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SMC Standard SMC-S-016
5 September 2014

Supersedes:
SMC-S-016 (2008)

Air Force Space Command

SPACE AND MISSILE SYSTEMS CENTER STANDARD

TEST REQUIREMENTS FOR LAUNCH, UPPER-STAGE AND SPACE VEHICLES

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FOREWORD

1. This standard defines the Government's requirements and expectations for contractor performance in defense system acquisitions and technology developments.

2. This revised SMC standard comprises the text of The Aerospace Corporation report number TR-RS-2014-00016, entitled *Test Requirements for Launch, Upper-Stage, and Space Vehicles (Supersedes TR-2004(8583)-1 REV A)* and dated June 25, 2014. Changes in this revision are documented in the revision change history within this standard.

3. Beneficial comments (recommendations, changes, additions, deletions, etc.) and any pertinent data that may be of use in improving this standard should be forwarded to the following addressee using the Standardization Document Improvement Proposal appearing at the end of this document or by letter:

Division Chief, SMC/ENE
SPACE AND MISSILE SYSTEMS CENTER
Air Force Space Command
483 N. Aviation Blvd.
El Segundo, CA 90245

4. This standard has been approved for use on all Space and Missile Systems Center/Air Force Program Executive Office - Space development, acquisition, and sustainment contracts.

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SMC Director of Engineering

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Change History

Description of Change	Effective Date
• Inserted clarifications in Chapter 4, General Requirements • Revised Tables 6.3-1, -2, Unit qualification, protoqualification and acceptance test requirements for units • Clarified “Evaluation Required” (ER) requirements • Revised Tables 7.3-1, -2, Subsystem qualification, protoqualification and acceptance test requirements • Revised Table 8.3-2, Vehicle acceptance test requirements • Added text in Chapter 4 General Requirements clarifying requirements for, and use of, the flightproof test method • Added criteria for waiver of proof testing on composite structures, Chapter 6 • Added random vibration reduction of minimum workmanship guidelines for units weighing >50 lb, Appendix B • Clarified criteria for unit shock testing, Chapter 6 • Reduced acoustic test spectrum minimums to reflect EELV flight experience, Appendix B • Decreased unit thermal cycling requirement on cycles from 27 to 20, Chapter 6 • Added Option 1, qualification using engineering qualification models (EQMs) • Added Option 2, qualification/protoqualification by similarity (QBS) • Added Option 3, alternate test sequence for vehicle level tests • Added Option 4, modification of unit level random vibration protoqualification margins and durations • Added Option 5, vehicle level flightproof acoustic testing • Added Option 6, Conditions for deletion of the vehicle level acoustic test • Added Option 7, two phase acoustic/vibration qualification/protoqualification • Added Option 8, Unit thermal cycle acceptance credit for pre-conditioning at the board/slice level • Added Option 9, two tier unit thermal testing • Added allowable notching methodology for vibration tests	June 25, 2014

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Contents

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Figures

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Tables

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1. Scope

1.1 Purpose

This standard establishes the environmental testing requirements for launch vehicles, upper-stage vehicles, space vehicles, and their subsystems and units. In addition, a uniform set of definitions of related terms is established.

1.2 Application

This standard is applicable to the procurement of space system hardware as a compliance document for the establishment of baseline test requirements. The test requirements herein focus on design verification and the identification of latent defects to help ensure a high level of confidence in achieving successful space missions.

1.3 Baseline Requirements

This standard establishes the qualification test strategy as the baseline set of test requirements. This strategy consists of testing dedicated hardware to qualification levels to verify design, followed by acceptance testing of flight hardware to screen workmanship defects and demonstrate performance.

1.4 Tailoring

It is intended that these test requirements be tailored to each specific program after considering the design complexity, design margins, vulnerabilities, technology state of the art, in-process controls, mission criticality, life cycle cost, number of vehicles involved, prior usage, and acceptable risk. However, the tailored requirements shall achieve a level of verification consistent with the customer's risk posture. During the tailoring process, rationale for each tailored requirement shall be documented. If the baseline requirements in this standard are not tailored by the contract, they stand as written.

1.5 Test Categories

The tests discussed herein are categorized and defined as follows:

a. **Development Tests.** Tests conducted on representative articles to characterize engineering parameters, gather data, and validate the design approach.

b. **Qualification Tests.** Tests conducted to demonstrate satisfaction of design requirements including margin and product robustness for designs that have no demonstrated history. A full qualification validates the planned acceptance program, in-process stress screens, and retest environmental stresses resulting from failure and rework. In general, qualification hardware is not flown. Qualification hardware selected for use as flight hardware shall be evaluated and refurbished as necessary to show that the integrity of the hardware is preserved and that adequate margin remains to survive the imposed environments and provide useful life on orbit. For launch vehicles, life includes ground test, launch, ascent and final maneu-

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vers. Life for on-orbit systems includes ground test, launch, and ascent followed by on-orbit life.

c. **Protoqualification Tests.** Tests conducted to demonstrate satisfaction of design requirements using reduced amplitude and duration margins. These types of tests are generally selected for designs having limited production where test units will be used for flight. The protoqualification test program is supplemented with analyses as well as development and other tests to demonstrate margin and life for flight of the protoqualification test hardware. Protoqualification tests shall validate the planned acceptance program.

d. **Acceptance Tests.** Vehicle, subsystem, and unit tests conducted to detect workmanship defects, demonstrate specified functional and performance requirements, and that the hardware is acceptable for delivery.

e. **Prelaunch Validation Tests.** Prelaunch validation tests conducted at the launch base to demonstrate readiness of the hardware, software, personnel procedures, and mission interfaces to support launch and the program mission.

f. **Post-launch Validation Tests.** Tests performed following launch to demonstrate performance, interface compatibility, calibration, and the ability to meet mission requirements.

1.6 Exclusions for Additional Environments

Environments other than those specified in this standard can be sufficiently stressful as to warrant special analysis and testing. These include environments such as nuclear and electromagnetic radiation, natural space environment, and lightning.

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2. Reference Documents

2.1 Applicable Documents

The following documents of the issue in effect on the date of invitation for bids or request for proposal form a part of this standard to the extent referenced herein.

1.	MIL-STD-810G	Environmental Engineering Considerations and Laboratory Tests
2.	MIL-STD-1833 (USAF)	Test Requirements for Ground Equipment and Associated Computer Software Supporting Space Vehicles (SMC-S-024, Test Requirements for Ground Systems)
3.	AFSPCMAN 91-710	Range Safety User Requirements Manual
4.	AIAA S-080-1998	Metallic Pressure Vessels, Pressurized Structures, and Pressure Components
5.	AIAA S-081A-2006	Composite Overwrapped Pressure Vessels (COPVs)
6.	AIAA S-110-2005	Structures, Structural Components, and Structural Assemblies
7.	AIAA S-114-2005	Moving Mechanical Assemblies for Space and Launch Vehicles
8.	AIAA S-113-2005	Criteria for Explosive Systems and Devices on Space and Launch Vehicles
9.	AIAA S-111-2005	Qualification and Quality Requirements for Space Solar Cells
10.	AIAA S-112-2005	Qualification and Quality Requirements for Space Solar Panels
11.	TOR-2003(8583)-2894	Space Systems-Structures Design and Test Requirements
12.	TOR-2007(8583)-6889	Reliability Program for Space Systems (SMC-S-013, Reliability Program for Space Systems)
13.	TOR-2005(8583)-3859	Quality Assurance Requirements for Space and Launch Vehicles (SMC-S-003, Quality Assurance for Launch Vehicles)
14.	TOR-2013(3909)-1	Objective Reuse of Heritage Products

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15.	TOR-2010(8591-20	Flight Unit Qualification Guidelines
16.	TOR-2011(8591)-2 V1	Space Vehicle Test and Evaluation Handbook, 2nd Edition
17.	TOR-2003(8583)-2886	Independent Structural Load Analyses of Integrated Spacecraft/Launch Vehicle Systems (SMC-S-004, Independent Structural Loads Analysis)
18.	TOR-2003(8583)-2896	Space Systems-Flight Pressurized Systems (SMC-S-005, Space Systems-Flight Pressurized Systems)
19.	TOR-2003(8583)-2895, Rev 1	Solid Rocket Motor Case Design and Test Requirements (SMC-S-006, Solid Rocket Motor Case Design and Test Requirements)
20.	TOR-2004(8583)-5, Rev 1	Space Battery Standard (SMC-S-007, Space Battery)
21.	TOR-2005(8583)-1	Electromagnetic Compatibility Requirements for Space Equipment and Systems (SMC-S-008, Electromagnetic Compatibility Requirements for Space Equipment and Systems
22.	TOR-2006(8583)-5235, Rev A	Parts, Materials, and Processes Control Program for Space and Launch Vehicles (SMC-S-009, Parts, Materials, and Processes Control Program for Space and Launch Vehicles)
23.	TOR-2006(8583)-5236	Technical Requirements for Electronic Parts, Materials, and Processes Used in Space and Launch Vehicles (SMC-S-010, Parts, Materials, and Processes Used for Space and Launch Vehicles)
24.	TOR-2004(3909)-3537, Rev B	Software Development Standard for Space Systems (SMC-S-012, Software Development for Space Systems)
25.	TOR-2008(8583)-8492, Rev A	Technical Requirements for Wiring Harness Space Vehicle, Design and Testing, General Specification (SMC-S-020, Technical Requirements for Wiring Harness, Space Vehicle)
26.	TOR-2005(8583)-1	Lithium Ion Battery Standards for Spacecraft Applications (SMC-S-017, Lithium-Ion Battery for Spacecraft Applications)
27.	TOR-2007(8583)-2	Acquisition Standard for Lithium-Ion-Based Launch Vehicle Batteries (SMC-S-018, Lithium-Ion Battery for Launch Vehicle Applications)

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2.2 Guidance Documents

28. MIL-HDBK-340A, Vol. II	Test Requirements for Launch, Upper-Stage and Space Vehicles: Application Guidelines
29. DNA-TR-84-140	Satellite Hardness and Survivability; Testing Rationale for Electronic Upset and Burnout Effects
30. JANNAF-GL-2012-01-RO	Test and Evaluation Guidelines for Liquid Rocket Engines
31. TOR-2013(3213)-6	Acoustic Testing on Production Space Vehicle (The Value of the Test and Deletion Conditions)
32. TOR-2006(8506)-4494	Systems Engineering Handbook, Chapter 20, Manufacturing and Production

Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from Department of Defense Single Supply Point at http://quicksearch.dla.mil.

AIAA standards must be procured directly from the owner.

Aerospace TORs are available from the Aerospace Corporate Library. Requests, on official letter-head, should be addressed to:

The Aerospace Corporate Library
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3. Definitions

3.1 Assembly
An integrated set of subassemblies and/or units that comprise a well-defined part of a subsystem.

3.2 Ambient Environment
The ambient environment for a ground test is defined as temperature of 23 ± 3°C (73 ± 5°F), atmospheric pressure of 101 +2/–23 kPa (29.9 +0.6/–6.8 in Hg), and relative humidity of 50 ± 20%.

3.3 Battery

A battery is an assembly of battery cells or modules, electrically connected to provide the desired voltage and current capability. The battery, encased in a restraining structure, may also include electrical bypass devices, charge control electronics, heaters, temperature sensors, thermal switches, and thermal control elements.

3.4 Burst Factor
The burst factor is a multiplying factor applied to the maximum expected operating pressure to obtain the design burst pressure. Burst factor is synonymous with ultimate pressure factor.

3.5 Computer Program
A computer program is a combination of computer instructions and data that enables computer hardware to perform computational or control functions.

3.6 Design Burst Pressure
The design burst pressure is a test pressure that pressurized components must withstand without rupture in their applicable operating environments

3.7 Design Factor of Safety
The design factor of safety is a multiplying factor used in design analysis to account for uncertainties such as mechanical tolerances, analysis limitations, and manufacturing variability. The design factor of safety is often called the design safety factor, factor of safety, or, simply, the safety factor. In general, two types of design factors of safety are specified: design yield factor of safety and design ultimate factor of safety.

3.8 Design Ultimate Load
The design ultimate load is a load, or combination of loads, that the structure must withstand without rupture or collapse in the applicable operating environments. It is equal to the product of the limit load and the design ultimate factor of safety.

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3.9 Design Yield Load

The design yield load is a load, or combination of loads, that a structure must withstand without detrimental deformation in the applicable operating environments. It is equal to the product of the limit load and the design yield factor of safety.

3.10 Development Test Article

A development test article is a vehicle, subsystem, or unit dedicated to provide design requirement information. The information may be used to check the validity of analytic techniques and assumed design parameters, uncover unexpected response characteristics, evaluate design changes, determine interface compatibility, demonstrate qualification and acceptance test procedures and techniques, and to determine whether the equipment meets its performance specifications. Development test articles are not intended for flight.

3.11 Electromagnetic Compatibility (EMC) Margin

EMC margin is the ratio of the susceptibility of the interface to the emissions present at the interface from all sources. The EMC margin is to be incorporated into the test levels. Qualification margins of 6 dB are acceptable if the combined test uncertainty, part variation, part degradation at end-of-life, and workmanship variation are less than 6 dB. Electro-explosive devices and bridge wires have a 20 dB margin requirement below the DC no-fire value and a 6 dB margin requirement below the RF no-fire value.

3.12 Effective Duration for Acoustics and Random Vibration

To establish basic test requirements, the effective duration in flight for the liftoff and the ascent acoustic and random environments (max-q and transonic) is taken to be 15 sec to be used in conjunction with the MPE spectrum (see 3.25 and 3.26). For other sources, the effective duration is the time within which the overall excitation is within 6 dB of the maximum overall level. Damage-based analysis methods, such as described in B.1.5, can be used to identify an environment duration and the corresponding spectrum.

3.13 Explosive Ordnance Device

An explosive ordnance device is a device that contains, or is operated by, explosives. A cartridge-actuated device (one type of explosive ordnance device) is a mechanism that employs the energy produced by an explosive charge to perform or initiate a mechanical action.

3.14 Firmware

Firmware is the combination of a hardware device (including both reprogrammable and non-reprogrammable devices) and computer instructions and/or computer data that reside as read-only software on the hardware device.

3.15 Flight Vehicle

The flight vehicle, often referred to as the space segment, is the combined launch system [i.e., the launch vehicle(s), the upper-stage vehicle(s), and the space vehicle(s)].

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3.16 Flight Critical Item

A flight-critical item (hardware or software) is one whose failure can affect the system operations sufficiently to cause the loss of the ability to perform the baseline mission or is essential from a range safety standpoint.

3.17 Functional Testing

Functional testing is performed to assess the operability of the item under test within the boundaries established by design requirements. For example, the test screens for malfunctions, failure to execute, sequence of action, interruption in continuous function, or failure in cause and response. Functional tests are conducted in the correct environment. All command functions should be exercised during functional testing.

3.18 Hot Operational Soak

Hot operational soak is the continuous operating time at hot test temperature on each thermal cycle. It begins following the hot start on the first and last cycle (Figures 6.3.8-1 and 6.3.8-3) or at the beginning of the thermal stabilization on intermediate cycles (Figure 6.3.8-2).

3.19 Launch System

A launch system is the composite of elements consisting 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.

3.20 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 an orbital trajectory. A fairing to protect the space vehicle during the boost phase is typically considered part of the launch vehicle.

3.21 Limit Load

Limit load is the highest predicted load or combination of loads that a structure or a component in a structural assembly may experience during its service life in association with the applicable operating environments. The corresponding stress is called limit stress.

3.22 Maximum and Minimum Model Temperature Predictions

The maximum and minimum model temperature predictions are the hottest and coldest temperatures predicted from thermal models using applicable effects of worst-case combinations of equipment operation, internal heating, vehicle orientation, solar radiation, eclipse conditions, ascent heating, descent heating, and degradation of thermal surfaces during the service life (Figure 6.3.8-4).

3.23 Maximum and Minimum Predicted Temperatures

The maximum and minimum predicted temperatures (MPT) are the highest and lowest temperatures that an item can experience during its service life, including all test and operational modes. The MPT are established by adding thermal uncertainty margins to the maximum and minimum model temperature predictions (Figure 6.3.8-4).

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3.24 Maximum Expected Operating Pressure (MEOP)

The MEOP is the highest pressure that pressurized hardware is expected to sustain during its service life and retain its functionality. Included are the effects of applicable operating environments, maximum ullage pressure, fluid head due to vehicle quasi-steady and dynamic accelerations, water hammer, slosh, pressure transients and oscillations, temperature, and operating variability of regulators or relief valves.

3.25 Maximum Predicted Acceleration

The maximum predicted acceleration, defined for analysis and test purposes, is the highest acceleration determined from the combined effects of quasi-steady acceleration, vibration and acoustics, and transient flight events (liftoff, engine ignitions and shutdowns, flight through transonic and maximum dynamic pressure, gust, and vehicle separation). Maximum accelerations are predicted for each of three mutually perpendicular axes in both positive and negative directions. When a statistical estimate is applicable, the maximum predicted acceleration is at least the acceleration that is not expected to be exceeded on 99% of flights, estimated with 90% confidence, or P99/90 (B.1.1).

3.26 Maximum Predicted Environment (MPE) for Acoustics

The MPE is statistically the P95/50 acoustic spectrum subject to a constraint discussed in B.1.1. The acoustic MPE is expressed as a 1/3-octave-band pressure spectrum in dB (Reference 20 μPa) for center frequencies spanning 31 to 10,000 Hz. For the liftoff and ascent acoustic environments during a flight, the spectra for each of a series of 1-second durations, overlapped by 50%, are enveloped to produce the maxi-max flight spectrum. The resulting P95/50 spectrum is 4.9 dB above the log-mean maxi-max spectrum from a series of flights or tests (B.1.1).

3.27 Maximum Predicted Environment (MPE) for Random Vibration

The MPE is statistically the P95/50 random vibration spectrum, subject to a constraint discussed in B.1.1. The random vibration MPE is expressed as a spectral density in g^2/Hz (commonly, termed the auto spectral density, ASD, or power spectral density, PSD) calculated at intervals no greater than 1/6 octave over the frequency range of at least 20 to 2000 Hz. For the liftoff and ascent acoustic environments during a flight, the spectra for each of a series of 1-second times, overlapped by 50%, are enveloped to produce the so-called maxi-max flight spectrum. Below 40 Hz, the resolution bandwidth need not be less than 5 Hz. The resulting P95/50 spectrum is 4.9 dB above the log-mean maxi-max spectrum from a series of flights or tests (B.1.1).

3.28 Maximum Predicted Environment (MPE) for Shock

The MPE is statistically the P95/50 shock spectrum, but no less than 4.9 dB above the log mean spectrum (see B.1.1). The shock MPE is expressed as a shock response spectrum (SRS) in units of acceleration (g). At each frequency, the shock response spectrum value is the maximum acceleration response induced by the shock in a single-degree-of-freedom system having a specified natural frequency and amplification, Q. Other methods of characterizing the shock environment, in addition to the SRS, may be used. Shock transients result from the sudden application or release of loads associated with deployment, separation, impact, and release events. Such events often employ explosive ordnance devices, resulting in a so-called pyroshock environment, characterized by a high-frequency acceleration transient that typically decays within 20 milliseconds. For such transients, the shock response spectrum is based on a Q of 10 and spans the range from at least 100 Hz to 10,000 Hz at

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intervals no greater than 1/6 octave. If shock isolators are used and have resonances below 100 Hz, then the range starts below the isolation resonance frequency. For a particular shock event, the P95/50 shock response spectrum is 4.9 dB above the log-mean shock response spectrum (B.1.1). The shock MPE is the envelope of the MPE for all shock events.

3.29 Maximum Predicted Environment (MPE) for Sinusoidal Vibration

The sine MPE is the basis for acceptance-level sinusoidal testing. The MPE is statistically the P95/50 sinusoidal vibration spectrum, subject to a constraint discussed in B.1.1. The MPE is expressed as the amplitude of sinusoidal acceleration, in units of g, over a frequency range of potentially significant severity as determined by development testing. Typically, a frequency sweep rate in octaves per minute is specified for a test. The sinusoidal vibration may be due to periodic excitations stemming from an instability (such as pogo, flutter, combustion) or to those due to rotating machinery. Significant sinusoidal excitations may also occur during transportation, typically in the frequency range below 200 Hz.

3.30 Moving Mechanical Assembly (MMA)

A moving mechanical assembly is a mechanical or electromechanical device that controls the movement of one mechanical element of a vehicle relative to another. Examples are gimbals, actuators, despin mechanisms, separation mechanisms, deployment mechanisms, release devices, valves, pumps, motors, latches, clutches, springs, dampers, and bearings.

3.31 Multipaction

Multipaction is a form of RF voltage breakdown in a vacuum where the electrons impact the electrodes producing more electrons in resonance, resulting in an electrical short.

3.32 Multi-Unit Module (MUM)

A multi-unit module is a testable functional item that is viewed as a complete and separate entity for purposes of manufacturing, maintenance, and record keeping. Examples: multi-functional box or module containing boards/slices with a common motherboard or output/input interface. A MUM is testable as a configured item against its own performance. It contains families of units, slices, or subassemblies where all of the components may be individually qualified and accepted and meet, at a minimum, the unit test requirements presented in this document (Tables 6.3-1 and 6.3-2).

3.33 On-Orbit System

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.

3.34 Operational Modes

The operational modes for a unit, assembly, subsystem, or system are operational configurations or conditions that can occur during its service life. Examples include battery charging conditions, command mode, readout mode, attitude control mode, redundancy management mode, safe mode, and spinning or despun condition.

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3.35 Part

A part is a single piece, or two or more joined pieces, that is not normally subject to disassembly without destruction or impairment of the design use. Examples are resistors, integrated circuits, relays, and roller bearings.

3.36 Performance Testing

Testing conducted to demonstrate measured electrical, optical, and mechanical operation to specification requirements before, during, and after satisfying environmental test requirements. Performance testing demonstrates design margins and specification compliance for all pathways and modes within the range of requirements.

3.37 Pressure Component

A pressure component is a unit in a pressurized subsystem that is designed primarily to sustain the acting pressure; excludes pressure vessels, special pressurized equipment (3.38), and pressurized structure (see 3.39). Examples are propulsion components such as propellant lines and tubes, fittings, valves, bellows, hoses, regulators, pumps, filters, and accumulators.

