X										
- Broken Wires	X			X				X				X		
- Wrong Part	X	X	X			X		X				X	X	X
• Defective Boards														
- Burrs	X													
- Fractured Traces	X													
- Poor Plating	X													
- Cracked Bonding	X													

	Type of Subsystem													
Failure Cause or Type	Electrical and Electronic	Antenna	MMA	Solar Array	Battery	Propulsion	Pressure Vessel or Component	Thermal Control	Optical	Structural	Tubing	Wiring and Connectors	Ordnance	Fluid
• Defective Wiring or Connectors														
- Inadequate Service Loop	X			X								X		
- Cracked or Abraded Insulation	X	X		X	X							X		
- Pinched Wires	X			X								X		
- Wrong Connector	X	X			X							X		
- Poor Routing	X	X										X		
- Wrong Wire Size	X	X		X	X							X		
- Miswiring	X	X		X	X							X		
- Poor Ground	X				X							X		
• Defective Seals														
- Gaskets & O-Rings	X				X	X	X		X		X			X
- Soldering/Welding	X				X	X	X		X		X			X
- Misaligned Seals	X	X	X			X	X		X		X			X
• Handling														
- Excessive	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Mishaps	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Incorrect Equipment	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Operator Error	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Failure Cause or Type	Type of Subsystem													
	Electrical and Electronic	Antenna	MMA	Solar Array	Battery	Propulsion	Pressure Vessel or Component	Thermal Control	Optical	Structural	Tubing	Wiring and Connectors	Ordnance	Fluid
• Inadequate Design														
- Precision Surfaces/Alignment			X			X		X	X					X
- Insufficient Structural Margin	X	X	X	X	X	X	X		X	X	X			X
- Poor Thermal Design	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Wrong Material	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Insufficient Fatigue Life	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Tiedown of Tubing/Wiring	X	X		X		X		X	X		X	X		X
- Inadequate Environmental Criteria	X	X		X	X	X		X	X	X			X	X
- Insufficient Life	X		X	X	X	X		X		X			X	X
- Wrong Lubricants			X											
- Incompatible Materials	X		X	X		X			X	X				X
- Insufficient Insulation/Isolation	X	X							X			X		
- Insufficient Spacing/Clearance	X	X	X						X	X				
- Tolerance Buildup	X	X	X						X	X				X
- Cold Welding			X											
• Electromagnetic Interference														
- Inadequate Grounding	X	X		X	X	X	X	X		X		X	X	
- Insufficient Shielding	X	X										X	X	
- Defective RF Seals	X	X										X	X	
- High Resistance	X	X										X	X	
- No RF Ground	X	X										X	X	

Failure Cause or Type	Type of Subsystem													
	Electrical and Electronic	Antenna	MMA	Solar Array	Battery	Propulsion	Pressure Vessel or Component	Thermal Control	Optical	Structural	Tubing	Wiring and Connectors	Ordnance	Fluid
• Testing and Test Procedures														
- Failure To Follow Procedures	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Wrong or No Procedure	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Incomplete Procedure	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Defective Test Equipment	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Test Equipment Failure/Anomaly	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Wrong Fixtures	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Over/Under Torqued Bolts	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Inadequate Instrumentation	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Operator Error	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Excessive Testing	X	X	X	X	X	X	X	X	X	X	X	X	X	X
• Repair, Rework and Retest														
- Ad Hoc Procedures	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Excessive Rework	X			X			X					X		
- Excessive Retest	X	X	X	X	X	X			X	X				
- Excessive Heat/Soldering /Welding	X			X		X						X		X
- Collateral Damage	X		X	X		X								
• Inexperienced Personnel														
- Manufacturing	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Handling	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Assembly	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Integration	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Testing	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Potential Failure Mechanism	Primary Qualification Tests to Identify Failure Mechanism									
	Functional	Vibration or Acoustic	Shock	Thermal Cycle	Thermal Vacuum	Acceleration	Leakage	Proof and Burst Pressure	E M E	Life
* Mounting broken/loose	X	X	X			X			X	
* Broken Part		X	X	X	X					
* Shorted Part	X	X			X				X	
* Defective Part	X	X		X	X				X	
* Defective Board	X	X		X	X				X	
* Broken/Shorted/Pinched Wires	X	X		X	X				X	
* Defective/Broken Solder	X	X		X	X				X	
* Contamination		X	X	X	X					
* Leaky Gaskets/Seals/RF					X		X		X	
* Incorrect Wiring/Routing Design	X	X							X	
* Relay/Switch Chatter		X	X						X	
* Adjacent Curciut Board Contact		X	X						X	
* Premature Wearout		X								X
* Electromagnetic Interference									X	
* Insufficient Design Margin	X					X		X	X	
* Corona Discharge/Arcing					X					
* Inadequate Tiedown of Tubing/Wiring		X				X			X	
* Inadequate Thermal Design				X	X					
* Brittle Material Failure			X							
* Inadequate Fatigue Life		X		X						X

Potential Failure Mechanism	Primary Acceptance Tests To Precipitate Failure Mechanism									
	Functional	Wear-in	Vibration or Acoustic	Shock	Thermal Cycle	Thermal Vacuum	Leakage	Proof Pressure	Proof Load	E M E
* Parameter Drift	X		X		X	X				
* Electrical Intermittants			X	X	X	X				X
- Solder Joints										
- Loose Wires										
- Connectors										X
* Latent Defective Parts	X		X	X	X	X				
* Parts Shorting			X							
* Chafed/Pinched Wires			X							X
* Adjacent Circuit Board Contact			X	X						
* Parameters Changing Due to Deflections			X		X	X				X
* Loose Hardware			X	X						X
* Moving Parts Binding		X				X				
* Leaky Gaskets/Seals					X	X	X			X
* Lubricants Changing Characteristics		X			X	X				
* Material Embrittlement				X	X	X				
* Outgassing/Contamination			X	X		X				
* Degradation of Electrical or Thermal Insulation						X				X
* Corona Discharge/Arcing						X				X
* Defective Pressure Vessels								X		
* Structural Defects									X	
* Defective Wiring	X									X
* Defective Tubing							X			

CONCLUDING MATERIAL

Custodian:
Air Force - 19

Preparing Activity:
Air Force - 19
(Project 1810-9806)

Review activities:
Air Force - 33
NASA - NA