3.38 Pressure Vessel

A pressure vessel is a container whose primary purpose is to store pressurized fluids, and has one or more of the following attributes:

a. Contains stored energy of 19,310 Joules (14,240 ft-lb) or greater, based on adiabatic expansion of a perfect gas;

b. Contains a gas or liquid that would endanger personnel or equipment or create a mishap if released; or

c. May experience a MEOP greater than 690 kPa (100 psi).

Special pressurized equipment, such as batteries, sealed containers, heat pipes, and cryostats are not included.

3.39 Pressurized Structure

A pressurized structure is a structure designed to sustain both pressure and vehicle structural loads. A main propellant tank of a launch vehicle is a typical example.

3.40 Pressurized Subsystem

A pressurized subsystem consists of pressure vessels or pressurized structures, or both, and pressure components. Electrical or other control units required for subsystem operation are not included.

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3.41 Proof Factor

The proof factor is a multiplying factor applied to the limit load, or maximum expected operating pressure, to obtain the proof load or proof pressure for use in a proof test.

3.42 Proof Test

A static load or pressure test performed as an acceptance workmanship screen to prove the structural integrity of a unit or assembly. The proof test gives evidence of satisfactory workmanship and material quality by requiring the absence of failure or detrimental deformation. The proof test load and/or pressure compensates for the difference in material properties between test and design temperature and humidity, if applicable.

3.43 Reusable Item

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

3.44 Service Life

The service life of an item starts at the completion of fabrication and continues through all acceptance testing, handling, storage, transportation, prelaunch testing, all phases of launch, orbital operations, disposal, reentry or recovery from orbit, refurbishment, retesting, and reuse that may be required or specified.

3.45 Significant Shock Event

A significant shock event is one that produces a shock MPE within 6 dB of the envelope of shock MPEs from all shock events.

3.46 Simulator

A simulator is an electrical, mechanical, or structural unit or part used to validate flight interfaces in lieu of available flight hardware on one side of the interface.

3.47 Software

Software consists of computer programs and/or data. This includes software residing within firmware (see 3.14).

3.48 Software Item

A software item is an aggregation of software, such as a computer program or data that satisfies an end use function. Software items are so designated for purposes of specification, qualification, testing, configuration management, and other purposes.

3.49 Software Unit

A software unit is an element in the design of software, for example, a major subdivision of a software item, a component of that subdivision, a class, object, module, function, routine, or data. A software unit is not the same as a “Unit,” defined in 3.63.

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3.50 Space Vehicle

A space vehicle is an integrated set of subsystems and units, including their software, capable of supporting a specified mission. It can also be called a satellite or spacecraft and includes the integrated bus and payloads.

3.51 Statistical Estimates of Vibration, Acoustic, and Shock Environments

Qualification and acceptance tests for vibration, acoustic, and shock environments are based upon statistically expected spectral levels. The level of the extreme expected environment used for qualification testing is that level not exceeded on at least 99% of flights, and estimated with 90% confidence (P99/90 level). The level of the maximum expected environment used for acceptance testing is that not exceeded on at least 95% of flights, and estimated with 50% confidence (P95/50 level). These statistical estimates are made assuming a lognormal flight-to-flight variability having a standard deviation of 3 dB, unless a different assumption can be justified. As a result, the P95/50 level estimate is 4.9 dB above the estimated mean (namely, the average of the logarithmic values of the spectral levels of data from all available flights). When data from N flights are used for the estimate, the P99/90 estimate in dB is $2.0 + 3.9/N^{1/2}$ above the P95/50 estimate. When data from only one flight are available, those data are assumed to represent the mean, and so the P95/50 is 4.9 dB higher and the P99/90 level is 6 dB higher than the P95/50 level. When ground testing produces the realistic flight environment (e.g., engine operation or activation of explosive ordnance), the statistical distribution can be determined using the test data, provided data from a sufficient number of tests are available (B.1.1).

3.52 Structural Component

A mechanical unit is considered a structural component if it sustains load and/or pressure or maintains alignment.

3.53 Subassembly

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

3.54 Subsystem

A subsystem is an assembly of functionally related units, including any associated software. 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: structure, electrical power, attitude control, telemetry, thermal control, and propulsion subsystems, spacecraft payloads, and instruments.

3.55 Survival Temperatures

Survival temperatures are the cold and hot temperatures a unit is expected to survive. Survival temperature limits are specified as operational and/or non-operational. For an operational survival limit, unit survival is the demonstration that the unit can operate at the survival limit. Although the unit does not need to meet performance to specification, it cannot show any performance degradation when the unit is returned to the operational or acceptance temperature range. For a non-operational survival limit, unit survival is the demonstration that the unit can be taken to the survival limit with the unit off and show no performance degradation when the unit is returned to the functional or performance temperature range.

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3.56 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.

3.57 Temperature Stabilization

Temperature stabilization in a thermal test is achieved when the controlling temperature location on the test article is within the allowed test tolerance at the specified test temperature and the temperature rate of change is less than a specified value.

3.58 Test Discrepancy

A test discrepancy is any anomalous or unexpected condition encountered during a test process. Test discrepancies include those associated with performance, premature operation, and failure to operate.

3.59 Test Item Failure

A failure of a test item is defined as a test discrepancy that is due to a design, workmanship, process, or any quality deficiency in the item being tested. Any test discrepancy is considered a failure of the test item unless it can be determined to have been due to an unrelated cause.

3.60 Thermal Dwell

Thermal dwell of a unit at the hot or cold temperature extreme is the time required to ensure that internal parts and subassemblies have achieved thermal equilibrium. Thermal dwell begins at the onset of temperature stabilization and is followed by performance testing.

3.61 Thermal Soak

Thermal soak consists of the total time that a test article is continuously maintained within the allowed tolerance of the specified test temperature. It begins at the onset of thermal stabilization and concludes at the end of performance testing.

3.62 Thermal Uncertainty Margin

The thermal uncertainty margin is included in the thermal analysis of units, subsystems, and space vehicles to account for uncertainties in modeling parameters such as complicated view factors, surface properties, contamination, radiation environments, joint conduction, and inadequate ground simulation. For units that have only passive thermal control, the thermal uncertainty margin is a temperature added to analytic thermal model predictions. For units with active thermal control, the thermal uncertainty margin is a control authority (Figure 6.3.8-4).

3.63 Unit

A unit is a functional item (hardware and, if applicable, software) that is viewed as a complete and separate entity for purposes of manufacturing, maintenance, record keeping and environmental testing. Examples: hydraulic actuator, valve, battery, and transmitter.

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3.64 Upper-Stage Vehicle

An upper-stage vehicle is a vehicle that has one or more stages of a flight vehicle capable of injecting a space vehicle or vehicles into orbit from the suborbital trajectory.

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4. General Requirements

This section addresses general environmental test requirements for space systems. They consist of test requirements for units, subsystems, and flight systems and include inspection, test condition tolerances, test plans and procedures, retest, and documentation requirements.

4.1 Baseline Requirements

This standard establishes a baseline of requirements as part of a verification program. The baseline strategy is unit, subsystem, and vehicle-level qualification and acceptance to provide a high level of probable success for meeting performance requirements over mission life. The specific requirements applicable at these three levels of assembly are presented in 6, 7, and 8. For those programs that utilize a different test strategy, the baseline approach provides a benchmark for assessing program risk. Regardless of the test strategy, hardware shall be designed to qualification levels.

4.1.1 Program Requirements

The requirements presented in this standard are intended to be tailored for program contractual use. Deviations from the final tailored requirements shall require pre-approval from the customer.

4.2 Testing Philosophy

The complete test program for launch vehicles, upper-stage vehicles, and space vehicles encompasses development, qualification, acceptance, system, pre-launch validation, and post-launch validation tests. Test methods, environments, and measured parameters shall be selected to permit the collection of empirical design or performance data for correlation or trending throughout the test program. See Reference 28 for further guidance.

A satisfactory test program requires the completion of specific test objectives in a specified sequence. The test program encompasses the testing of progressively more complex assemblies of hardware and computer software. Design suitability should be demonstrated in the earlier development tests prior to formal qualification testing. All qualification testing for an item shall be completed, and design modifications incorporated prior to the initiation of flight hardware acceptance testing.

The baseline qualification test strategy is shown schematically in Figure 4.2-1. This strategy consists of designing and testing dedicated hardware to qualification levels to verify the design, demonstrate margin, and validate an acceptance test program allowing multiple rework cycles. Subsequent flight hardware shall be acceptance tested to demonstrate functional and/or performance to specification.

The protoqualification test strategy is shown schematically in Figure 4.2-2. This strategy consists of testing flight hardware to protoqualification levels for limited design verification, demonstration of reduced margin, functional and/or performance testing, and workmanship screening.

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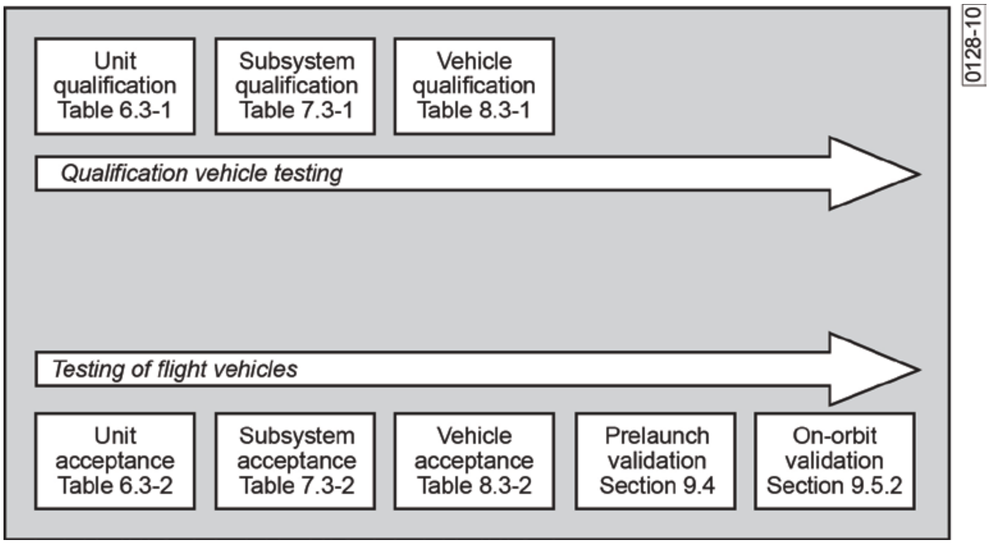

Figure 4.2-1. Baseline qualification test strategy.

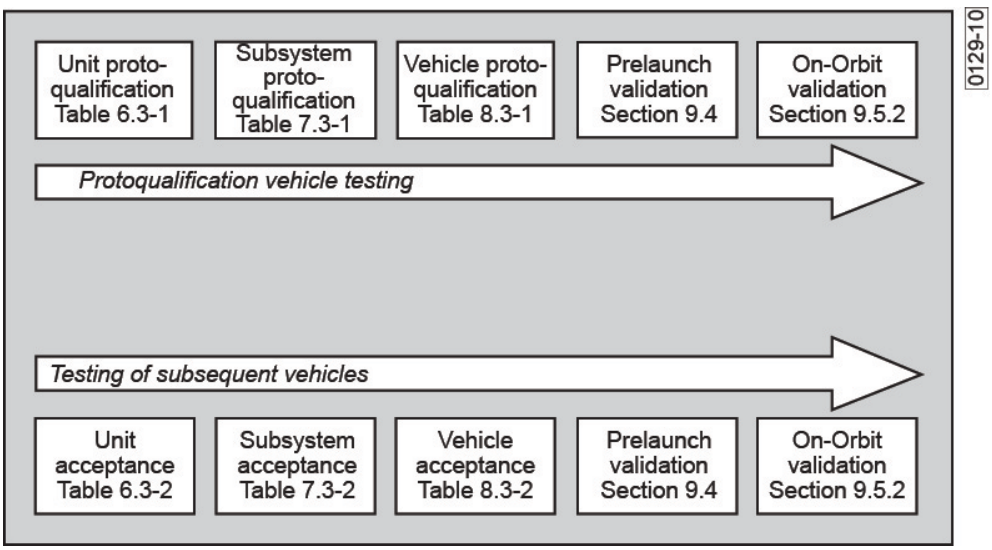

Figure 4.2-2. Protoqualification strategy.

Subsequent flight hardware is acceptance tested. This strategy does not allow multiple retest cycles. (See B.1.2 for dynamic environments.)

The requirement to design hardware to qualification levels (see 4.1) provides the basis for the protoqualification test strategy. This approach mitigates the risk inherent in flying protoqualification tested hardware without demonstration of qualification margins. (See B.1.3 for dynamic environments.)

A brief overview of alternate strategies, such as the flightproof strategy, the judicious use of test hardware as spares, and combinations of qualification and protoqualification strategies, is presented in 5.

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The environmental tests specified are intended to be imposed sequentially, rather than in combination. Nevertheless, features of the hardware design or of the service environments may warrant the imposition of combined environments in some tests. Examples include combined temperature, acceleration, and vibration when testing units employing elastomeric isolators in their design; and combined shock, vibration, and pressure when testing pressurized components. In formulating the test requirements in these situations, a logical combination of environmental factors should be imposed to enhance test perceptiveness and effectiveness.

4.2.1 Development Tests

Development tests, or engineering tests, may be performed to:

a. Evaluate new design concepts or the application of proven concepts and techniques to a new configuration.

b. Assist in the evolution of designs from the conceptual phase to the operational phase.

c. Validate design changes.

d. Reduce the risk involved in committing designs to the fabrication of qualification and flight hardware.

e. Develop and validate qualification and acceptance test procedures.

f. Investigate problems or concerns that arise after successful qualification.

Requirements for development testing therefore depend upon the maturity of the subsystems and units used, and upon the operational requirements of the specific program. An objective of development testing is to identify problems early in their design evolution so that corrective actions can be taken prior to starting formal qualification testing. Development tests should be used to confirm structural and performance margins, manufacturability, testability, maintainability, reliability, life expectancy, and compatibility with system safety. Where practical, development tests should be conducted over a range of operating conditions that exceeds the design limits to identify marginal capabilities and marginal design features. Comprehensive development testing is an especially important ingredient to mission success in programs that plan to use qualification items for flight, including those that allow a reduction in the qualification test levels and durations. Development tests may be conducted on breadboard equipment, prototype hardware, or the development test vehicle equipment.

4.2.2 Qualification Tests

Qualification testing (Figure 4.2-1) is conducted to demonstrate that the design, manufacturing process, and acceptance program produce hardware/software meeting specification requirements with adequate margin to accommodate multiple rework and test cycles. In addition, the qualification tests shall validate the planned acceptance program, including test techniques, procedures, equipment, instrumentation, and software. A full qualification ensures that subsequent hardware production units remain flightworthy after surviving multiple acceptance tests that may be necessary because of next assembly failures and/or overstress that may precipitate rework. A single qualification test specimen of a given design shall be exposed to all applicable environmental tests. The use of multiple qualifi-

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cation test specimens may be required for one-time-use devices (such as explosive ordnance or solid-propellant rocket motors).

4.2.3 Protoqualification Tests

Protoqualification testing (Figure 4.2-2) applies reduced amplitude and duration margins to flight hardware. This testing strategy leads to a higher level of risk, unless mitigated by other testing and analyses. It also presents reduced retest opportunities in the event of hardware failure, and the potential for late discovery of design defects.

The protoqualification described in this section may be used at the vehicle, subsystem, and unit levels. Acceptance testing shall be conducted on all subsequent flight items. The protoqualification strategy shall require technical justification demonstrating that the strategy meets program requirements. Alternate strategies are discussed in 5.

4.2.4 Acceptance Tests

Acceptance tests shall be conducted on each deliverable item to demonstrate acceptable quality of workmanship, functional capability, and performance to specifications. Acceptance testing is intended to stress screen items to precipitate failures due to latent defects.

If the equipment is to be used by more than one program or in different vehicle locations, the acceptance test conditions shall envelop the worst-case environments. For certain items the specified acceptance test environments could result in physical deterioration of materials or other damage. In those cases, less severe acceptance test environments that still satisfy the system operational requirements may be used.

Acceptance testing as discussed in this section does not apply to hardware acquired through lot acceptance testing.

4.3 Testing Approach

4.3.1 Development

Development tests on representative unit, subsystem, or vehicle hardware may be performed to evaluate design feasibility, performance acceptability or to obtain engineering data. The development test plan may use hardware such as breadboards, engineering models, or development models.

4.3.1.1 Parts, Materials, and Process Development Tests and Evaluations

Parts, materials, and process development tests and evaluations are conducted to demonstrate the feasibility of using certain items or processes in the implementation of a design. Development tests, evaluations, and subsequent qualifications are required for new types of parts, materials, and processes. References 22 and 23 shall be used as a source of requirements for this process.

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4.3.2 Qualification

4.3.2.1 Qualification Hardware

The hardware subjected to qualification testing shall be produced in the same factory from the same drawings, using the same parts, materials, tooling, manufacturing process, and level of personnel competency as used for flight hardware.

A single qualification test specimen of a given design shall be exposed to all applicable environmental tests. The use of multiple qualification test specimens may be required for one-time-use devices (such as explosive ordnance devices).

A vehicle or subsystem qualification test article shall be fabricated using qualification units to the maximum extent practical. Modifications are permitted, if required, to accommodate benign changes that may be necessary to conduct the test. These changes include adding instrumentation to record functional parameters, test input and response data, or design parameters for engineering evaluation. When structural items are rebuilt or reinforced to meet specific strength or rigidity requirements, all modifications shall be structurally identical to the changes incorporated in flight articles.

The testing allowed prior to the start of qualification testing of an item includes:

a. Wear-in or run-in necessary to achieve a smooth, consistent, and controlled operation of MMAs,

b. In-process workmanship screening, and

c. Burn-in of certain electrical/electronic assemblies to screen latent defects.

Acceptance testing of qualification hardware may be conducted to verify successful performance at acceptance levels before proceeding to higher levels for formal qualification testing in that environment. For those environments that are applied by axis, both the acceptance and qualification tests may be completed in one axis before switching to another.

4.3.2.2 Qualification Test Levels and Durations

The qualification test level for an environment shall provide a specified margin to the acceptance level. Qualification test durations or repetitions demonstrate life remaining for flight after a maximum time or repetitions of acceptance testing at all levels of assembly in support of rework or retest of flight hardware. Qualification testing should not cause unrealistic modes of failure. If the hardware is to be used by more than one program or in different applications within the same program, the qualification test conditions should envelop the worst-case application. Required qualification margins and durations are summarized in the following chapters for unit, subsystem, and system testing.

4.3.2.3 Qualification Retest

Qualification retests occur when the design has changed the form, fit, or function of the hardware or when the hardware service environment has reduced or eliminated demonstrated qualification margins. Qualification tests shall be repeated in the impacted environments and include any invalidated

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tests. Re-qualification testing shall also include performance testing and validate all related interfaces.

Retesting may also be necessary if a test discrepancy or test item failure occurs while performing any of the required testing steps. After performing a failure analysis, which identifies and isolates the root cause of the failure, a retest in the failed environment shall be performed. When previous tests have been invalidated by the failure, those tests shall be repeated. See Reference 16 for further retest guidance.

The minimum retesting for units and Multi-Unit Modules (MUM) shall consist of three axes of random vibration and three thermal cycles or thermal vacuum cycles. The random vibration retest shall be conducted at qualification levels and durations and the unit or MUM shall be powered on and monitored. The choice of thermal cycling or thermal vacuum testing shall be consistent with the thermal testing performed for the baseline qualification of the unit. The thermal cycles shall be conducted at qualification test temperatures and include performance testing at the hot and cold temperature extremes during the first and the last cycle. More extensive rework requires retesting that repeats the entire acceptance and qualification test sequence. See 4.3.4.3 for testing the reworked qualification test item to verify workmanship before retesting to qualification levels. Justification shall be required and approval received if the retest is to be performed at a different level of integration than that in which the discrepancy was detected.

4.3.3 Protoqualification

The protoqualification strategy requires the design of the hardware to qualification level environments and testing to protoqualification levels. Subsequent to protoqualification testing, a baseline acceptance program shall be conducted on all other flight items.

The protoqualification strategy applies when test hardware is used for flight. This strategy introduces a higher level of risk into a program since it does not establish service life for the first flight hardware, unless mitigated by other testing. Limited life is established for subsequent flight hardware.

Pressurized vessels and components cannot follow a protoqualification approach in regard to pressure testing. Verification of pressure capability must, instead, conform to a qualification approach although other requirements could then follow a protoqualification strategy (see 6.3.12).

4.3.3.1 Protoqualification Hardware

The hardware subjected to protoqualification testing shall be produced from the same drawings, using the same materials, tooling, manufacturing process, and level of personnel competency as acceptance hardware.

A single protoqualification test specimen of a given design shall be exposed to all applicable environmental tests. When practical, the protoqualification test specimen shall be selected randomly from a group of production items. The use of multiple protoqualification test specimens is required for one-time-use devices (such as explosive ordnance or solid-propellant rocket motors).

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A vehicle or subsystem protoqualification test article shall be fabricated using protoqualification units to the maximum extent practical. Modifications are permitted if required to accommodate benign changes that may be necessary to conduct the test. These changes include adding instrumentation to record functional parameters, test input and response data, or design parameters for engineering evaluation. The only tests allowed prior to the start of protoqualification testing of an item include:

a. Wear-in or run-in necessary to achieve a smooth, consistent, and controlled operation of MMAs

b. In-process workmanship screening, and

c. Burn-in of certain electrical/electronic assemblies to screen out latent defects

4.3.3.2 Protoqualification Test Levels and Durations

The protoqualification test level for an environment shall include margin and duration, reduced from that for qualification. The protoqualification test demonstrates that subsequent hardware has life remaining for flight after acceptance testing at all levels of assembly, but demonstrates little or no margin for retest (see B.1.2). Protoqualification testing should not create conditions that exceed applicable safety margins or cause unrealistic modes of failure. If the equipment is to be used by more than one program or in different applications within the same program, the test conditions should envelop the worst-case application. Required margins and durations are summarized in the following chapters for unit, subsystem, and system testing.

4.3.3.3 Protoqualification Retest

Protoqualification retesting is required when the design has changed the form, fit, or function of the hardware or when predicted environments have increased. Protoqualification retesting shall be performed at protoqualification levels and durations. Protoqualification retesting shall include performance testing and validation of all related interfaces.

Retesting may also be necessary if a test discrepancy or test item failure occurs while performing any of the required testing steps. Following the identification of the root cause and necessary hardware rework, a retest in the failed environment shall be performed. Customer approval shall be required if the retest is to be performed at a different level of integration than that in which the discrepancy was detected. When previous tests have been invalidated by the failure, those tests shall be repeated.

The minimum retesting for units and Multi-Unit Modules (MUM) shall consist of three axes of random vibration and three thermal cycles or thermal vacuum cycles. The random vibration retest shall be conducted at protoqualification levels and durations and the unit or MUM shall be powered on and monitored. The choice of thermal cycling or thermal vacuum testing shall be consistent with the thermal testing performed for the baseline protoqualification of the unit. The thermal test shall be conducted at protoqualification test temperatures and include performance testing at the hot and cold temperature extremes during the first and the last cycle. More extensive rework requires retesting that repeats the entire protoqualification test sequence. See 4.3.4.3 for workmanship screening to be performed prior to retesting to protoqualification levels. Adequate life for retesting and flight shall be established. Justification shall be required and customer approval received if the retest is to be performed at a different level of integration than that in which the discrepancy was detected.

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4.3.4 Acceptance

4.3.4.1 Acceptance Hardware

The item subjected to acceptance testing shall be flight hardware, including software, as applicable.

4.3.4.2 Acceptance Test Levels and Durations

To demonstrate workmanship, the acceptance environmental conditions shall stress the hardware to the maximum conditions expected for all flight events, including transportation and handling, but not less than the minimum workmanship levels defined by this standard. Required margins on flight and acceptance test levels and durations are summarized in the following chapters for unit, subsystem, and system testing.

4.3.4.3 Acceptance Retest

Retesting shall be necessary if a test discrepancy or test item failure occurs while performing any of the required testing steps (see 3.58). After performing a failure analysis, which identifies, isolates, and corrects the root cause of the failure, a retest in the failed environment shall be performed. Justification shall be required and approval received if the retest is to be performed at a different level of integration than when the discrepancy was detected. Customer approval shall be required if the retest is to be performed at a different level of integration than that in which the discrepancy was detected. When previous tests have been invalidated by the failure, those tests shall be repeated.

To verify workmanship after rework, the minimum retesting for units and Multi-Unit Modules (MUM) shall consist of three axes of random vibration and three thermal cycles or thermal vacuum cycles. The random vibration retest shall be conducted at acceptance levels for one minute per axis and the unit or MUM shall be powered on and monitored. The choice of thermal cycling or thermal vacuum testing shall be consistent with the thermal testing performed for the baseline acceptance of the unit. The thermal cycles shall be conducted at acceptance test temperatures and include performance testing at the hot and cold temperature extremes during the first and the last cycle. More extensive rework requires retesting that repeats the entire acceptance test sequence. Justification shall be required and approval received if the retest is to be performed at a different level of integration than that in which the discrepancy was detected.

4.4 Special Considerations

4.4.1 Propulsion Equipment Tests

Units that make up a vehicle propulsion subsystem, including units that are integral to or mounted on a motor or engine are covered by this Standard in that they shall be qualified and acceptance tested to the applicable unit requirements specified herein. Testing of a unit on an engine during the engine acceptance test firing may be substituted for part of the unit level acceptance test if it can be established that the environments and duration meet the intent of the individual acceptance test criteria, or if such units are not amenable to testing individually. Environmental testing of thrusters (such as staging rockets, retro-motors, and attitude control thrusters) shall meet the applicable unit requirements of this Standard. Further guidance on functional testing of launch vehicle engines is addressed in Reference 30.

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4.4.1.1 Engine Line Replaceable Unit (LRU) Acceptance Testing

An engine LRU is a unit that may be removed and replaced by a new unit, without requiring re-acceptance test firing of the engine with the new unit. If the unit being replaced was included in an engine acceptance test firing as part of its acceptance test, then the replacement unit shall either be subjected to such a test on an engine, or shall undergo equivalent unit-level acceptance testing. Equivalent testing shall consider all appropriate environments, such as temperature, vibration, pressure, vacuum, and chemical. Testing shall demonstrate functionality and performance of the unit under conditions similar to those achieved in the engine acceptance test firing and flight.

4.4.1.2 Engine Line Replaceable Unit (LRU) Qualification Testing

All engine LRUs shall be qualified at a unit level to the requirements of this Standard.

4.4.2 Thermal Uncertainty Margins

For the purpose of thermal uncertainty margin specification, thermal control hardware is categorized as either passive or active. Passive hardware uses a thermal uncertainty margin, whereas active hardware uses excess power as a thermal uncertainty margin. Examples of passive and active thermal control hardware for purposes of uncertainty margin are identified in Table 4.4-1.

Table 4.4-1. Categorization of Passive and Active Thermal Hardware

Passive	Active
• Constant conductance or diode heat pipes	• Variable conductance heat pipes
• Hardwired heaters (fixed or variable resistance, such as auto trace or positive temperature coefficient thermistors)	• Heat pumps and refrigerators
• Thermal storage devices (such as phase-change or sensible heat)	• Stored coolant subsystems
• Thermal insulator (such as multilayer insulation, foams, or discrete shields)	• Resistance heater with commandable or mechanical or electronic controller (including proportional control)
• Radiators (fixed articulated or deployable) with louvers or pinwheels	• Capillary-pumped loops and loop heat pipes
• Surface finishes (such as coating, paints, treatments, second-surface mirrors)	• Pumped fluid loops
	• Thermoelectric cooler

4.4.2.1 Margins for Passive Thermal Control Hardware

For units that have only passive thermal control, the minimum thermal uncertainty margin shall be 11°C. For units that have large uncertainties in operational or environmental conditions, the thermal uncertainty margin may be greater than 11°C. Examples of these units for a launch vehicle are a vehicle heat shield, external insulation, and units within the aft skirt. For any unit or subsystem that is not thermal balance tested, the thermal uncertainty margin shall be 17°C.

a. **Margin for Radiators.** Radiator margins shall be implemented based upon analytic predictions using worst-case power modes and environments. Prior to thermal model correlation with thermal balance test data, the design of radiators shall include 10% excess radiator area

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in addition to normal power growth uncertainties. When technically justified and approved by the customer, the 10% margin may be reduced for the final mission phase predictions made with the correlated thermal model.

b. **Margin for Passive Hardware at Cold Temperatures.** Uncertainty margins for spacecraft hardware operating below -70°C (including passive cryogenic subsystems) may be reduced as presented in Table 4.4-2.

Table 4.4-2. Thermal Uncertainty Margins for Passive Hardware at Cold Temperatures

Predicted Temperature (°C)	Thermal Uncertainty Margin (°C)
Above –70	11
–70 to –87	10
–88 to –105	9
–106 to –123	8
–124 to –141	7
–142 to –159	6
–160 to –177	5
–178 to –195	4
–196 to –213	3
–214 to –232	2
Below –232	1

4.4.2.2 Margins for Active Thermal Control Hardware

Thermal designs in which temperatures are actively controlled shall use a power margin of 25% above the minimum design value in lieu of the thermal margins specified in 4.4.2.1. This margin is applicable at the condition that imposes the maximum or minimum expected temperatures. For example, for heaters regulated by a mechanical thermostat or electronic controller, a 25% heater capacity margin may be used in lieu of the thermal margins at the minimum expected temperature and at minimum bus voltage, which translates into a duty cycle of no more than 80% under these cold conditions.

4.4.2.2.1 Margins for Cryogenic Hardware

Subsystem designs in which the temperatures are actively controlled to below –70°C by expendable coolants or refrigerators shall have a thermal uncertainty heat-load margin of 50% for the conceptual phase, 45% for the preliminary design review phases, 35% for the critical design review phase, 30% for the qualification hardware, and 25% for the acceptance hardware.

4.4.2.3 Margins for Units Controlled by Heat Pipes

All units whose temperatures are controlled by heat pipes (constant conductance or variable conductance) shall demonstrate that maximum model temperature predictions of the units can be maintained within the unit's acceptance temperature limits should any one of the controlling heat pipes fail. Demonstration is by analysis, wherein conductive heat paths to heat pipes are individually disconnected and resulting temperature predictions are compared to acceptance limits. A minimum 25% excess heat transport margin shall be maintained by the remaining operating heat pipes. These two provisions constitute the requirement for heat pipe redundancy.

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4.4.3 Explosively Actuated Devices

For explosively actuated devices, the requirements specified in Reference 8 shall be satisfied.

4.5 Software and Firmware Tests

4.5.1 Software Development Tests

Software development testing verifies that the software performs as designed. Software development testing shall include software unit testing, software unit integration testing, and software/hardware integration testing.

Software unit testing shall be performed in accordance with Reference 24.

Software unit integration testing shall be performed in accordance with Reference 24. Software/hardware integration testing shall be performed in accordance with Reference 24.

4.5.2 Software Qualification Tests

Software qualification testing verifies that the software meets its specified requirements. Software qualification testing shall be performed in accordance with Reference 24, paragraph 5.9 and its subparagraphs.

4.5.3 Testing of Commercial Off-the-Shelf (COTS) and Reuse Software

Testing of COTS and reuse of software shall be performed in accordance with Reference 24, paragraphs, 5.7.2, 5.8.1, 5.9.3, and 5.10.1.

4.5.4 Software Regression Testing

Regression testing of affected software unit test cases, software unit integration test cases, software/hardware integration test cases, and software qualification test cases shall be performed after any modification to previously tested software. Regression testing of appropriate software unit integration, software/hardware integration and/or software qualification test cases shall be performed after the initial loading of the operational flight constants and also after loading any changes to the operational flight constants.

4.5.5 Other Software-Related Testing

Software shall be included along with hardware in all types of testing specified by this standard where the software is needed in order to verify the functionality and performance of the hardware itself or of the integrated hardware/software unit, subsystem, or system.

4.6 Inspections

All units and higher levels of assembly shall be inspected to identify discrepancies before and after testing. Disassembly or removal of unit covers during inspections shall only be allowed when specifically called out in the test procedures. Included should be applicable checks of finish, identification markings, and cleanliness. Weight, dimensions, clearances, fastener tightness torques, and

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breakaway forces and torques shall be measured, as applicable, to determine compliance with specifications. (See Reference 13.)

Upon completion of the environmental test program, tested hardware shall be inspected as follows:

4.6.1 Post-Qualification Test Inspections

Inspection of unit/subsystem hardware following completion of qualification shall entail disassembly to the extent that wear and/or mechanical integrity can be confirmed (e.g., fractures in circuit boards are not present, heavy component staking is in place, there are no broken brackets, wedge locks and internal connectors are secure, etc.). Moving mechanical assemblies that undergo life test can be subjected to an abbreviated inspection sufficient to confirm viability to continue on to the life test followed by a complete disassembly inspection at the conclusion of life testing.

4.6.2 Post-Test Flight Hardware Inspection (Including Launch Site)

Flight hardware shall be inspected following environmental testing. Inspection should include applicable checks of finish, identification markings, and cleanliness. Weight, dimensions, clearances, fastener tightness torques, and breakaway forces and torques shall be measured, as applicable, to determine compliance with specifications. Inspection of flight hardware shall not entail the removal of unit covers or any specific disassembly unless called out in the test procedures.

4.7 Test Input Tolerances

Unless stated otherwise, the specified test parameters shall include the maximum allowable test tolerances listed in Table 4.7-1.

Table 4.7-1 Maximum Allowable Test Tolerances

Test Parameters		Test Tolerance
Temperature		
–54°C to +100°C		± 3°C
Relative Humidity		± 5%
Acceleration		+10/–0%
Static Load and Pressure		+5/–0%
Atmospheric Pressure		
Above 133 Pa (>1 Torr)		±10%
133 to 0.133 Pa (1 Torr to 0.001 Torr)		+10/–25%
Below 0.133 Pa (<0.001 Torr)		+0/–80%
Test Time Duration		+10/–0%
Vibration Frequency		± 2%
Random Vibration Power (Auto) Spectral Density (g^2/Hz)		
Frequency Range	Maximum Control Bandwidth	
20 to 100 Hz	10 Hz	± 1.5 dB
100 to 1000 Hz	10% of mid-band frequency	± 1.5 dB
1000 to 2000 Hz	100 Hz	± 3.0 dB
Overall Level (Grms)		± 1.0 dB
Note: Control bandwidths may be combined for tolerance evaluation purposes. The statistical degrees of freedom shall be at least 100.		
Sound Pressure Levels		
1/3-Octave Midband Frequencies		
31.5 to 40 Hz		± 5.0 dB

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Test Parameters	Test Tolerance
50 to 2000 Hz 2500 to 10000 Hz Overall SPL Note: The statistical degrees of freedom shall be at least 100.	± 3.0 dB ± 5.0 dB ± 1.5 dB
Shock Response Spectrum (Peak Absolute Acceleration, Q = 10) Natural Frequencies Spaced at 1/6-Octave Intervals At or below 3000 Hz Above 3000 Hz Note: At least 50% of the spectrum values shall be greater than the nominal test specification.	 ± 6.0 dB + 9.0/–6.0 dB
Electromagnetic Compatibility	± 2 dB

4.8 Test Plans and Procedures

The test plans 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.

4.8.1 Test Plans

The test plans shall provide a general description of each test planned and the conditions of the tests. The test plans shall be based upon a function-by-function mission analysis and any specified testing requirements. To the degree practical, tests shall be planned and executed to fulfill test objectives from development through operations. Test objectives shall be planned to verify compliance with the design and specified requirements of the items involved, including interfaces.

Test plans shall include an allowable experimental uncertainty requirement for each measured parameter. Each allowable uncertainty statement shall include a positive and negative uncertainty. Such experimental uncertainty requirements shall support the objectives of the test.

As a minimum, the test plan shall address the following:

a. The allocation of requirements to appropriate testable levels of assembly. Usually this is a reference to a requirements traceability matrix listing all design requirements and indicating a cross-reference to a verification method and to the applicable assembly level.

b. The identification of separate environmental test zones (such as the engine, fairing, or payload)

c. The identification of separate states or modes where the configuration or environmental levels may be different (such as during testing, launch, upper-stage transfer, on-orbit, eclipse, or re-entry)

d. The environmental specifications or life-cycle environmental profiles for each of the environmental test zones

e. The overall test philosophy, testing strategy, and test objective for each item, including any special tailoring or interpretation of design and testing requirements

f. Required special test equipment, facilities, interfaces, and downtime requirements

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g. Required test tools, test beds, and specialty items necessary to support testing

h. Standards to be used for the recording of test data on computer-compatible electronic media, such as disks or magnetic tape, to facilitate automated accumulation and sorting of data

i. Procedures to guard against damage to test article during transportation handling and testing

j. The collection of parameters and development of a database during testing of units, subsystems, and at the vehicle level to be used for trending and test effectiveness assessment.

4.8.2 Test Procedures

Tests shall be conducted using documented test procedures prepared for performing all of the required tests in accordance with the test objectives in the approved test plans. The test objectives, testing criteria, and pass/fail criteria shall be stated clearly in the test procedures. The test procedures shall cover all operations in enough detail so that there is no doubt as to the execution of any step. Test objectives and criteria shall be stated to relate to design or operations specifications. Minimum/ maximum requirements for valid data and pass/fail criteria shall be verified in the test procedure. Traceability shall be provided from the specifications or requirements to the test procedures. Where practical, the individual procedure step that satisfies the requirement shall be identified. The test procedure for each item shall include, as a minimum, descriptions of the following:

a. Criteria, objectives, assumptions, and constraints

b. Test setup

c. Initialization requirements

d. Input data

e. Test instrumentation

f. Expected intermediate test results

g. Requirements for recording output data

h. Expected output data

i. Minimum/maximum requirements for valid data to consider the test successful

j. Pass/fail criteria for evaluating results, including uncertainty constraints

k. Safety considerations and hazardous conditions

4.9 Documentation

4.9.1 Test Documentation Files

The test plans and procedures including a list of test equipment, calibration dates and uncertainty, computer software, test data, test log, test results and conclusions, test discrepancies or deficiencies,

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operating time/cycles, pertinent analyses, and resolutions shall be documented and maintained. The applicable contractors shall maintain the test documentation file for the duration of their contracts.

4.9.2 General Test Data

Pertinent test data shall be maintained in a quantitative form to permit the evaluation of performance under the various specified test conditions.

4.9.3 Qualification, Protoqualification, and Acceptance

For qualification, protoqualification, and acceptance tests, a summary of the test results shall be documented in test reports. The test report shall state the degree of success in meeting the test objectives and shall document and summarize the test results, deficiencies, problems encountered, and problem resolutions. The responsible contractor design engineer shall certify the accuracy of the results.

4.9.4 Test Log

Formal test conduct shall be documented in a test log. The test log shall identify the personnel involved and be time recorded to permit a reconstruction of test events such as start time, stop time, anomalies, and any periods of interruption. (See Reference 1.)

4.9.5 Test Discrepancy

Anomalies, discrepancies, and failures occurring during test activities shall be documented and dispositioned as specified in the contractor's approved quality control plan. (See Reference 13.)

4.10 Exceptions to General Requirements

4.10.1 Qualification and Protoqualification by Similarity (QBS)

A unit may be a candidate for qualification, or protoqualification, by similarity to a heritage unit that has already been qualified, or protoqualified, for launch vehicle, upper stage or space vehicle use. The following conditions shall be met in order to apply QBS:

a. Heritage unit was not qualified by similarity or analysis.

b. Heritage unit was a representative flight article.

c. The environments, both amplitude and duration, encountered by the heritage unit during its qualification or flight history are equal to, or more severe than, the qualification environments intended for the candidate QBS unit.

d. The candidate QBS unit and the heritage units are produced by the same manufacturer in the same facility using identical tools, manufacturing processes, quality control procedures, and manufacturing staff training/certification levels, without gaps that impact in production continuity.

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e. Heritage unit shall have successfully passed a post-environmental functional test series, without need for waivers, associated with performance indicating survival of the qualification stresses.

f. The candidate QBS unit and the heritage units shall perform similar functions, and the heritage unit shall have equivalent or greater operating life with variations only in terms of performance such as accuracy, sensitivity, formatting, and input-output characteristics.

g. Supporting documentation for the heritage unit is available and includes specifications, drawings, qualification test procedures, qualification and acceptance test reports, ground and flight discrepancy reports with closure history, test waivers, and flight history summary.

h. Modified units may be a minor variation of the heritage unit. Dissimilarities of safety, reliability, maintainability, weight, thermal effects, dynamic response, and structural, mechanical and electrical configurations shall require that the candidate QBS unit characteristics be enveloped by the characteristics of the heritage unit. Minor design changes involving substitution of piece parts and materials with equivalent reliability items can generally be accepted. Design dissimilarities resulting from addition or subtraction of piece parts and particularly moving parts, ceramic or glass parts, crystals, magnetic devices, and power conversion or distribution equipment shall void qualification by similarity, unless the contractor's QBS analysis includes technical rationale supporting the similarity claim.

i. In some cases, the item to be qualified by similarity is not a unit but is some other level of assembly, such as a subsystem. In that case, the criteria for the item to be qualified by similarity would be the same as though the item were a unit.

Deviations from these conditions shall require customer approval of the assessment and documentation.

4.10.2 Electrical and Electronic Unit Thermal Vacuum Test Exemptions

Requirements for unit testing are provided in Tables 6.3-1 and 6.3-2. For electronic units, there may be instances where unit-level thermal vacuum testing is unnecessary if it can be shown that the design is insensitive to the vacuum environment. Deletion of the thermal vacuum test when this or other tailored criteria demonstrate unit vacuum insensitivity is restricted to electronic units only (not mechanical units) and for acceptance testing only. A criterion delineating the conditions under which vacuum testing may be exempted needs to be defined early in the program to allow for test planning and risk mitigation activities. As a minimum, the criteria used in assessing vacuum-sensitivity in electronic units should include consideration for confidence gained from identical flight units, the vacuum-sensitive nature of any high-voltage or radio frequency (RF) units, susceptibility for arcing, thermal control features that need to be verified in vacuum, deflection of any sealed devices, and electrical or thermal performance issues that may be different under vacuum conditions, such as:

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a. Units that have no flight heritage or do not have a qualification unit thermal vacuum test associated with their design shall be tested in a vacuum environment.

b. Units that are inherently vacuum and/or temperature sensitive, such as RF equipment, shall be tested in a vacuum environment.

c. Units susceptible to corona or multipaction, such as high-voltage units, shall be tested in a vacuum environment.

d. Devices that are temperature controlled on-orbit to within a range of 3°C or less to maintain performance shall be tested in a vacuum environment.

e. If a hermetically sealed device can physically deflect under worst-case conditions such that the clearance between the device wall and a nearby item could cause an electrical short (e.g., a clearance of 2.5 mm or less), the unit shall be tested in a vacuum environment.

f. Units whose electrical performance may be affected by temperature differences between the ambient and vacuum thermal environments shall be tested in a vacuum environment. If the unit performance in vacuum and ambient conditions has been well characterized by test data such that performance problems can be clearly detected in ambient testing, deletion of the vacuum environment may be considered.

g. A unit with any part case temperature prediction within 10ºC of its allowable derated temperature limit under worst-case power dissipation shall be tested in a vacuum environment.

h. Unit thermal analyses shall be performed in vacuum and ambient environments to assess vacuum-sensitivity.

    1. If the worst-case temperature difference between the two environments is greater than 10°C, thermal vacuum testing shall be performed.

    2. If the worst-case temperature difference is between 3ºC and 10ºC and all criteria support ambient testing in lieu of vacuum testing, the base plate temperature shall be increased during the ambient test to account for junction/case temperature differences between the two environments.

    3. If the worst-case temperature difference is less than 3ºC and all criteria support ambient testing in lieu of vacuum testing, thermal cycling may be performed in lieu of thermal vacuum testing without base plate temperature modification.

If a unit's qualification test was performed with a baseplate temperature higher than 10ºC above the acceptance baseplate test temperature, then the 10ºC limit specified above may be increased to the corresponding higher baseplate temperature margin.

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5. Alternative Strategies

The qualification testing in 4.3.2 provides a demonstration that the design, manufacturing, and acceptance testing produces flight items that meet specification requirements. In a minimum-risk program, the hardware items subjected to qualification tests are not eligible for flight without careful analysis and refurbishment since the remaining life from fatigue and wear standpoints is not demonstrated. In programs where it is necessary to demonstrate the flightworthiness of tested hardware, the strategies described in 5.1 and 5.2 as alternatives to the protoqualification strategy may be used at the system, subsystem, and unit levels. A combination of various applications of qualification and protoqualification strategies should be considered to meet the needs for particular items, as deemed necessary. As in the case for protoqualification, the higher risk of deviating from qualification may be partially mitigated by enhanced development testing and by increasing the design margins. Care should be exercised to ensure that an acceptable balance of demonstrated margin, workmanship screening, and remaining life for flight is achieved for programs pursuing these options.

5.1 Spares Strategy

This strategy does not alter the qualification and acceptance test requirements presented in 4.3.2 and 4.3.4. Yet, in some cases, qualification hardware may be used for flight if the risk is minimized. Typically, the qualification test program results in a qualification test vehicle that was built using units that had been qualification tested at the unit level. After completing the qualification tests, the critical units can be removed from the vehicle, and the qualification vehicle can then be refurbished, as necessary. Usually a new set of critical units would be installed that had only been acceptance tested. This refurbished qualification vehicle would then be certified for flight when it satisfactorily completed the vehicle acceptance tests. The qualification units that were removed could be refurbished and used as flight spares.

5.2 Flightproof Strategy

This strategy applies only for dynamic environments. It subjects all flight items to a flightproof test that is an enhanced acceptance test using protoqualification levels, while retaining acceptance duration. The risk taken is that there has been no formal demonstration of remaining life for flight and limited demonstration of capability to withstand the flight environment. This strategy does not validate subsequent acceptance testing. Flightproof testing is applicable to single vehicle procurements. Flightproof testing is a check on the adequacy of the capability of each flight item, considering build variability or defects introduced due to handling or testing. Development testing, design to enhanced margins, and rigorous analysis should be used to gain confidence that adequate margin remains after the maximum allowed accumulation of preflight testing. For thermal testing, flightproof hardware shall be tested to protoqualification requirements.

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5.3 Combination Test Strategies

Various combinations of test strategies may be considered, depending on specific program considerations and the degree of risk deemed acceptable. For example, the protoqualification strategy for units (4.3.3) may be combined with the flightproof strategy for the vehicle. In other cases, the flightproof strategy would be applied to some units peculiar to a single mission, while the protoqualification strategy may be applied to multi-mission units. In such cases, the provisions of each method would apply, and the resultant risk would be increased correspondingly.

5.4 Qualification Using Engineering Qualification Models (EQM)

The use of EQM hardware to achieve qualification testing may be acceptable in cases where hardware configuration and successful test exposure provide demonstration of desired qualification of the hardware. In those cases where the EQM hardware differs from flight hardware, a quantitative risk assessment shall be performed and documented. See Reference 15 for additional guidance.

The EQM shall have, as a minimum, the following characteristics:

a. Use of flight-like parts (same part numbers as flight units; up-screening not required)

b. Use of flight-like boards, slices and housings

c. All redundancies included

d. All boards and slices must be present in the EQM

e. All qualification testing shall occur on the same EQM

f. EQM built using flight build processes, personnel, and skill set in the same factory as flight units. Production gaps between the EQM qualification and acceptance manufacturing shall be assessed.

g. EQM tested with same verification and validation approach, and test equipment as flight units.

Deviations from these conditions shall require assessment and documentation.

The EQM shall meet all flight hardware requirements after exposure to qualification environments. An assessment of the differences between the EQM and the flight units requires customer approval before commencement of flight hardware manufacturing.

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6. Unit Test Requirements

6.1 General Requirements

Unit tests shall normally be accomplished entirely at the unit level. However, in certain circumstances where one or more units are needed to complete a function, the required unit tests may be conducted at the next level of assembly. Tests of units such as interconnect tubing, radio-frequency circuits, and wiring harnesses are examples where at least some of the tests may be accomplished at higher levels of assembly. If moving mechanical assemblies or other units have static or dynamic fluid interfaces or are pressurized during operation, those conditions should be replicated during unit testing. Units shall meet the applicable requirements over the entire qualification and acceptance environmental test range.

6.2 Development Tests

6.2.1 Subassembly Development Tests, In-Process Tests, and Inspections

Subassemblies are subjected to development tests and evaluations as required to minimize design risk, to demonstrate manufacturing feasibility, and to assess the design and manufacturing alternatives and trade-offs required to best achieve the development objectives. Tests are conducted as required to develop in-process manufacturing tests, inspections, and acceptance criteria for the items. Opportunity to establish subassembly qualification should be exploited when appropriate. For example, it is often easier to demonstrate design margin and performance at lower levels of assembly, especially in cases where existing designs are integrated into a new and unique next assembly, which will then be re-qualified.

6.2.2 Unit Development Tests

Units are subjected to development tests and evaluations as may be required to minimize design risk, to demonstrate manufacturing feasibility, to establish packaging designs, to demonstrate electrical and mechanical performance, and to demonstrate the capability to withstand environmental stress, including storage, transportation, extreme combined environments, and launch base operations.

6.2.3 Development Tests for Composite Structures

Development tests should be conducted on structural components made of composite and/or bonded materials used in space vehicles, interstages, payload adapters, payload fairings, motor cases, nozzles, propellant tanks, and over-wrapped pressure vessels.

If appropriate, testing should include:

a. Demonstration of manufacturing feasibility

b. Static load or burst testing to verify analysis models and design margin predictions

c. Damage tolerance testing to define acceptance criteria for fracture critical structural items

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d. Demonstration of scalability of basic design data to full scale design

e. Characterization of mechanical properties (strength, stiffness, acoustic loss, etc.) and electrical conductivity

f. Characterization of venting and other relevant material properties, such as material porosity, density, and outgassing. For perforated sandwich structures, if venting at the flight depressurization rate cannot be demonstrated, tests should be conducted to verify the unit has sufficient strength to withstand internal pressure.

6.2.4 Thermal Development Tests

For critical electrical and electronic units designed to operate in a vacuum environment less than 0.133 Pa (0.001 Torr), thermal mapping for known boundary conditions may be performed in the vacuum environment to verify the internal unit thermal analysis, and to provide data for thermal mathematical model correlation. Once correlated, the thermal model is used to demonstrate that critical part temperature limits, consistent with reliability requirements and performance, are not exceeded.

When electrical and electronic packaging is not accomplished in accordance with known and accepted techniques relative to the interconnect subsystem, parts mounting, board sizes and thickness, number of layers, thermal coefficients of expansion, or installation method, development tests should be performed. The tests should establish confidence in the design and manufacturing processes.

Heat transport capacity tests may be required for constant and variable conductance heat pipes at the unit level to demonstrate compliance. Thermal conductance tests should be considered to verify conductivity across items such as vibration isolators, thermal isolators, cabling, and any other potentially significant heat conduction path.

Engineering Development Units (EDU) of cryogenic systems may be tested in a vacuum environment for early verification of system performance and margins, and assessment of parasitic heat leaks. A thermal balance test may also be conducted to demonstrate thermal control hardware and subsystem performance and to collect data for thermal model correlation.

6.2.5 Shock and Vibration Isolator Development Tests

When a unit is to be mounted on shock or vibration isolators whose performance is not well known, development testing should be conducted to verify their suitability. The isolators should be exposed to the various induced environments (e.g., temperature and chemical environments) to verify retention of isolator performance (especially resonant frequencies and amplifications) and to verify that the isolators have adequate service life. The unit or a rigid simulator with proper mass properties (mass, center of gravity, mass moments of inertia) should be tested on its isolators in each of three orthogonal axes, and, if necessary, in each of three rotational axes. Responses at all corners of the unit should be determined to evaluate isolator effectiveness and, when applicable, to establish the criteria for unit acceptance testing without isolators. When multiple units are supported by a vibration-isolated panel, responses at all units should be measured to account for the contribution of panel vibration modes.

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6.2.6 Battery Development Tests

See Reference 20 for development test guidance. For power systems using lithium-ion batteries, see Reference 26 for recommendations on spacecraft batteries and Reference 27 for recommendations on launch vehicle batteries. Safety testing is required for lithium-ion batteries during qualification and evaluation of safety devices is required during acceptance testing.

6.2.7 EMI/EMC Development Tests

See Reference 21 for test guidance.

6.3 Test Program for Units

Tables 6.3-1 and 6.3-2 identify unit qualification, protoqualification, and acceptance test requirements. When units fall into two or more categories, the most stressing combination of tests shall be performed. For example, a star sensor may be considered to fit both "Electrical and Electronic" and "Optical" categories. A thruster with integrated valves would be considered to fit both "Thruster" and "Valve" categories. Table 6.3-3 provides a summary of unit test level margins and durations that are discussed in this section.

In all tables shown in this standard where "Evaluation Required" (ER) is noted, an engineering assessment shall be performed and documented to develop rationale for performing or not performing a test. The customer will approve the contractor's evaluation.

Additional requirements are specified in Reference 9 for solar cells and Reference 10 for solar panels. See 6.2.6 for additional test requirements for batteries.

6.3.1 Unit Wear-In Test

6.3.1.1 Purpose

The wear-in test detects material and workmanship defects that occur early in the unit life. Testing also serves to wear-in or run-in mechanical units so they perform in a smooth, consistent, and controlled manner.

6.3.1.2 Test Description

While the unit is operating under conditions representative of operational loads, speed, and environments, and while perceptive parameters are being monitored, the unit shall be operated for the specified duration or number of cycles.

Pressure components with no moving mechanical assembly aspects, such as filters, are not subject to wear-in testing. Thruster wear-in is limited to valves, which may be tested prior to integration within a thruster.

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Table 6.3-1. Unit Qualification and Protoqualification Test Summary

Test	Reference Paragraph	Suggested Sequence	Electrical and Electronic	Antenna	MMA	Solar Panel	Battery (12)	Pressure Component	Pressure Vessel	Thruster	Thermal	Optical	Structural Components
Inspection[1]	4.6	1, 18	R	R	R	R	R	R	R	R	R	R	R
Performance[1]	6.3.2	2, 17	R	R	R	R	R	R	R	R	R	R	ER
Leakage	6.3.3	3, 7, 12	ER	--	R[11]	--	R	R	R	R	R	--	--
Shock	6.3.4	4	R	ER	ER	ER	R[6]	ER	ER	ER	ER	ER	ER
Vibration or Acoustic[2]	6.3.5 6.3.6	5	R	R	R	R	R	R	R	R	R	R	ER
Acceleration	6.3.7	6	ER	ER	ER	ER	ER	--	ER	--	--	ER	ER
Thermal Cycle	6.3.8	8	R[7]	ER	ER	ER	R	ER	ER	ER	ER	ER	ER[3]
Thermal Vacuum	6.3.9	9	R[7]	R	R	R[9]	R	ER	ER	R[8]	R	R	–
Climatic	6.3.10	10	ER	ER	ER	ER	ER	ER	ER	ER	ER	ER	ER
Pressure	6.3.12	11	ER	--	ER	--	R	R	R	ER	ER[5]	--	--
EMC[4]	6.3.13	13	R	ER	ER	ER	ER	ER	ER	ER	ER	ER	ER
Life	6.3.14	14	ER	ER	R	ER	R	R	ER	R	ER	ER	ER
Static Load	6.3.11	15	ER	ER	ER	ER	ER	--	ER	--	--	--	R
Burst Pressure	6.3.12	16	--	--	ER	--	R	R[10]	R[10]	R	ER	--	--

R Required
ER Evaluation required (see 6.3)
(1) Performance tests shall be conducted prior to, during, and following each environmental test, as appropriate.
(2) Either vibration or acoustic required, with the other discretionary.
(3) Required on composite and/or bonded structural components.
(4) Required for non-electrical/electronic units when they provide required electromagnetic shielding, when there is a passive intermodulation requirement or when the unit contains active or passive electrical components.
(5) Required for sealed and pressurized units (such as heat pipes). Evaluation required for other components.
(6) Required for launch vehicle and upper stage. Evaluation required for space vehicle.
(7) Burn-in required for protoqualification units.
(8) Thruster thermal vacuum requirement may be satisfied with hot fire testing.
(9) Thermal vacuum testing of solar panels may be performed on solar arrays.
(10) Burst pressure testing is required for qualification testing only.
(11) Required only for pressurized and hermetically sealed MMAs.
(12) Safety device evaluation required for lithium-ion batteries.

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Table 6.3-2. Unit Acceptance Test Summary

Test	Reference Paragraph	Suggested Sequence	Electrical & Electronic	Antenna	MMA	Solar Panel	Battery (12)	Pressure Component	Pressure Vessel	Thruster	Thermal	Optical	Structural Components
Inspection[1]	4.6	1, 15	R	R	R	R	R	R	R	R	R	R	R
Wear-in	6.3.1	2	--	--	R	--	ER	R	--	R	--	--	--
Performance[1]	6.3.2	3, 14	R	R	R	R	R	R	R	R	R	R	ER
Leakage	6.3.3	4, 7, 12	ER	--	R[11]	--	R	R	R	R	ER [4]	--	--
Shock	6.3.4	5	ER	--	ER	--	ER	ER	--	ER	--	ER	--
Vibration or Acoustic[2]	6.3.5 6.3.6	6	R	R	R	R	R[6]	R	ER	R	ER[3]	R	ER
Thermal Cycle	6.3.8	8	R[8]	ER	ER	ER	ER	ER	ER	ER	ER	ER	ER[3]
Thermal Vacuum	6.3.9	9	R[7][8]	R	R	R[10]	R[6]	ER	ER	R[9]	R	R	--
Proof Pressure	6.3.12	10	ER	--	ER	--	R	R	R	ER	ER[4]	--	--
Proof Load	6.3.11	11	--	ER	ER	--	ER	--	ER	--	--	ER	R[3]
EMC [5]	6.3.13	13	ER	ER	--	ER	ER	ER	--	--	--	--	--

R Required
ER Evaluation required (see 6.3).
(1) Performance tests shall be conducted prior to, during, and after each environmental test, as appropriate.
(2) Vibration or acoustic required, with the other discretionary.
(3) Required only on composite and/or bonded structures.
(4) Required for sealed or pressurized units (such as heat pipes).
(5) Required when there is less than 12 dB margin.
(6) Evaluation required for silver-zinc batteries.
(7) See 4.10.2 for exemptions.
(8) Burn-in required.
(9) Thruster thermal vacuum requirement may be satisfied with hot fire testing.
(10) Thermal vacuum testing of solar panels may be performed on solar arrays.
(11) Required only for pressurized or hermetically sealed units.
(12) Safety device testing required for lithium-ion batteries.

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Table 6.3-3. Unit Test Level Margins and Duration

Test	Qualification	Protoqualification	Acceptance
Shock[1]	6 dB above MPE, 3 times in each of 3 orthogonal axes	3 dB above MPE, 2 times in each of 3 orthogonal axes	Maximum predicted environment (MPE), once in each of 3 orthogonal axes
Acoustic[2]	6 dB above acceptance for 3 minutes	3 dB above acceptance for 2 minutes	Envelope of MPE and minimum spectrum (Figure 6.3.6-1) for 1 minute
Vibration[2]	6 dB above acceptance for 3 minutes in each of 3 axes	3 dB above acceptance for 2 minutes in each of 3 axes	Envelope of MPE and minimum spectrum (Figure 6.3.5-1) for 1 minute in each of 3 axes
Thermal Vacuum (non-electrical and non-electronic)	±10°C beyond acceptance for 6 cycles	±5°C beyond acceptance for 3 cycles	MPT for 1 cycle
Thermal Cycle or Thermal Vacuum Only	±10°C beyond acceptance for 27 cycles	±5°C beyond acceptance for 20 cycles	Envelope of MPT and minimum range (–24 to 61°C) for 14 cycles
Combined Thermal Vacuum and Thermal Cycle	±10°C beyond acceptance for 4 thermal vacuum cycles and 23 thermal cycles	±5°C beyond acceptance for 4 thermal vacuum cycles and 16 thermal cycles	Envelope of MPT and minimum range (–24 to 61°C) for 4 thermal vacuum cycles with minimum 2-hour hot operational dwell and 10 thermal cycles
Static Load[3]	1.25 times the limit load for unmanned flight or 1.4 times limit load for manned flight	1.25 times the limit load for unmanned flight or 1.25 times limit load for manned flight,	1.1 times the limit load
Pressure[4]	Pressures as specified in Table 6.3.12-2 following acceptance proof pressure test, duration sufficient to collect data	Not applicable	1.1 times MEOP for pressurized structures; 1.25 times MEOP for pressure vessels; 1.5 times MEOP for pressure components. Other metallic pressurized hardware items per References 4 and 5
EMC	12 dB minimum duration same as acceptance	6 dB minimum duration same as acceptance	6 dB 20 minutes at each space vehicle transmitter frequency for radiated susceptibility

(1) See B.1.6 for additional information.
(2) See B.1.2 and B.1.3 for units with effective duration greater than 15 seconds.
(3) See References 6 and 11.
(4) See Reference 19 for solid rocket motor cases used in expendable launch vehicles.

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6.3.1.3 Test Levels and Duration

a. Pressure. Ambient pressure is normally used (see 3.2).

b. Temperature. Ambient temperature shall be used for operations if the test objectives can be met. Otherwise, temperatures representative of the operational environment shall be used.

c. Duration. The run-in, or wear-in, test shall be performed as indicated in Reference 7. It consists of at least five cycles or 5% of the total expected service life (3.44), whichever is greater, unless the unit demonstrates the capability to perform in a predictably consistent and controlled manner with fewer cycles.

Additional requirements for MMAs are provided in Reference 7.

6.3.1.4 Supplementary Requirements

Perceptive parameters shall be monitored during the wear-in test to detect evidence of functional or performance degradation.

6.3.2 Unit Performance and Functional Test

6.3.2.1 Purpose

The performance test verifies that the unit meets the requirements of the unit specification. Functional testing verifies that the unit is operational. For MMAs see Reference 7 for functional test description.

6.3.2.2 Electrical Test Description

Electrical tests shall include application of expected voltages, impedances, frequencies, pulses, and waveforms (commands, data, clocking, polarity, etc.) at the electrical interfaces of the unit, including all redundant circuits. These parameters shall be varied throughout their specification ranges and the sequences expected in flight operation. The unit output and response shall be measured to verify that the unit performs to requirements. Performance shall also include electrical continuity, response time, or other tests that relate to a particular unit design. Harness specific testing is required by Reference 25.

6.3.2.3 Mechanical Test Description

Testing of moving mechanical assemblies shall be performed according to Reference 7.

For other unit types, tests shall be conducted to demonstrate that the unit is capable of operating such that all performance requirements are satisfied. These tests shall be conducted before, during, and after exposure to environmental test conditions and shall include measurements to determine whether performance specifications are met and whether damage or degradation in performance has occurred.

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6.3.3 Unit Leakage Test

6.3.3.1 Purpose

The leakage test demonstrates the capability of pressurized components and hermetically sealed units to meet the specified design leakage rate requirements.

6.3.3.2 Test Description

An acceptable leak rate to meet mission requirements is based upon development tests and appropriate analyses. An acceptable measurement technique is one that accounts for leak rate variations with differential pressure and hot and cold temperatures and has the required threshold, resolution, and accuracy to detect any leakage equal to, or greater than, the maximum acceptable leak rate. Consideration should be given to testing units at differential pressures greater or less than the maximum or minimum operating differential pressure to provide some assurance of a qualification margin for leakage. Consideration should also be given to testing at operational temperature extremes using an appropriate fluid to account for geometry and viscosity changes, as well as leakage under dynamic conditions during mission operations.

6.3.3.3 Test Level and Duration

The leakage tests shall be performed with the unit pressurized at the maximum differential operating pressure, as well as at the minimum differential operating pressure if the seals are dependent upon pressure for proper sealing. If appropriate to sealing capability, the leak rate test shall be made at qualification hot and cold temperatures with the representative fluid to account for geometry alterations and viscosity changes. If appropriate to mission operations, the leak rate test shall be conducted under dynamic conditions. The test duration shall be sufficient to detect any significant leakage. This test shall be performed for qualification, protoqualification, and acceptance testing.

6.3.4 Unit Shock Test

6.3.4.1 Purpose

The qualification or protoqualification shock test demonstrates the capability of the unit to survive shock and meet requirements during and after exposure to a margin over the maximum predicted shock environment (MPE) as defined in 3.28. The acceptance shock test demonstrates the workmanship of the unit during and after exposure to the maximum predicted shock environment.

6.3.4.2 Test Description

The unit shall be mounted to a fixture through the normal mounting points. The same test fixture should be used in the qualification, protoqualification, flightproof, and acceptance shock tests. If shock isolators are to be used in service, they shall be installed. The selected test method shall be capable of meeting the required shock spectrum with a transient that has duration comparable to the duration of the expected shock in flight.

A mounting of the unit on an actual, or dynamically similar, flight structure provides a more realistic test than does a mounting on a rigid structure such as a shaker armature or slip table. Sufficient prior development of the test mechanism shall have been carried out to validate the proposed test method

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before testing qualification, protoqualification, flightproof, or acceptance flight hardware. The test environment shall comply with the following conditions:

a. The prescribed shock spectrum can be generated within specified tolerances.

b. The applied shock transient shall approximate the duration and frequency content of the service shock event.

6.3.4.3 Test Level and Exposure

The shock spectrum in each direction along each of the three orthogonal axes shall meet the test specification for that direction. For vibration- or shock-isolated units, the lower frequency limit of the response spectrum shall be below 0.5 times the natural frequency of the isolated unit. The minimum number of shocks shall be imposed to meet the amplitude criteria in both directions of each of the three orthogonal axes as follows:

Qualification:	MPE + 6 dB applied 3 times
Protoqualification:	MPE + 3 dB applied 2 times
Acceptance:	MPE for one application

If a shock application cannot concurrently satisfy requirements in both directions of any axis, the test shall be conducted separately in each direction of that axis.

6.3.4.4 Supplementary Requirements

During shock testing wiring harnesses and hydraulic and pneumatic lines, instrumentation, and other connected items shall be equivalent to, or simulate the flight configuration to the first attachment point. The intent of this requirement is to simulate the external interconnecting mass, inertia, and stiffness effects on the unit's dynamic response unless shown to be insignificant.

Electrical and electronic units, including redundant circuits, shall be energized and monitored, if feasible and safe. Functional performance shall be monitored during the unit shock test. A performance test shall be performed before and after completion of shock testing.

A shock qualification or protoqualification test shall be required for electrical and electronic units and batteries for which any of the following conditions apply:

a. Shock MPE response spectrum (SRS) envelopes the unit random vibration spectrum converted to its corresponding acceptance SRS, at any frequency below 2,000 Hz or exceeds 50 in/sec modal velocity at any frequency below 10,000 Hz

b. The unit contains shock-sensitive components. Typical examples are crystals, ceramic chips, relays, etc.

For batteries see References 20, 26, and 27 for additional considerations.

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6.3.5 Unit Vibration Test

6.3.5.1 Purpose

The vibration qualification and protoqualification tests demonstrate the ability of the unit to endure a limited duration of acceptance testing and then meet requirements during and after exposure to a margin over the maximum predicted vibration environment (MPE) in flight. The vibration test may be discretionary for a unit having a large surface causing its vibration response to be due predominantly to direct acoustic excitation. Both acoustic and vibration tests are required, if necessary, to demonstrate the capability to withstand vibration excitation transmitted through its attachments.

6.3.5.2 Test Description

The unit shall be mounted to a test fixture through the normal mounting points of the unit. The same fixture shall be used in the qualification, protoqualification, and acceptance vibration tests. Attached wiring harnesses and hydraulic and pneumatic lines, instrumentation, and other connected items shall be equivalent to, or simulate the flight configuration to the first attachment point. The intent of this requirement is to simulate the external interconnecting mass, inertia, damping, and stiffness effects on the unit's dynamic response, unless shown to be insignificant. These items shall be connected using flight-like connectors. Such a configuration shall also be required when units that employ shock or vibration isolators are tested on their isolators. The suitability of the fixture and test control shall have been established (6.3.5.6) prior to the qualification testing. The unit shall be tested in each of three orthogonal axes.

Units mounted on shock or vibration isolators shall typically require vibration testing at qualification levels in two configurations. A first configuration is with the unit hard-mounted to qualify for the acceptance-level testing if, as is typical, the acceptance testing is performed without the isolators present. The second configuration is with the unit mounted on the isolators to qualify for the flight environment. The unit shall be mounted on isolators of the same production lot as those used in service. Units mounted on isolators shall be controlled at the locations where the isolators are attached to the fixture. Hard-mounted units shall be controlled at the unit mounting attachment or attachments as appropriate.

6.3.5.3 Test Levels and Duration

The basic test levels and duration required for units exposed to the liftoff and ascent vibration, effective duration of 15 seconds (see 3.12), are as follows:

Qualification:	6 dB above acceptance for 3 min/axis (B.1.1, B.1.2)
Protoqualification:	3 dB above acceptance for 2 min/axis (B.1.1, B.1.2)
Acceptance:	Envelope of MPE and minimum level shown in Figure 6.3.5-1 for 1 min/axis; for units heavier than 50 lbs, see B.2 for minimum level rationale

The qualification test demonstrates that adequate life remains for flight units after up to eight minutes of acceptance testing for each axis. The protoqualification test demonstrates that adequate life remains for subsequent flight units after only one minute of acceptance-level testing for each axis. However, the protoqualification test does not demonstrate adequate life left for flight of the

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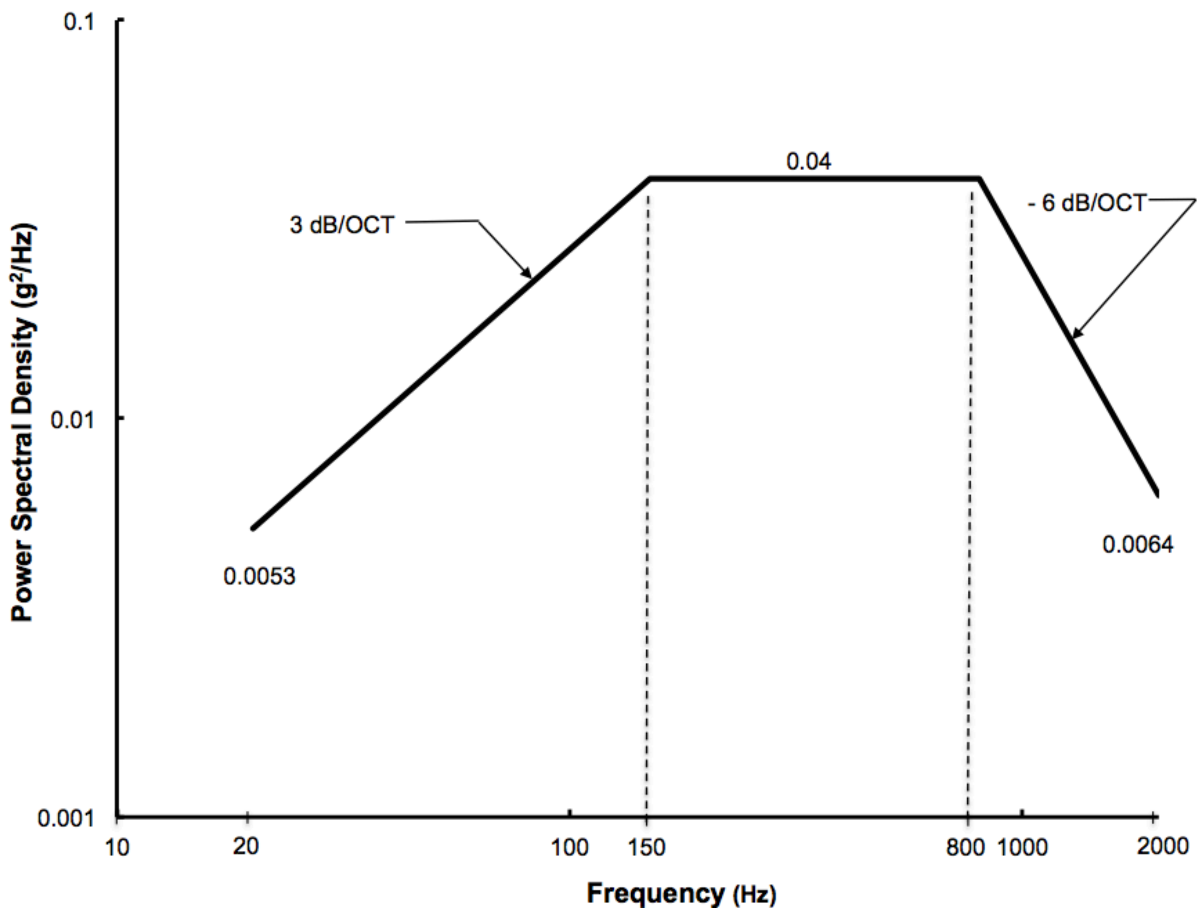

Spectrum Values	
Frequency (Hz)	**Minimum PSD (g^2/Hz)**
20	0.0053
20 to 150	+3 dB per octave slope
150 to 800	0.04
800 to 2000	-6 dB per octave slope
2000	0.00644
For heavier units see B.2	

Figure 6.3.5-1. Minimum random vibration spectrum, unit acceptance test.

protoqualification unit itself. The acceptance test demonstrates quality of workmanship and performance to specification.

For units subject to exposure to flight vibration longer than 15 seconds, or to demonstrate another bound on the accumulated duration of acceptance testing, see B.1.3 for changes to the qualification and protoqualification durations. See B.1.4 for an alternate test strategy.

For qualification and protoqualification testing of units flown on isolators, see 6.3.5.2 and B.1.4.

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Low-level testing shall be performed in each axis before and after the specified vibration tests to detect any structural changes.

6.3.5.4 Performance Test

During the test, all electrical and electronic units shall be electrically energized and functionally sequenced through various operational modes to the maximum extent practical. This includes all primary and redundant circuits, and all circuits that do not operate during launch. Several perceptive parameters, such as voltage, current, relay contact, software Built In Test (BIT), etc., shall be monitored for failures or intermittent performance during the test. Continuous monitoring of the unit, including the main bus by a power transient monitoring device, shall be provided to detect intermittent failures.

6.3.5.5 Supplementary Requirements

The vibration spectrum may be reduced, or notched, to prevent unrealistic input forces or unit responses due to differences in boundary conditions between test and flight. Reductions in the spectrum may also be appropriate to account for attenuation due to weight of units exceeding 50 lb (23 kg). See B.2 for additional information.

Units required to operate under pressure during ascent shall be pressurized to simulate flight conditions, from structural and leakage standpoints, and monitored for pressure decay. Units designed for operation during ascent, and whose maximum or minimum expected temperatures fall outside the normal temperature range, are candidates for combined vibration and temperature testing. When such testing is employed, units shall be conditioned to be as close to the worst-case flight temperature as is practical and monitored for temperature performance during vibration exposure.

For silver-zinc launch vehicle batteries, this test must be performed after full wet stand time and completion of non-operational thermal cycle testing in order to demonstrate compliance despite corrosion modes stimulated by long stand times or high temperature.

See B.1.5 for a discussion of a damage-based analysis approach of flight vibration data and its use for defining an MPE.

6.3.5.6 Fixture Evaluation

The vibration fixture shall be verified by test to uniformly impart motion to the unit under test and to limit the energy transfer, or crosstalk, from the test axis to the other two orthogonal axes. The crosstalk levels shall not exceed the input levels for the respective axes. The dynamic test configuration, fixture, and test article shall be evaluated for crosstalk before initial testing. The fixture shall be re-evaluated for changes in shaker or orientation of the test configuration.

6.3.5.7 Special Considerations for Structural Units

Vibration acceptance tests of structural units are normally not conducted because the process controls, inspections, and proof testing that are implemented are sufficient to assure performance and quality. However, to demonstrate structural integrity of structural units sensitive to fatigue modes with low margins of safety, a vibration qualification test shall be conducted. The test duration shall be four

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times the fatigue equivalent duration during flight and ground testing. When a structural unit is not subjected to a static strength qualification test, a brief random vibration qualification test shall be conducted with an exposure to 3 dB above acceptance. The duration shall be that necessary to achieve a steady-state response, but not less than ten seconds, to demonstrate that strength requirements are satisfied.

6.3.5.8 Options for Vibration Testing

Alternate vibration test techniques may be employed in those cases where baseline procedures do not satisfy the objectives of the program.

6.3.5.8.1 Two-Phase Testing

The two-phase approach to vibration qualification, or protoqualification, testing is an alternate test strategy that may be used for:

a. Units that are isolated in flight but acceptance tested without isolators, or by

b. Cases where reduction in the conservatism in accelerated testing (see B.1.2) for acceptance life is appropriate. This is especially relevant for units that are exposed to environments for extended periods of time, such as units located close to operating engines.

The two-phase approach consists of a Phase I test for acceptance life performed at the acceptance spectrum for the duration required to demonstrate life for flight and expected acceptance testing. This is followed by a Phase II test at the qualification/protoqualification spectrum for a period four times the effective duration of MPE in flight. Both tests shall be conducted on the same test specimen. B.1.4 provides additional details on this approach.

6.3.5.8.2 Alternate Vibration Test for Qualification and Protoqualification

As stated in 4.2.2, qualification/protoqualification testing is performed to verify the capability of the design to withstand the flight maximum predicted environments with a specified margin and validate the acceptance test program for subsequent flight hardware. The discussion in B.1.1 indicates that baseline qualification testing, performed for three minutes duration at +6 dB margin, demonstrates eight acceptance lives in addition to flight for subsequent flight hardware. Protoqualification testing, performed for two minutes duration at +3 dB margin, demonstrates life for one acceptance test, and flight, but does not demonstrate life for retesting. In some cases it may be possible to qualify the hardware at intermediate levels and durations, between baseline qualification and protoqualification to demonstrate capability to withstand stress levels and durations higher than protoqualification but less stringent than qualification.

As an example consider qualification testing involving vibration exposure at +4.5 dB for 2.5 minutes. This demonstrates enhanced stress capability and additional acceptance lives compared to protoqualification but increases risk for the tested flight hardware. The +6 dB analytical design margin must be retained to provide for possible risk mitigation. This option demonstrates life for three acceptance tests and flight. Two of those lives may be set aside for retesting following possible hardware repairs. Section B.1.4 provides an explanation of the trades between test levels and durations which may be used for tailoring this requirement to satisfy program needs.

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Another example may be to increase the exposure time from two to three minutes at acceptance +3 dB for protoqualification. This option demonstrates life for two acceptance tests plus flight. One of those acceptance lives may be used for retest.

If any of these options are adopted, the test tolerances shown in Table 4.7-1 shall be adjusted to avoid degradation of the test to levels below requirements at the low tolerance side of the spectrum. For the case of the protoqualification example shown above, the test tolerance will be ±0.5 dB between 20 Hz and 1000 Hz and ±1.5 dB between 1000 Hz and 2000 Hz or as close to these values as the test facility can achieve.

6.3.6 Unit Acoustic Test

This test is applicable to units with large surface areas that are sensitive to direct acoustic excitation.

6.3.6.1 Purpose

The acoustic qualification and protoqualification tests demonstrate the ability of a unit to endure a limited duration of acceptance testing and then meet requirements during and after exposure to a margin over the acceptance test level, which is an envelope of MPE and the minimum acoustic spectrum shown in Figure 6.3.6-1. Acoustic testing is required for a unit having large surfaces, causing its vibration response to be due predominantly to direct acoustic excitation. For such units, the vibration test is discretionary except as noted in 6.3.5.1.

6.3.6.2 Test Description

The unit in its ascent configuration shall be installed in an acoustic test facility capable of generating sound fields or fluctuating surface pressures that induce unit vibration environments sufficient for unit qualification. The unit shall be mounted on a flight-like support structure. Significant fluid and pressure conditions affecting structural damping shall be replicated. Appropriate dynamic instrumentation shall be installed to measure vibration and strain responses. Control microphones shall be placed at a minimum of four well-separated locations at one-half the distance from the test article to the nearest chamber wall, but no closer than 20 in. to both the test article surface and the chamber wall. The average of all control microphones shall be used for spectrum control.

6.3.6.3 Test Levels and Duration

The basic test levels and duration required for units exposed to the liftoff and ascent acoustic excitation, effective duration of 15 seconds (see 3.12), are as follows:

Qualification:	6 dB above acceptance for 3 min (see B.1.1, B.1.2)
Protoqualification:	3 dB above acceptance for 2 min (see B.1.1, B.1.2)

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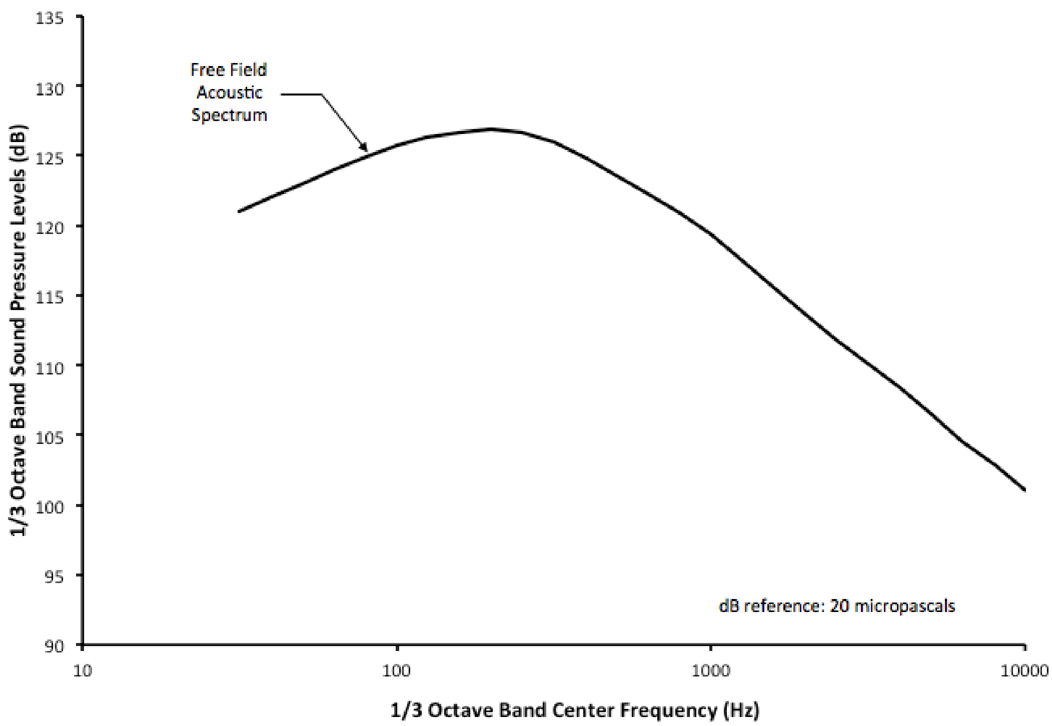

Spectrum Values			
1/3 Octave Band Center Frequency (Hz)	Minimum Sound Pressure Levels (dB)	1/3 Octave Band Center Frequency (Hz)	Minimum Sound Pressure Levels (dB)
31.5	121.0	630.0	122.2
40.0	122.0	800.0	120.9
50.0	123.0	1000.0	119.3
63.0	124.0	1250.0	117.5
80.0	124.9	1600.0	115.5
100.0	125.7	2000.0	113.6
125.0	126.3	2500.0	111.9
160.0	126.7	3150.0	110.1
200.0	126.9	4000.0	108.4
250.0	126.6	5000.0	106.5
315.0	126.0	6300.0	104.6
400.0	124.8	8000.0	102.8
500.0	123.6	10000.0	101.1
Overall Sound Pressure Level (OASPL) = 136.8 dB			

Figure 6.3.6-1. Minimum acoustic spectrum, unit and vehicle.

Acceptance: Envelope of acoustic MPE (see 3.26) and minimum level shown in Figure 6.3.6-1 for 1 min

The qualification test demonstrates that adequate life remains for flight units after up to eight minutes of acceptance testing. The protoqualification test demonstrates that adequate life remains for subsequent flight units after only one minute of acceptance-level testing for each axis. However, the protoqualification test does not demonstrate adequate life left for flight of the protoqualification unit itself. The acceptance test demonstrates quality of workmanship and performance to specification.

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For a longer exposure to flight acoustic excitation, or to demonstrate another bound on the accumulated duration of acceptance testing, see B.1.3 for changes to the qualification and protoqualification durations. See B.1.4 for an alternate test strategy.

6.3.6.4 Supplementary Requirements

During the test, electrically active units shall be electrically energized and functionally sequenced through various operational modes to the maximum extent practical. This includes all primary and redundant circuits, and all circuits that do not operate during launch. Several perceptive parameters, such as voltage, current, relay contact, software Built In Test (BIT), etc., shall be monitored for failures or intermittent performance during the test. Continuous monitoring of the unit, including the main bus by a power transient monitoring device, shall be provided to detect intermittent failures.

See B.1.5 for discussion of a damage-based approach to the analysis of flight acoustic data for determining the adequacy of established acceptance qualification or protoqualification testing when new flight data lead to questioning the adequacy of the MPE spectrum.

6.3.6.5 Options for Acoustic Testing

Alternate acoustic test techniques may be employed in those cases where baseline procedures do not satisfy the objectives of the program.

6.3.6.5.1 Two-Phase Testing

The two-phase approach to acoustic qualification/protoqualification testing is an alternate test strategy that may be used for:

a. Units that are isolated in flight but acceptance tested without isolators, or

b. Cases where it is desired to avoid the increase in test level required for accelerated testing. This is relevant for units that are exposed to environments for extended periods of time.

This approach consists of a Phase I test for acceptance life performed with the acceptance spectrum for the duration required to demonstrate life for flight and expected testing. This is followed by a Phase II test for flight with the qualification/protoqualification spectrum for a period four times the effective duration of MPE. Both tests shall be conducted on the same test specimen. See B.1.4 for further guidance and examples on how to apply this strategy

6.3.6.5.2 Alternate Acoustic Test for Qualification and Protoqualification

As stated in 4.2.2, qualification/protoqualification testing is performed to verify the capability of the design to withstand the flight maximum predicted environments with a specified margin and validate the acceptance test program for subsequent flight hardware. The discussion in B.1.1 indicates that baseline qualification testing, performed for three minutes duration at +6 dB margin, demonstrates eight acceptance lives in addition to flight for subsequent flight hardware. Protoqualification testing, performed for two minutes duration at +3 dB margin, demonstrates life for one acceptance test, and flight, but does not demonstrate life for retesting. In some cases it may be possible to qualify the hardware at intermediate levels and durations, between baseline qualification and protoqualification

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to demonstrate capability to withstand stress levels and durations higher than protoqualification but less stringent than qualification.

As an example, consider qualification testing involving acoustic exposure at +4.5 dB for 2.5 minutes. This demonstrates enhanced stress capability and additional acceptance lives compared to protoqualification but increases risk for the tested flight hardware. The +6 dB analytical design margin must be retained to provide for possible risk mitigation. This option demonstrates life for three acceptance tests and flight. Two of those lives may be set aside for retesting following possible hardware repairs. B.1.4 provides an explanation of the trades between test levels and durations which may be used for tailoring this requirement to satisfy program needs.

Another example is to increase the exposure time from two to three minutes at acceptance +3 dB for protoqualification. This option demonstrates life for two acceptance tests plus flight. One of those acceptance lives may be used for retest. If any of these options are adopted, the test tolerances shown in Table 4.7-1 shall be adjusted to avoid degradation of the test to levels below requirements at the low tolerance side of the spectrum. For the case of the protoqualification example shown above, the test tolerance will be ±0.5 dB between 20 Hz and 1000 Hz and ±1.5 dB between 1000 Hz and 2000 Hz, or as close to these values as the test facility can achieve.

6.3.7 Unit Acceleration Test

6.3.7.1 Purpose

The acceleration test demonstrates the capability of the unit to withstand or, if appropriate, to operate in the qualification-level acceleration environment. This test shall be performed for qualification and protoqualification testing.

6.3.7.2 Test Description

The unit shall be attached, as it is during flight, to a test fixture and subjected to acceleration in appropriate directions. The specified accelerations apply to the center of gravity of the test item. If a centrifuge is used, the arm (measured to the geometric center of the test item) shall be at least five times the dimension of the test item measured along the arm. The acceleration gradient across the test item should not result in accelerations that fall below the qualification level on any critical member of the test item. In addition, any over-test condition shall be minimized to prevent unnecessary risk to the test article. Inertial units such as gyros and platforms may require counter-rotating fixtures on the centrifuge arm. The unit shall be tested in both directions of three orthogonal axes.

6.3.7.3 Test Levels and Duration

a. **Acceleration Level.** The test acceleration level shall be at least 1.25 times the maximum predicted acceleration (see 3.25).

b. **Duration.** Unless otherwise specified, the test duration shall be at least five minutes for each direction of test.

6.3.7.4 Supplementary Requirements

If the unit is to be mounted on shock or vibration isolators in the vehicle, the unit shall be mounted on these isolators during the qualification test.

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6.3.8 Unit Thermal Cycle Test

6.3.8.1 Purpose

The thermal cycle test imposes environmental stress screens in an ambient pressure environment to detect flaws in design, parts, processes, and workmanship. The thermal cycle qualification test demonstrates robustness of the electrical and electronic unit design, operation over the design temperature range, and the ability to function during subsequent acceptance testing. The thermal cycle acceptance test demonstrates workmanship integrity and the ability of the unit to survive and operate properly in the maximum expected conditions of its life cycle.

6.3.8.2 Test Description for Electrical and Electronic Units

With the unit operating (power on), the unit shall be tested while subjected to the temperature profiles in Figures 6.3.8-1, 6.3.8-2, and 6.3.8-3, or as appropriate, for first, intermediate, and last cycle testing, respectively. The test control temperature shall be measured at a representative location on the unit, such as at the mounting point on the baseplate.

For testing at the hot temperature on the first cycle per Figure 6.3.8-1:

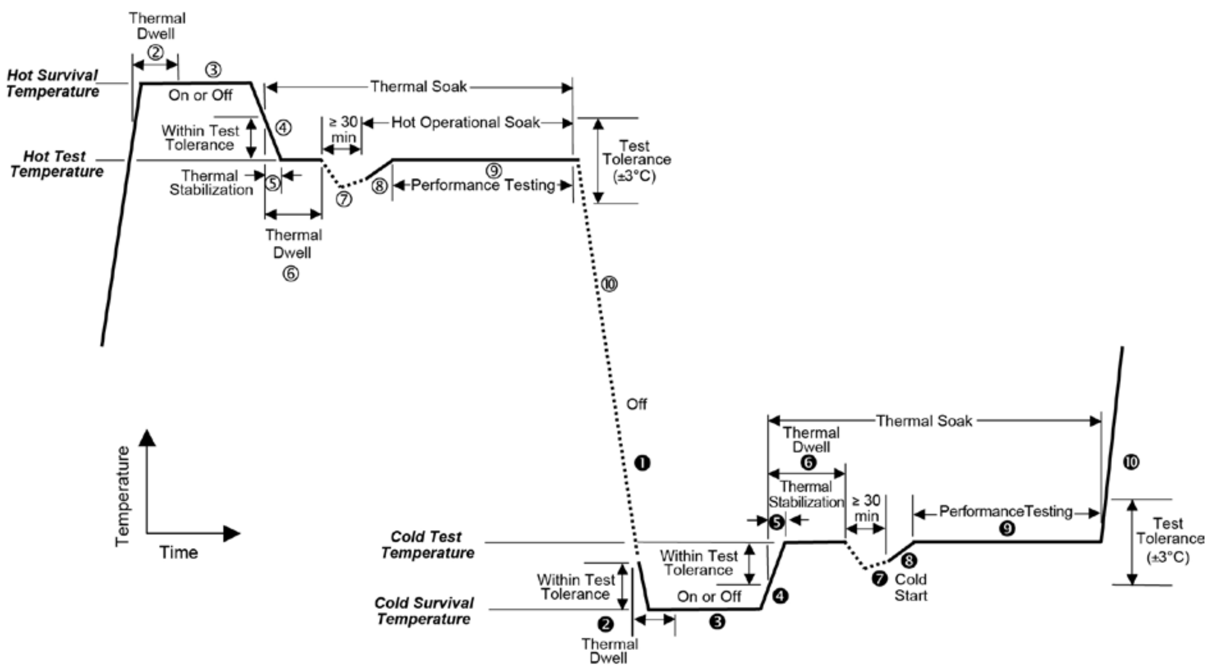

Figure 6.3.8-1. Notional temperature profile for first cycle testing.

① The environment (chamber temperature) and unit power are set to ramp the unit to its hot survival test temperature. If the hot survival temperature is an operational survival limit, the unit shall be operational (turned on either at ambient or at a hot turn-on temperature) during this transition. If the hot survival temperature is a non-operational limit, the unit shall not be operating during this transition.

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② At the survival temperature, time shall be accrued to allow internal unit locations to reach the survival temperature (thermal dwell).

③ The unit shall be soaked at the survival temperature.

④ The temperature shall be transitioned to the hot test temperature (e.g., qualification, protoqualification, or acceptance). If the hot survival temperature is a non-operational limit, the unit shall be turned on at the hot turn-on temperature during the transition to the hot test temperature.

⑤ When the control temperature is within the test tolerance, the environment shall be adjusted to bring the control temperature to the hot test temperature.

⑥ Additional time shall be accrued at the hot test temperature to allow internal unit locations to reach the test temperature (thermal dwell).

⑦ Following this dwell, the unit shall be turned off for at least 30 minutes off to allow internal temperatures to stabilize to non-operational levels. During the non-operational time, the environment may be adjusted to keep the unit temperature within the test tolerance.

⑧ The unit shall then be turned on, and if necessary, the environment shall be adjusted to re-stabilize the unit at the test temperature.

⑨ Performance testing at the hot test temperature shall be conducted.

⑩ After the hot operational soak time is satisfied and performance testing is completed, the environment shall be set to ramp the unit to the cold survival temperature.

For testing at the cold temperature on the first cycle per Figure 6.3.8-1:

❶ To aid in the transition to the cold temperature, the unit may be powered off at the completion of hot performance testing. If the cold survival temperature is an operational survival limit, the unit shall be turned on at the cold turn-on temperature or, if not specified, a temperature that is no colder than the test tolerance above the cold survival temperature. If the cold survival temperature is a non-operational limit, the unit shall not be operating during this transition.

❷ At the cold survival temperature, time shall be accrued to allow internal unit locations to reach the survival temperature (thermal dwell).

❸ The unit shall be soaked at the survival temperature.

❹ The temperature shall be transitioned to the cold test temperature. If the cold survival temperature is a non-operational limit, the unit shall be turned on at the cold turn-on temperature during the transition to the cold test temperature.

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❺ When the control temperature is within the test tolerance, the environment shall be adjusted to bring the control temperature to the cold test temperature.

❻ Additional time shall be accrued at the hot test temperature to allow internal unit locations to reach the test temperature (thermal dwell).

❼ Following this dwell, the unit shall be turned off for at least 30 minutes off to allow internal temperatures to stabilize to non-operational levels. During the non-operational time, the environment may be adjusted to keep the unit temperature within the test tolerance.

❽ The unit shall then be turned on, and, if necessary, the environment shall be adjusted to re-stabilize the unit at the test temperature.

❾ Performance testing at the cold test temperature shall be conducted.

❿ After cold performance testing is completed, the environment shall be set to ramp the unit to the hot test temperature on cycle 2.

Temperature change from ambient to hot, to cold, and return to ambient constitutes one thermal cycle.

On the first cycle, the unit shall demonstrate survival capability requirements at its survival hot and survival cold temperatures (see 3.55). Following a thermal dwell at the survival temperature, the unit shall be maintained at the survival temperature for a minimum of one hour. For a unit with a hot or cold turn-on temperature requirement different from its operational value, turn-on capability at the turn-on temperature shall be demonstrated on the first cycle.

Testing at the hot and cold temperatures on intermediate cycles (Figure 6.3.8-2) is similar to that described for the first cycle except there is no survival demonstration (steps ②,③, ④, ❷, ❸, and ❹), there are no hot/cold starts (steps ⑦, ⑧, ❼, and ❽) and functional testing replaces performance testing.

Testing at the hot and cold temperatures on the last cycle (Figure 6.3.8-3) is similar to that described for the first cycle except there is no survival demonstration (steps ②, ③, ④, ❷, ❸ and ❹). At the completion of cold performance testing, the environment is adjusted to return the unit to ambient.

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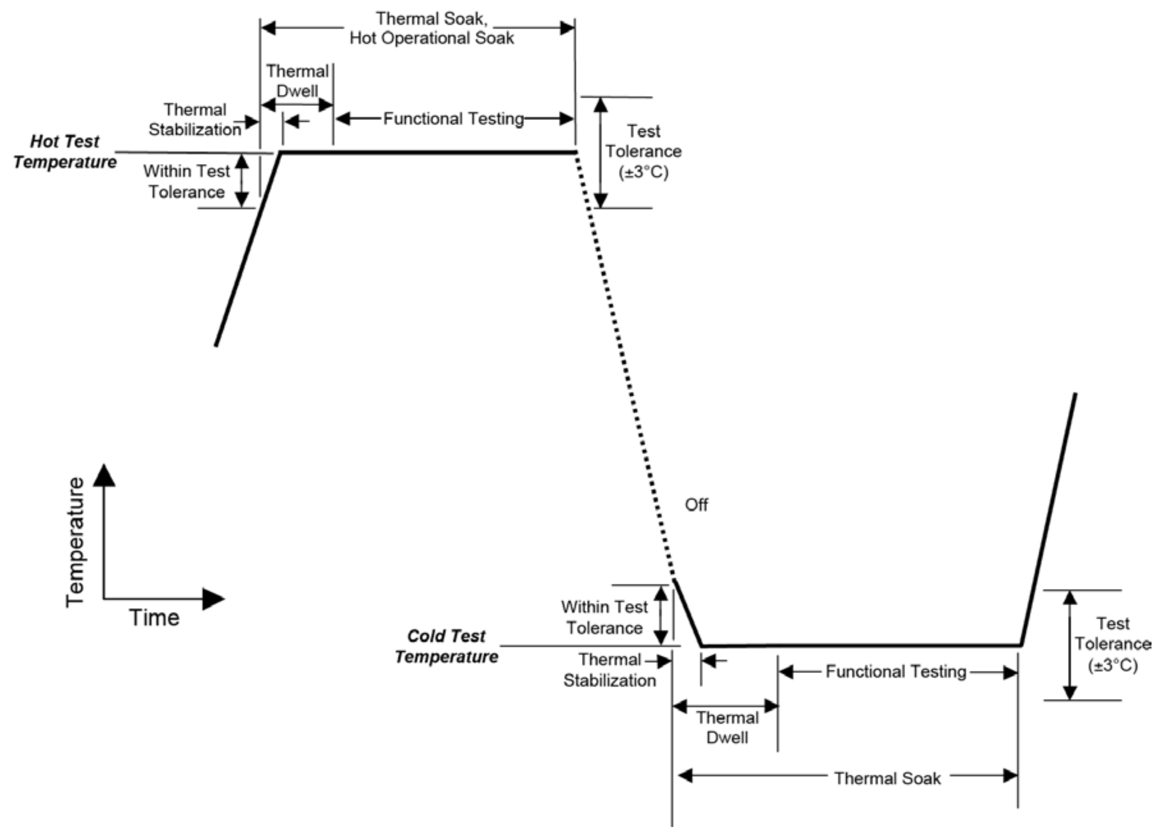

Figure 6.3.8-2. Notional temperature profile for intermediate cycle testing.

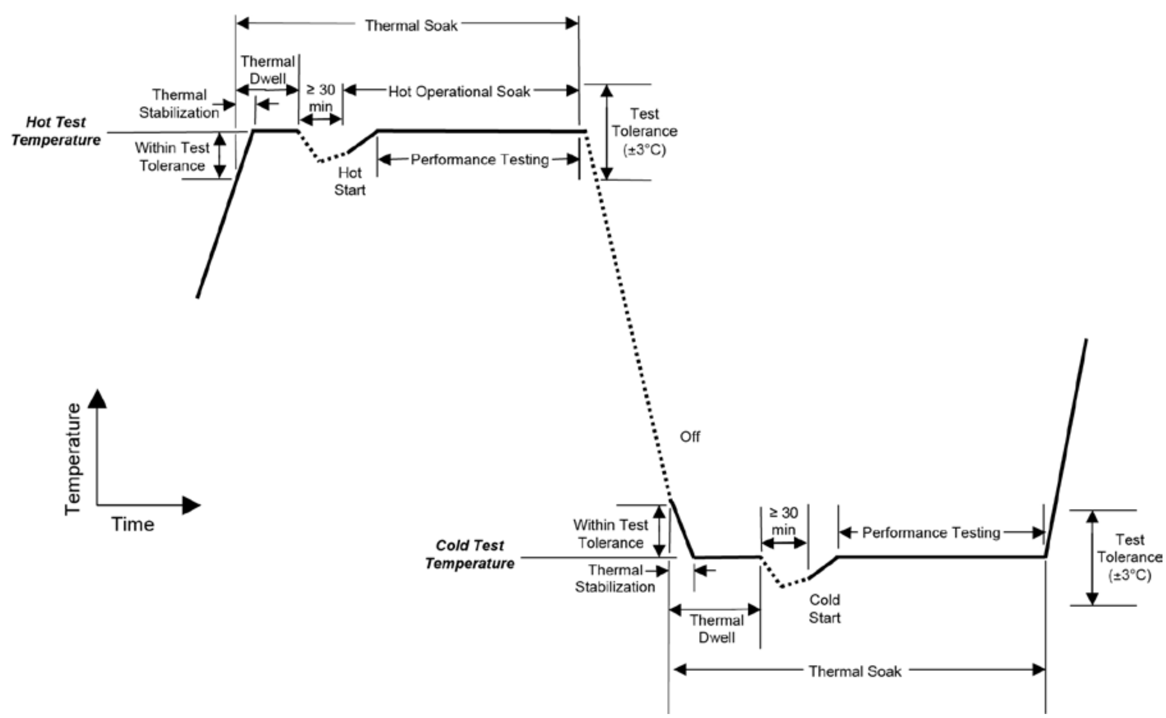

Figure 6.3.8-3. Notional temperature profile for last cycle testing.

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Compliance to specified performance requirements shall be required over acceptance, protoqualification, and qualification temperature ranges. Performance tests shall be conducted after electrical and electronic unit temperatures have stabilized (see 3.57) at the hot and cold temperatures during the first and last cycle, and at ambient temperature prior to and following the test. Functional tests shall be performed at hot and cold temperature plateaus on intermediate cycles. These tests shall include:

a. During performance and functional tests, the unit shall be cycled through a sufficient number of operational modes to fully characterize the performance and functionality of the unit.

b. Performance tests shall test all paths, including continuity, with functional testing as a subset of performance testing that focuses on critical, primary, and redundant paths to check functionality.

c. During the test, perceptive parameters shall be monitored for failures, degradation trends, and intermittent behavior.

d. All electrical circuits and all paths shall be verified for circuit performance and continuity.

e. For units with internal redundancy, performance testing, functional testing, and hot and cold starts shall be demonstrated on primary and redundant circuits and paths.

f. During temperature transitions, the unit shall be powered on and monitored, except as noted, and the health of the unit shall be monitored and key parameters trended. Any performance of the unit required during temperature transitions shall be tested during the test transitions.

6.3.8.3 Test Levels and Duration for Electrical and Electronic Units

a. **Pressure and Humidity.** The test shall be performed at ambient pressure. When unsealed units are being tested, precautions shall be taken to preclude condensation on and within the unit at low temperature. For example, the chamber may be flooded with dry air or nitrogen. Careful consideration shall also be given to the starting temperatures and temperature transitions applied to avoid moisture condensation. A common practice is to require the first and last half cycle to be conducted hot.

b. **Temperature.** Units shall be tested to temperature ranges given below and as shown in Figure 6.3.8-4.

Qualification:	10°C beyond acceptance test temperatures or –34 to 71°C (minimum range)
Protoqualification:	5°C beyond acceptance test temperatures or –29 to 66°C (minimum range)
Acceptance:	Maximum and minimum predicted temperatures or –24 to 61°C (minimum range)

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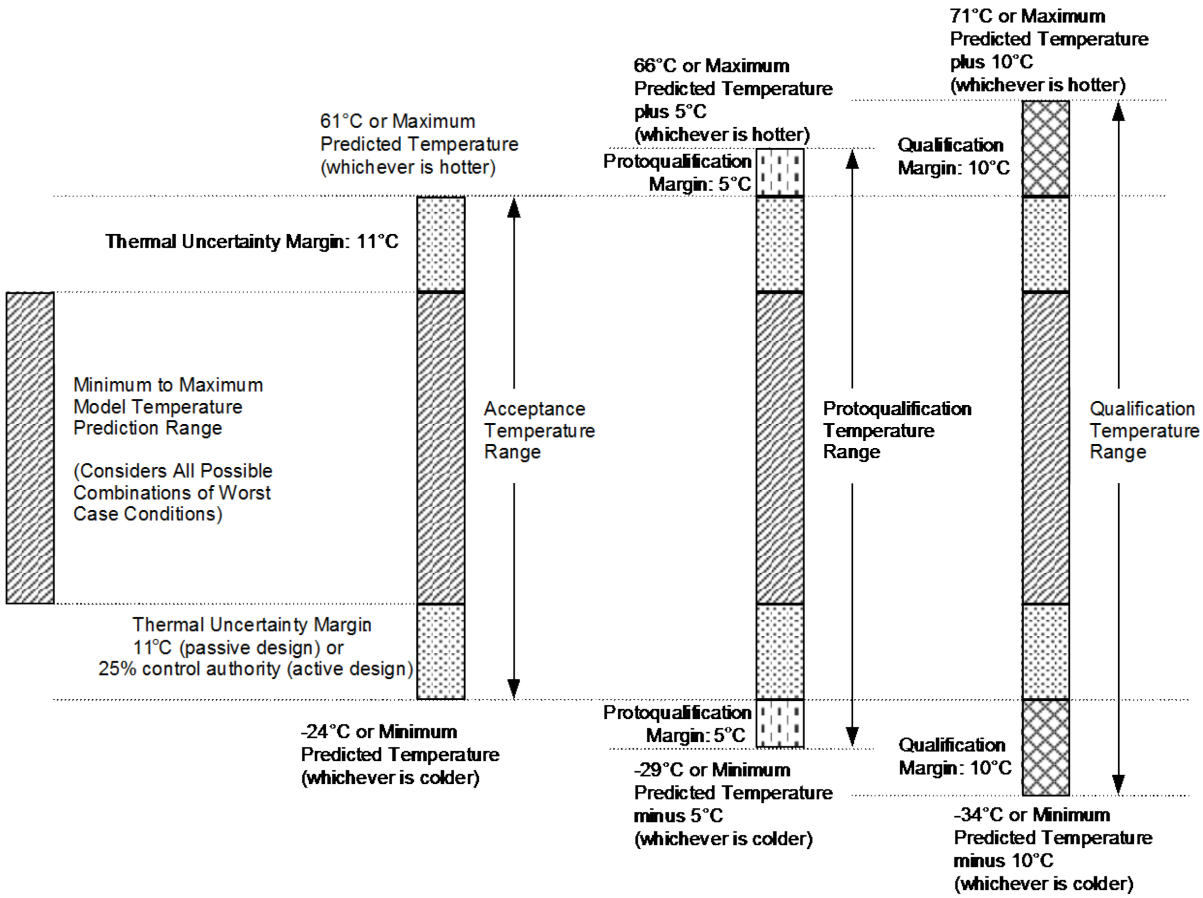

Figure 6.3.8-4. Unit test temperature ranges and margins.

The transition rate between hot and cold shall be at an average rate of 3°C to 5°C per minute, and shall not be slower than 1°C per minute.

c. **Duration.** The minimum number of thermal cycles (TC) shall be as shown when combined with the unit thermal vacuum (TV) test (Table 6.3-3):

Qualification:	23 TC and 4 TV cycles
Protoqualification:	16 TC and 4 TV cycles
Acceptance:	10 TC and 4 TV cycles

When an acceptance unit is insensitive to the vacuum environment (4.10.2) and only the thermal cycle test is performed (no thermal vacuum test), the minimum number of cycles is:

Acceptance:	14 TC cycles

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For Multi-Unit Module (MUM) (see 3.32), acceptance unit test cycles shall be reduced to ten thermal cycles if four thermal vacuum cycles are performed at the MUM level. The ten unit thermal cycles may either be unit thermal vacuum cycles or unit thermal cycles.

The last three thermal cycles shall be failure free. Units shall remain operational except during the first and last cycle, where a minimum one-half hour is required between unit turn-off and turn-on for stabilization. Units may be turned off during the cold ramp on intermediate cycles to accelerate testing.

Thermal soaks at hot and cold temperature plateaus shall be a minimum of six hours on the first and last cycle and one hour on intermediate cycles. Hot operational soaks shall be a minimum of two hours on the first and last cycle and a minimum of one hour (coincident with thermal soak) on intermediate cycles. At cold temperatures, the unit shall be thermally stabilized before proceeding to further testing.

Temperature stabilization is achieved when the unit baseplate is within the allowed test tolerance on the specified test temperature, and the temperature rate of change is less than 3°C per hour. Thermal dwells at hot and cold temperatures shall be a minimum of one hour for all cycles. For intermediate cycles, thermal dwell may be shorter than one hour, provided analysis results verify internal temperature stabilization of the unit. For units in which the dwell duration may be greater than one hour, analysis results or test data shall be used to predict the appropriate dwell duration.

When a unit's design precludes testing over the temperature ranges specified in paragraph 6.3.8.3.b, the number of test cycles shall be increased to provide an equivalent level of screening effectiveness. The relationships given below shall be used to calculate equivalent cycles for units that are subjected to thermal cycling only or subjected to thermal vacuum and thermal cycle testing. The term ΔT is the proposed test temperature range (in °C).

Qualification:	$27(105/\Delta T)^{1.4}$ cycles
Protoqualification:	$20(95/\Delta T)^{1.4}$ cycles
Acceptance:	$14(85/\Delta T)^{1.4}$ cycles

6.3.8.3.1 Option for Use of Slice/Board Testing for Acceptance Cycles

If slice/board thermal testing is performed on flight hardware, then a credit may be taken toward meeting unit-level thermal test requirements. To allow slice/board credit toward unit level requirements, the following criteria shall be satisfied:

a. Slices/boards shall be powered on and monitored during testing.

b. All slices, boards, and cards in a unit shall be tested in the same manner. Temperature levels (average values at the same relative locations) shall envelope (hot and cold) those at the unit level.

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c. Performance and functional testing, as appropriate, shall be conducted during the first and last cycles of slice/board thermal tests at hot and cold temperature plateaus. Perceptive parameters shall be monitored during all other phases of the tests.

d. Slice/board thermal test plans and procedures shall be documented in a manner similar to unit-level thermal testing.

e. Slice/board thermal test results shall be documented and approved by the customer. The reports shall address all anomalies, failures, corrective actions, and observations found during the test.

f. An assessment shall be made on all items or aspects of the unit not subjected to slice/board thermal testing (interfaces, connecting cables, subassemblies not mounted to boards, parts mounted to chassis walls or base plate, etc.). This assessment shall consider the integrity and robustness in meeting unit level design and performance requirements as these items are exposed to fewer unit cycles when the slice/board thermal test credit is taken.

If the above criteria are satisfied and approved by the customer, unit-level test credit shall be applied to the thermal cycle test and burn-in test requirements (not thermal vacuum test) in that the required number of unit-level thermal cycles and the burn-in test duration shall be reduced. The maximum cycle credit given for slice/board level thermal testing shall be half the required number of unit thermal cycles. For example, an acceptance unit requiring 14 thermal test cycles (ten thermal cycles and four thermal vacuum cycles) may be given a seven-cycle maximum credit for slice/board level testing, and the unit thermal cycle test program is modified to three thermal test cycles and four thermal vacuum test cycles.

When slice/board temperature ranges differ from required unit level test ranges, the relationships provided in 6.3.8.3c may be used to compute equivalent test cycles. The slice/board with the fewest number of equivalent unit-level cycles shall be used for determining the cycle credit to be taken. For example, a three-slice unit with three, seven, and ten equivalent unit-level cycles shall be given a three cycle credit in reducing unit cycle requirements. Likewise for the burn-in duration credit, the slice/board with the minimum equivalent thermal test hours shall be used for determining the unit-level burn-in credit. Duration hours count only when the slice/board is powered on in the slice/board test. Unlike the thermal cycle credit, the minimum equivalent duration slice/board testing that meets the above criteria may be sufficient to eliminate the need for any unit-level burn-in testing when the number of accrued hours in slice/board testing meets or exceeds the number of hours required at the unit level and when all critical unit hardware has been subjected to adequate slice/board testing.

Slice/board level thermal testing shall not eliminate or reduce other unit thermal requirements (e.g., failure-free cycles, survival demonstration, dwell times, etc.) to be demonstrated in unit thermal tests.

6.3.8.3.2 Option for Two Tier Testing

When a unit's performance temperature limits do not comply with Figure 6.3.8-4 temperature ranges, but operational temperature limits do, a two-tier thermal test approach may be adopted whereby the unit demonstrates operational requirements at the minimum temperature range shown in Figure 6.3.8-4 and performance requirements at a narrower temperature range. The two tier test approach is described in A.1.2.

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6.3.8.4 Burn-in for Electrical and Electronic Units

For acceptance and protoqualification testing, units shall be "burned in" to detect latent infant mortality defects. During burn-in, the test unit shall be powered on, and key parameters monitored and trended. The duration of burn-in is such that the combined duration of unit thermal cycling, unit thermal vacuum, and the additional burn-in testing shall be at least 200 hours. The durations of the thermal cycle and thermal vacuum test accrue toward the 200-hour duration requirement. Performance tests shall be performed prior to and following the burn-in test. The test is performed with the unit temperature either cycled between the acceptance temperature limits or elevated at the acceptance hot temperature. Testing may be performed at ambient pressure as a continuation of the unit thermal cycle test. The last 100 hours of operation shall be failure free. For burn-in tests of less than 100 hours in duration, the test shall be failure free. For units with internal redundancy, the operating hours shall consist of at least 100 hours for each redundancy with a minimum total of 200 operating hours. The last 50 hours of each circuit (primary and redundant) shall be failure free.

6.3.8.5 Thermal Cycle Testing for Units Other Than Electrical and Electronic

When a thermal cycle test is performed for non-electrical and non-electronic units (see Table 6.3-2), the purpose and test description are similar to that described for electrical and electronic units. The primary difference is in the test levels and duration.

a. **Pressure and Humidity.** Same as 6.3.8.3.a.

b. **Temperature.** Units shall be tested to the ranges given below:

Qualification:	10°C beyond acceptance test temperatures
Protoqualification:	5°C beyond acceptance test temperatures
Acceptance:	Maximum and minimum predicted temperatures

c. **Durations.** The minimum number of thermal cycles shall be:

Qualification:	6 cycles
Protoqualification:	3 cycles
Acceptance:	1 cycle

These cycles can be accrued as a combination of unit thermal cycle and unit thermal vacuum tests (6.3.9.5).

The temperature transition rate shall be the same as stated for electrical and electronic units, but shall also demonstrate a transition rate representative of flight conditions, if practical. The thermal stabilization and thermal dwell durations shall be the same as specified for electronic and electrical units. Thermal soak durations shall be specified for the unit to achieve thorough performance verification. Unit performance shall be demonstrated at the required test temperatures. These requirements are specified in 6.3.8.3.

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The unit shall demonstrate survival capability requirements after exposure to survival hot and survival cold temperatures (see 3.55) on the first cycle. Survival cycle requirements shall be identical to those stated for electronic and electrical units.

6.3.9 Unit Thermal Vacuum Test

6.3.9.1 Purpose

The thermal vacuum test demonstrates performance and survivability over combined thermal and vacuum conditions. The qualification thermal vacuum test demonstrates the ability of the unit to perform to specification limits in the qualification environment and to endure the thermal vacuum testing imposed on flight units during acceptance testing. It also serves to verify the unit thermal design. The acceptance thermal vacuum test detects material and workmanship defects and proves flightworthiness of the unit. Criteria for exemptions to unit acceptance thermal vacuum testing are given in 4.10.2.

6.3.9.2 Test Description for Electrical and Electronic Units

The unit under test shall be mounted in a vacuum chamber on a thermally controlled heat sink or in a manner similar to its actual installation in the vehicle. The unit surface finishes, which affect radiative heat transfer or contact conductance, shall be thermally equivalent to those on the flight units. For units designed to reject their waste heat through the baseplate, a control temperature sensor shall be attached to either the unit baseplate or the heat sink. The location shall be chosen to correspond as closely as possible to the temperature limits used in the vehicle thermal design analysis or applicable unit-to-vehicle interface criteria. For components cooled primarily by radiation, a representative location on the unit case shall similarly be chosen. The unit heat transfer to the thermally controlled heat sink and the radiation heat transfer to the environment shall be controlled to the same proportions as calculated for the flight environment.

The chamber pressure shall be reduced to the required vacuum conditions. Units that are required to operate during ascent shall be operating and monitored for arcing and corona during the reduction of pressure to the specified lowest levels and during the early phase of vacuum operation. Units that do not operate during launch shall have electrical power applied after the test pressure level has been reached.

A thermal cycle begins with the conductive or radiant sources and sinks at ambient temperature. With the unit operating (power on), the unit shall be tested while subjected to the temperature profiles in Figures 6.3.8-1, 6.3.8-2, and 6.3.8-3, or as appropriate, for first, intermediate and last cycle testing, respectively. The unit temperature shall be raised to the specified hot temperature and maintained for thermal dwell to ensure the unit internal temperature has stabilized. On the first cycle, survival requirements shall be demonstrated at the unit's survival hot and cold limits as described for unit thermal cycle testing (6.3.8.2). On the first and last cycles, the unit shall be turned off, then hot-started and performance tested. Following the thermal soak and with the unit operating, the unit temperature shall be reduced to the specified cold temperature. To aid in reaching the cold temperature, the unit may be powered off at the completion of hot performance testing. After the unit temperature has reached the specified cold temperature, the unit shall be turned off (if not previously turned off during the transition) until the internal temperature stabilizes through the thermal dwell, and then cold started and performance tested. The unit shall be maintained at the cold temperature until the end of

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the thermal soak. The temperature of the sinks shall then be raised to ambient conditions. This constitutes one complete thermal cycle.

On the first cycle, the unit shall demonstrate survival capability requirements at its survival hot and survival cold temperatures (see 3.55). Following a thermal dwell at the survival temperature, the unit shall be maintained at the survival temperature for a minimum of one hour. For a unit with a hot or cold turn-on temperature requirement different from its operational value, turn-on capability at the turn-on temperature shall be demonstrated on the first cycle.

Compliance to specified performance requirements shall be required over acceptance, protoqualification, and qualification temperature ranges. Performance tests shall be conducted after electrical and electronic unit temperatures have stabilized (see 3.57) at the hot and cold temperatures during the first and last cycle, and at ambient temperature prior to, and following, the test. Functional tests shall be performed at hot and cold temperature plateaus on intermediate cycles. These tests shall include:

a. During performance and functional tests, the unit shall be cycled through a sufficient number of operational modes to fully characterize the performance and functionality of the unit.

b. Performance tests shall test all paths, including continuity, with functional testing as a subset of performance testing that focuses on critical, primary, and redundant paths to check functionality.

c. During the test, perceptive parameters shall be monitored for failures, degradation trends, and intermittent behavior.

d. All electrical circuits and all paths shall be verified for circuit performance and continuity.

e. For units with internal redundancy, performance testing, functional testing, and hot and cold starts shall be demonstrated on primary and redundant circuits and paths.

f. During temperature transitions, the unit shall be powered on and monitored, except as noted, and the health of the unit shall be monitored and key parameters trended. Any performance of the unit required during temperature transitions shall be tested during the test transitions.

g. Any performance of the unit required during temperature transitions shall be tested during the test transitions.

6.3.9.3 Test Levels and Durations for Electrical and Electronic Units

a. **Pressure.** The time for reduction of chamber pressure from ambient to 20 Pa (0.15 Torr) shall be at least ten minutes to allow sufficient time in the region of critical pressure for units required to operate during ascent. The pressure shall be further reduced from 20 Pa for operating equipment, or from atmospheric for equipment that does not operate during ascent, to 13.3 mPa (10^{-4} Torr) at a rate that simulates the ascent profile to the extent practical. For launch vehicle units, the vacuum pressure test shall be modified to reflect an altitude consistent with the maximum service altitude and duration consistent with maximum time at altitude.

b. **Temperature.** Electrical and electronic units shall be tested to temperature ranges given below and as shown in Figure 6.3.8-4

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Qualification:	10°C beyond acceptance test temperatures or –34 to 71°C (minimum range)
Protoqualification:	5°C beyond acceptance test temperatures or –29 to 66°C (minimum range)
Acceptance:	Maximum and minimum predicted temperatures or –24 to 61°C (minimum range)

The transitions between hot and cold shall be at an average rate greater than 1°C per minute.

c. **Duration.** Electrical and electronic units shall have the following minimum number of thermal vacuum cycles (with thermal cycling performed):

Qualification:	4 TV cycles
Protoqualification:	4 TV cycles
Acceptance:	4 TV cycles

When performing thermal vacuum testing only, the minimum number of cycles shall be:

Qualification:	27 TV cycles
Protoqualification:	20 TV cycles
Acceptance:	14 TV cycles

Units shall remain operational except during the first and last cycles, where a minimum one-half hour is required between unit turn-off and turn-on for stabilization. Units may be turned off during the cold ramp on intermediate cycles to accelerate testing, but the unit shall be thermally stabilized after being turned on before proceeding to functional or performance testing. When performing thermal vacuum testing only, the last three thermal cycles shall be failure free.

Thermal soaks at hot and cold temperature plateaus shall be a minimum of six hours on the first and last cycle and one hour on intermediate cycles. Hot operational soaks shall be a minimum of two hours on the first and last cycle and a minimum of one hour (coincident with thermal soak) on intermediate cycles.

Temperature stabilization is achieved when the unit baseplate is within the allowed test tolerance on the specified test temperature, and the temperature rate of change is less than 3°C per hour. Thermal dwells at hot and cold temperatures shall be a minimum of four hours for all cycles. Thermal dwell durations greater than four hours may be necessary to ensure that internal locations have reached the test temperature. In such cases, either thermal design analysis results or test measurements of internal unit components shall be used to predict an appropriate dwell time. Thermal dwell durations of less than four hours may be used when analysis results or test measurements indicate that such a change is appropriate.

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When a unit's design precludes testing over the temperature ranges specified in 6.3.9.3.b, the number of test cycles shall be increased to provide an equivalent level of screening effectiveness. The relationships given below shall be used to calculate equivalent cycles for units that are subjected to thermal vacuum only or subjected to thermal vacuum and thermal cycle testing. The term ΔT is the proposed test temperature range (in °C).

Qualification:	$27(105/\Delta T)^{1.4}$ cycles
Protoqualification:	$20(95/\Delta T)^{1.4}$ cycles
Acceptance:	$14(85/\Delta T)^{1.4}$ cycles

6.3.9.3.1 Option for Two-Tier Testing

When a unit's performance temperature limits do not comply with Figure 6.3.8-4 temperature ranges, but operational temperature limits do, a two-tier thermal test approach may be adopted whereby the unit demonstrates operational requirements at the minimum temperature range shown above and performance requirements at a narrower temperature range. The two-tier test approach is described in A.1.2.

6.3.9.4 Burn-In for Electrical and Electronic Units

For acceptance and protoqualification testing, units shall be "burned in" to detect latent infant mortality defects. During burn-in, the test unit shall be powered on, and key parameters monitored and trended. The duration of burn-in is such that the combined duration of unit thermal cycling, unit thermal vacuum, and the additional burn-in testing shall be at least 200 hours. The durations of the thermal cycle and thermal vacuum test accrue toward the 200-hour duration requirement. Performance tests shall be performed prior to and following the burn-in test. The test is performed with the unit temperature either cycled between the acceptance temperature limits or elevated at the acceptance hot temperature. Testing may be performed at ambient pressure as a continuation of the unit thermal cycle test. The last 100 hours of operation shall be failure free. For burn-in tests of less than 100 hours in duration, the test shall be failure free. For units with internal redundancy, the operating hours shall consist of at least 100 hours for each redundancy with a minimum total of 200 operating hours. The last 50 hours of each circuit (primary and redundant) shall be failure free.

6.3.9.5 Thermal Vacuum Testing for Units Other Than Electrical and Electronic

When a thermal vacuum test is performed for non-electrical and non-electronic units, the purpose and test description are not significantly different from that described for electrical and electronic units. The primary difference is in the test levels and duration. Non-electrical and non-electronic units are tested to temperature ranges that have the same thermal margins, but without the required temperature ranges:

a. **Temperature.** Units shall be tested to the ranges given below:

Qualification:	10°C beyond acceptance test temperatures

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Protoqualification:	5°C beyond acceptance test temperatures
Acceptance:	Maximum and minimum predicted temperatures

b. **Duration.** The minimum number of thermal cycles shall be:

Qualification:	6 TV cycles
Protoqualification:	3 TV cycles
Acceptance:	1 TV cycle

These cycles can be accrued as a combination of unit thermal cycle (6.3.8.5) and unit thermal vacuum tests.

The test shall demonstrate a transition rate representative of flight conditions. The thermal stabilization and thermal dwell durations shall be the same as specified for electronic and electrical units. Thermal soak durations shall be specified for the unit to achieve thorough performance verification. Unit performance shall be demonstrated at the required test temperatures. These requirements are specified in 6.3.9.3.

The unit shall demonstrate survival capability requirements at its survival hot and survival cold temperatures (see 3.55) on the first cycle. Survival cycle requirements shall be identical to those stated for electronic and electrical units.

For moving mechanical assemblies, performance parameters (such as current draw, resistance torque or force, actuation time, velocity, or acceleration) shall be monitored. Where practical, force or torque margins shall be determined on moving mechanical assemblies at the temperature extremes. Where this is not practical, minimum acceptable force or torque margin shall be demonstrated.

Compatibility with operational fluids shall be verified at test temperature extremes for valves, propulsion units, and other units, as appropriate.

6.3.10 Unit Climatic Tests

6.3.10.1 Purpose

These tests demonstrate that the unit is capable of surviving exposure to various climatic conditions without excessive degradation, or operating during exposure, as applicable. Exposure conditions include those imposed upon the unit during fabrication, test, shipment, storage, preparation for launch, launch itself, and reentry, if applicable. These can include, but not be limited to, such conditions as humidity, sand and dust, rain, salt fog, and explosive atmosphere. Tests shall conform to the methods given in Reference 1 when applicable. Degradation due to fungus, ozone, and sunshine shall be verified by design and material selection.

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It is the intent that environmental design of flight hardware not be driven by terrestrial natural environments. To the greatest extent feasible, the flight hardware shall be protected from the potentially degrading effects of extreme terrestrial natural environments by procedural controls and special support equipment. Only those environments that cannot be controlled need be considered in the design and testing.

6.3.10.2 Humidity Test, Unit Qualification

6.3.10.2.1 Purpose

The humidity test demonstrates that the unit is capable of surviving or operating in, if applicable, warm humid environments. In the cases where exposure is controlled throughout the life cycle to conditions with less than 55% relative humidity, and the temperature changes do not create conditions where condensation occurs on the hardware, then verification by test is not required.

6.3.10.2.2 Test Description and Levels

For units exposed to unprotected ambient conditions, the humidity test shall conform to the method 507.5 in Reference 1. For units located in protected, but uncontrolled environments, the unit shall be installed in a humidity chamber and subjected to the following conditions (time line illustrated in Figure 6.3.10-1):

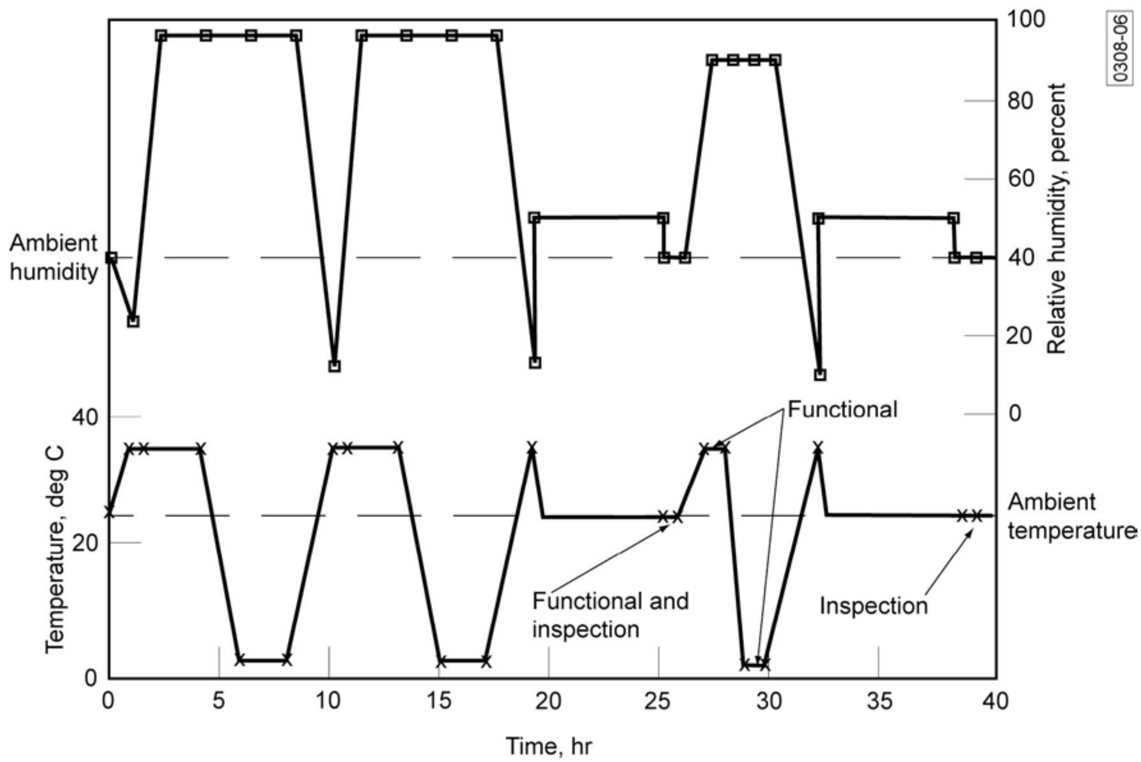

Figure 6.3.10-1. Humidity test time line.

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a. **Pretest Conditions.** Chamber temperature shall be at room ambient conditions with uncontrolled humidity.

b. **Cycle 1.** The temperature shall be increased to +35°C over a one-hour period; then the humidity shall be increased to not less than 95% over a one-hour period with the temperature maintained at +35°C. These conditions shall be maintained for two hours. The temperature shall then be reduced to +2°C over a two-hour period with the relative humidity stabilized at not less than 95%. These conditions shall be maintained for two hours.

c. **Cycle 2.** Cycle 1 shall be repeated except that the temperature shall be increased from +2°C to +35°C over a two-hour period; moisture is not added to the chamber until +35°C is reached.

d. **Cycle 3.** The chamber temperature shall be increased to +35°C over a two-hour period without adding any moisture to the chamber. The test unit shall then be dried with air at room temperature and 50% maximum relative humidity by blowing air through the chamber for six hours. The volume of air used per minute shall be equal to one to three times the test chamber volume. A suitable container may be used in place of the test chamber for drying the test unit.

e. **Cycle 4.** If it had been removed, the unit shall be placed back in the test chamber, the temperature increased to +35°C, and the relative humidity increased to 90% over a one-hour period; and these conditions shall be maintained for at least one hour. The temperature shall then be reduced to +2°C over a one-hour period with the relative humidity stabilized at 90%; and these conditions shall be maintained for at least one hour. A drying cycle shall follow (see Cycle 3).

6.3.10.2.3 Supplementary Requirements

The unit shall be functionally tested prior to the test and at the end of Cycle 3 (within two hours after the drying) and visually inspected for deterioration or damage. The unit shall be functionally tested during the Cycle 4 periods of stability, after the one-hour period to reach +35°C and 90% relative humidity, and again after the one-hour period to reach the +2°C and 90% relative humidity.

6.3.10.3 Sand and Dust Test, Unit Qualification

6.3.10.3.1 Purpose

The sand and dust test is conducted to determine the resistance of units to blowing fine sand and dust particles. This test shall not be required for units protected from sand and dust by contamination control, protective shipping and storage containers, or covers. However, in those cases, rain testing demonstrating the adequacy of the protective shelters, shipping and storage containers, or covers, as applicable, may be required instead of a test of the unit itself.

6.3.10.3.2 Test Description

The test requirements for the sand and dust test shall conform to the method given in Reference 1.

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6.3.10.4 Rain Test, Unit Qualification

6.3.10.4.1 Purpose

The rain test shall be conducted to determine the resistance of units to rain. Units protected from rain by protective shelters, shipping and storage containers, or covers, shall not require verification by test.

6.3.10.4.2 Test Description

Buildup of the unit, shelter, container, or the cover being tested shall be representative of the actual fielded configuration, without any duct tape or temporary sealants. The initial temperature difference between the test item and the spray water shall be a minimum of 10°C. For temperature-controlled containers, the temperature difference between the test item and the spray water shall at least be that between the maximum control temperature and the coldest rain condition in the field. Nozzles used shall produce a square spray pattern or other overlapping pattern (for maximum surface coverage) and droplet size predominantly in the 2 to 4.5 mm range at approximately 375 kPa gage pressure (40 psig). At least one nozzle shall be used for each approximately 0.5 m^2 (6 ft^2) of surface area, and each nozzle shall be positioned at 0.5 m (20 in.) from the test surface. All exposed faces shall be sprayed for at least 40 minutes. The unit under test interior shall be inspected for water penetration at the end of each 40-minute exposure.

6.3.10.5 Salt Fog Test, Unit Qualification

6.3.10.5.1 Purpose

The salt fog test is used to demonstrate the resistance of the unit to the effects of a salt spray atmosphere. The salt fog test is not required if the flight hardware is protected against the salt fog environment by suitable preservation means and protective shipping and storage containers.

6.3.10.5.2 Test Description

The requirements for the salt fog test shall conform to the method given in Reference 1.

6.3.10.6 Explosive Atmosphere Test, Unit Qualification

6.3.10.6.1 Purpose

Where applicable, devices operating in explosive atmospheric conditions need to be proven incapable of igniting a fuel-air mixture of concern.

6.3.10.6.2 Test Description

The test requirements for the explosive atmosphere test shall conform to the method given in Reference 1.

6.3.11 Unit Static Load Test

6.3.11.1 Purpose

The structural static load test demonstrates the adequacy of the structural components to meet requirements of strength and stiffness, with the desired test factors, when subjected to simulated critical environments predicted to occur during its service life (such as loads, temperature, humidity, and pressure).

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6.3.11.2 Test Description

The interface between the test article and the test fixture shall provide flight-like boundary conditions including stiffness. The test fixture shall allow for the proper sequencing or simultaneous application of all load cases. When prior loading histories affect the structural adequacy of the test article, these shall be included in the test requirements. If more than one design load condition is to be applied to the same test specimen, a method of sequential load application shall be developed by which each condition may, in turn, be tested to progressively higher load levels.

Measurements of strains and deformations shall be recorded for all static load cases. Strain, load, and deformation shall be measured before and during loading, after removal of the loads, and at several intermediate levels for post-test diagnostic purposes. The test conditions shall encompass the extreme predicted combined effects of acceleration, vibration, pressure, preloads, and temperature. These effects can be simulated in the test conditions as long as the design margins for all failure modes are enveloped by the test. For example, temperature effects, such as material strength degradation and additive thermal stresses, can often be accounted for by increasing mechanical loads.

6.3.11.3 Test Levels and Duration

Qualification:

a. **Level.** Unless otherwise specified, the load level for the static load test is 1.4 times limit load (3.21) for manned systems and 1.25 times limit load for unmanned systems.

b. **Temperature.** Critical flight temperature and load combinations shall be simulated or taken into account by modification of the applied mechanical loads.

c. **Duration.** The dwell time at each load level shall be sufficient to achieve stable structural response and record test data such as strain, load, displacement, and temperature.

Protoqualification:

Same as qualification except the load level for static test is 1.25 limit load (3.21) for manned and unmanned systems.

Acceptance:

A unit proof load test (see 3.42) shall be conducted for all structural units made of composite materials or having adhesively bonded parts. The proof load test is intended to detect material, process, and workmanship defects that could lead to structural failure.

a. **Level.** Unless otherwise specified, the proof load for flight items shall be 1.1 times limit load (see 3.21).

b. **Duration.** The dwell time at each load level shall be sufficient to achieve stable structural response and record test data.

Proof testing may be deleted if the following conditions are met:

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a. Units are manufactured using established and controlled processes

b. Nondestructive inspection methods, together with well-established accept/reject criteria, are used to verify the workmanship of each unit. The selected methods have been demonstrated to be effective for identifying critical flaws in units of identical or similar geometry, construction, and materials.

c. Qualification/Protoqualification on a similar unit has been successfully completed

d. Mechanical properties of each component material are verified by tag end or witness tests and whose data are in-family (2-sigma) to heritage data

e. Approval obtained from customer

6.3.11.3.1 Test Success Criteria

Qualification:	The unit shall withstand the qualification loads without rupture or collapse. There shall be no material gross yielding or detrimental deformation at 1.1x limit loads.
Protoqualification:	The unit shall withstand the applied loads without material gross yielding or detrimental deformation.
Acceptance:	The unit shall withstand the applied loads without material gross yielding or detrimental deformation

6.3.11.4 Supplementary Requirements

For fracture-critical metallic parts, proof tests shall be conducted when non-destructive evaluation is not sufficient to determine the maximum initial crack sizes used in the damage tolerance (safe-life) analyses or tests. The required proof test load level shall be determined based on fracture mechanics calculations. Structural test requirements are specified in References 6 and 11. Qualification or protoqualification testing shall be required for all composite and bonded primary structures.

6.3.12 Unit Pressure Test

6.3.12.1 Purpose

The pressure test verifies adequate margin that structural failure does not occur before the design burst pressure is reached, or excessive deformation does not occur at the maximum expected operating pressure, MEOP (see 3.24). Table 6.3.12-2 provides minimum design burst pressures for pressurized vessels and hardware.

For solid rocket motor cases used in expendable launch vehicles, Reference 19 specifies applicable requirements.

6.3.12.2 Test Description

a. **Proof Pressure Test.** For items such as pressurized structures, vessels, and pressure components, a proof test with a minimum of one cycle of proof pressure shall be conducted. Evidence of leakage, a permanent set, or distortion that exceeds a drawing tolerance or failure of

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any kind shall constitute failure to pass the test. This test shall be performed for qualification and acceptance testing.

b. **Qualification Test.** The qualification test procedures consist of cyclic testing followed by one additional cycle at burst pressure, and are described below. Requirements for application of external loads in combination with internal pressures during testing shall be evaluated based on the relative magnitude and on the destabilizing effect of stresses due to the external load.

Pressure Cycle Test. For pressurized structures and pressure vessels, a pressure cycle test shall be conducted. If limit combined tensile stresses are enveloped by the test pressure stress, the application of external load is not required. Table 6.3.12-1 provides a summary of unit test requirements.

Burst Test. For pressurized structures and vessels, after demonstrating no burst at the design burst pressure, the pressure shall be increased to actual burst of the test unit, and the actual burst pressure shall be recorded.

c. **Exception to Tests.** For special pressurized equipment (see 3.38), such as silver-zinc batteries that contain a pressure relief mechanism, proof test of the pressure release mechanism shall be performed on all flight units. For space vehicle batteries using a special pressurized equipment design without a pressure release mechanism, such as nickel-hydrogen batteries, proof testing shall be performed at the vessel level for each vessel in a flight battery. See Reference 4 for design and test requirements.

Table 6.3.12-1. Unit Pressure Cycle and Burst Test Requirements

Hardware Type	Pressure Cycles	Burst Pressure
Pressurized Structures	Cycle at 1.0 times MEOP for 4 times predicted number of service life cycles in sequence, including proof test	1.25 x MEOP
Metallic Pressure Vessels	Cycle at 1.0 times MEOP for 4 times predicted number of service life cycles in sequence (50 cycles minimum) or Cycle at 1.5 times MEOP for 2 times predicted number of service life cycle in sequence. (50 cycles minimum)	1.5 x MEOP
Composite Overwrapped Pressure Vessels with Metal Liners	Cycle for 4 times service life cycles, including proof tests (50 cycles minimum)	1.5 x MEOP

Table 6.3.12-2. Minimum Design Burst Pressure Requirements

Pressurized Hardware Item Type	Minimum Design Burst Pressure
Pressurized Structures	1.25 x MEOP
Metallic Pressure Vessels, Cryostats, Battery Cases and Sealed Containers	1.5 x MEOP
Composite Overwrapped Pressure Vessels with Metal Liners	1.5 x MEOP
Lines and Fittings with Diameters Equal to or Greater Than 1.5 in.	2.5 x MEOP
Heat Pipes, Valves, Regulators, Accumulators, and others Pressure Components	2.5 x MEOP
Fluid Return Section	3.0 x MEOP
Lines and Fittings with Diameters Less Than 1.5 in.	4.0 x MEOP
Fluid Return Hose	5.0 x MEOP

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6.3.12.3 Test Levels and Durations

a. **Temperature and Humidity.** The test temperature and humidity conditions shall be consistent with the critical-use temperature and humidity. As an alternative, tests may be conducted at ambient conditions if the test pressures are suitably adjusted to account for temperature and humidity effects on material strength and fracture toughness.

b. **Proof Pressure.** Unless otherwise specified, the minimum proof pressure for pressurized structures shall be 1.1 times the MEOP. For pressure vessels, and other pressure components such as lines and fittings, the minimum proof pressure shall comply with the requirements specified in References 4 and 5, as appropriate. The hold time for pressure vessels shall comply with the requirements specified in References 4 and 5, as appropriate. For other pressure components, the pressure shall be maintained for a time just sufficient to assure that the proper pressure was achieved.

c. **Pressure Cycle.** Unless otherwise specified, the peak pressure for pressurized structures shall equal the MEOP during each cycle, and the number of cycles shall be four times the predicted number of operating cycles. For pressure vessels, the test shall comply with the requirements specified in References 4 and 5, as appropriate.

d. **Burst Pressure.** For pressurized structures, vessels and components, the minimum design burst pressure and duration shall comply with References 4 and 5, as appropriate.

6.3.12.4 Supplementary Requirements

Applicable safety standards shall be followed in conducting all tests. Unless otherwise specified, the qualification testing of metallic pressure vessels shall include a demonstration of a leak-before-burst (LBB) failure mode using pre-flawed specimens as specified in Reference 4. The LBB pressure test may be omitted if available material data are directly applicable to be used for an analytical demonstration of the leak-before-burst failure mode.

For composite over-wrapped pressure vessels with metallic liners, the LBB requirements specified in Reference 5 shall be met.

For perforated sandwich structures, when venting tests cannot simulate the flight depressurization rate, tests shall be conducted to verify the unit has sufficient strength to withstand internal pressure.6.3.13 Unit Electromagnetic Compatibility (EMC) Test

6.3.13 Unit Electromagnetic Compatibility (EMC) Test

6.3.13.1 Purpose

The electromagnetic compatibility test shall demonstrate that the electromagnetic interference characteristics (emission and susceptibility) of the unit, under normal operating conditions, do not result in malfunction of the unit. It also demonstrates that the unit does not emit, radiate, or conduct interference, which could result in malfunction of other units.

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6.3.13.2 Test Description

The test shall be conducted in accordance with the requirements of Reference 21. The intent of testing at the lowest level possible shall be followed. This means that all tests shall be conducted at the unit level to improve the chance of passing the subsystem and vehicle level tests. Radiated emissions shall be performed on all units capable of generating emissions. Acceptance tests shall be performed when there is less than 12 dB qualification margin, or the radiated emissions requirement is more stringent than 10 dBuV/m, or the units have a passive intermodulation requirement. Radiated emission acceptance tests can be deferred to the subsystem or functional module level.

The EMC margin is to be incorporated into the test levels. Qualification margins of 6 dB are acceptable if the combined test uncertainty, part variation, part degradation at end-of-life, and workmanship variation is less than 6 dB. Electroexplosive devices and bridge wires have a 20 dB margin requirement below the DC no-fire value and a 6 dB margin requirement below the RF no-fire value.

6.3.13.3 Test Levels and Duration

The test levels shall be as follows:

Qualification:	12 dB
Protoqualification:	6 dB
Acceptance:	6 dB

The test duration shall be 20 minutes at each space vehicle transmitter frequency for radiated susceptibility. Otherwise, the duration is the greater of three seconds or the unit response time for susceptibility requirements and 15 ms duration for emission requirements.

6.3.14 Unit Life Test

6.3.14.1 Purpose

The life test applies to units which may have a wear-out, drift, or fatigue-type failure mode, or performance degradation in the operational environment. The test demonstrates that the units have the capability to perform within specification limits for the maximum duration or cycles of operation during repeated ground testing and flight. The unit life test is an environmental test and not to be confused with pressure cycle test, which is covered in 6.3.12.3.

6.3.14.2 Test Description

One or more units shall be operated under conditions that simulate their service conditions. Service conditions define the operational environment in which the unit is expected to operate. As such, it is reasonable to demonstrate the condition when the unit is in an active and operational mode. For solar cell devices and unit life testing, the test conditions are to simulate the as-used powered-on or current loaded operational condition. These conditions shall be selected for consistency with end-use requirements and the significant life characteristics of the particular unit. Typical environments are ambient, thermal, thermal vacuum pressure, vibration and radiation. The test shall be designed to demonstrate the ability of the unit to withstand the maximum operating time and/or the maximum

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number of operational cycles predicted during its service life (including manufacturing assembly and test) with a suitable margin. Accelerated life testing is permitted provided the acceleration method is valid for the expected operational conditions.

6.3.14.3 Test Levels and Durations

a. **Pressure.** Ambient pressure shall be used except where degradation due to a vacuum environment may be anticipated. Examples include unsealed units such as bearings, coaxial cables routed across rotating joints, or any other friction-prone device. For these cases, a pressure of 13.3 mPa (10^{-4} Torr) or less shall be used.

b. **Environmental Levels.** The maximum expected environmental levels shall be used. Higher levels may be used to accelerate the life testing if the resulting increase in the rate of degradation is well established and that unrealistic failure modes are not introduced.

c. **Duration.** The total operating time or number of operational cycles shall be at least two times that predicted during the service life, including ground testing, in order to demonstrate an adequate margin. For a structural component having a fatigue-type failure mode that has not been subjected to a vibration qualification test, the test duration shall be at least four times the specified service life.

d. **Functional Duty Cycle.** Complete functional tests shall be conducted before the test begins and after completion of the test. During the life test, functional tests shall be conducted in sufficient detail, and at sufficiently short intervals to establish trends.

6.3.14.4 Supplementary Requirements

Life testing of moving mechanical assemblies (MMA) shall be performed according to Reference 7. Life testing of batteries shall be performed according to Reference 20.

For statistically based life tests, the duration is dependent upon the number of samples, confidence, and reliability to be demonstrated. The duration of the life test shall assure with high confidence that the unit does not wear out and/or unacceptably degrade during its service life.

Critical areas of parts that may be subject to fatigue failure shall be inspected to determine their integrity. Life testing is necessary for pressure vessels using bellows or other flexible fluid devices or lines. Life testing on a lot basis is necessary for silver-zinc batteries to verify capacity and voltage response at the end of wet stand life for at least one charge cycle.

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7. Subsystem Test Requirements

Subsystems shall be tested to reduce risk when system testing cannot verify subsystem performance. For example, structural testing and mode survey should be performed at subsystem level to provide early verification.

7.1 Requirements

Subsystem tests shall be conducted on subsystems for any of the following purposes:

a. To verify the design and performance and demonstrate that those subsystems subjected to environmental acceptance tests perform to specification (Table 7.3-2). Table 7.3-1 summarizes qualification and protoqualification testing performed to verify design margins.

b. To provide a more perceptive test versus other levels of testing. A summary of subsystem test level margins and durations is shown in Table 7.3-3.

Table 7.3-1. Subsystem Qualification and Protoqualification Test Summary

Test	Reference	Suggested Sequence	Payload Fairing	Structure	Bus	Payload/ Instrument	Multi-Unit Module
Inspection (1)	4.6	1, 11	R	R	R	R	R
Performance(1)	7.3.1	2–10	R	R	R	R	R
Static Load	7.3.2	3	R	R	R	R	R
Pressure and Leak	7.3.3	4	ER	ER	ER(4)	ER	ER
Shock	7.3.6	7	--(5)	ER	ER	ER	ER
Random Vibration or Acoustic	7.3.4 7.3.5	5	R	ER	ER	ER	ER
Thermal Vacuum	7.3.7	6	--	ER	ER	R	R
Separation and Deployment(3)	7.3.8	8	R	--	R	R	ER
EMC	7.3.9	9	ER(6)	--	R	R	ER
Mode Survey	7.3.10	Any	R	--	R(2)	R(2)	ER

R Required
ER Evaluation required (see 6.3)
(1) Performance tests conducted prior to, during and following each environmental test, as appropriate
(2) Mode survey testing is required for both if not performed at the System level
(3) Preferred at the vehicle level; if not feasible, perform test at the subsystem level
(4) Required for propulsion subsystem
(5) Performed as part of the separation and deployment test
(6) Evaluation required when active electronics installed on fairing

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Table 7.3-2. Subsystem Acceptance Test Summary

Test	Reference	Suggested Sequence	Payload Fairing	Structure	Bus	Payload	Multi-Unit Module
Inspection(1)	4.6	1, 11	R	R	R	R	R
Performance(1)	7.3.1	2, 10	R	R	R	R	R
Static Load	7.3.2	3	ER(2)	ER(2)	ER(2)	R	--
Pressure and Leak	7.3.3	4	--	--	R	R	R
Shock	7.3.6	5	--(5)	ER	ER	ER	ER
Random Vibration or Acoustic	7.3.4 7.3.5	6	ER	--	--	ER	R
Thermal Vacuum	7.3.7	7	--	--	ER	R	R
Separation and Deployment(3)	7.3.8	8	ER	--	R	R	ER
EMC(4)	7.3.9	9	--	--	ER	ER	--

R Required
ER Evaluation required (see 6.3)
(1) Performance tests conducted prior to, during and following each environmental test, as appropriate
(2) Required for composite and/or bonded structures. Evaluation required for all other structures.
(3) Preferred at the vehicle level; if not feasible, perform test at the subsystem level.
(4) Required when there is less than 12 dB qualification margin
(5) Performed as part of the separation and deployment test

Table 7.3-3. Subsystem Test Level Margins and Durations

Test	Qualification	Protoqualification	Acceptance
Shock	1 activation of all shock-producing events; 2 additional activations of significant events	1 activation of all shock-producing events; 1 additional activation of significant events	1 activation of significant shock-producing events
Acoustic(1)	6 dB above acceptance for 3 min	3 dB above acceptance for 2 min	Envelope of MPE and minimum spectrum (Figure 6.3.6-1) for 1 minute
Vibration(1)	6 dB above acceptance for 3 min in each of 3 axes	3 dB above acceptance for 2 min in each of 3 axes	Envelope of MPE and minimum spectrum (Figure 8.3.7-1) for 1 min in each of 3 axes
Thermal Vacuum	±10°C beyond acceptance for 8 cycles	±5°C beyond acceptance for 4 cycles	MPT for 4 cycles
Static Load(2)	1.25 times the limit load for unmanned flight or 1.4 times limit load for manned flight; duration sufficient to record data	1.25 times the limit load for unmanned flight or 1.25 times limit load for manned flight; duration sufficient to record data	1.1 times the limit load for bonded, composite, or sandwich structures; duration sufficient to record data
Pressure(3)	Not applicable	Not applicable	1.1 times MEOP for pressurized structures. 1.5 times MEOP for pressurized subsystems including only pressure components. 1.25 times MEOP for pressurized subsystems containing pressure vessels.
EMC	12 dB minimum; duration same as acceptance	6 dB minimum; duration same as acceptance	6 dB minimum; 20 min at each space vehicle transmitter frequency for radiated susceptibility

(1) See B.1.3 for subsystems with effective duration greater than 15 seconds
(2) Refer to References 6 and 11
(3) Refer to References 18 and 19

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7.2 Subsystem Development Tests

Vehicles and subsystems are subjected to development tests and evaluations using structural and thermal development models as may be required to confirm dynamic and thermal environmental criteria for design of subsystems, to verify mechanical interfaces, and to assess functional performance of deployment mechanisms and thermal control subsystems. Vehicle-level development testing also provides an opportunity to develop handling and operating procedures as well as to characterize interfaces and interactions.

7.2.1 Mechanical Fit Development Tests

For launch and upper-stage vehicles, a mechanical fit, assembly, and operational interface test with the facilities at the launch or test site is recommended. Flight-weight hardware should be used, if practical; however, a facsimile or portions thereof may be used to conduct the development tests at an early point in the schedule in order to reduce the impact of hardware design changes that may be necessary.

7.2.2 Mode Survey Development Tests

A mode survey test could be conducted at the subsystem level when uncertainty in the analytically predicted structural dynamic characteristics is judged to be excessive for purposes of structural or control subsystem design. The test article may be the full vehicle or one or more subsystem segments, depending on the physical size of the subsystem being tested relative to the physical size of the test facility and dynamic model verification strategy. Requirements are specified in Reference 17.

7.2.3 Structural Development Tests

Structural tests may be required to verify the stiffness and strength properties and to measure member loads, stress distributions, deflections, and thermal distortion. Structures with redundant load paths fall in this category. The stiffness data are of particular interest where significant nonlinear structural behavior exists. The structural development tests may also be required as an aid to structural analysis. The member load and stress distribution data may be used to experimentally verify the structural analysis model. This development test does not replace the structural static load test that is required for subsystem qualification.

7.2.4 Acoustic Development Tests

Since high-frequency vibration responses are difficult to predict by analytical techniques, acoustic development testing of the launch, upper stage, and space vehicles subsystems may be necessary to verify the adequacy of the dynamic design criteria for units. Units that are not installed at the time of the test shall be dynamically simulated with respect to mass, center of gravity, moments of inertia, interface stiffness, and geometric characteristics. To demonstrate adequate design margin of the system in the launch environment, the subsystem shall be exposed to the qualification or proto-qualification acoustic levels and durations. To demonstrate adequacy of workmanship, the subsystem shall be exposed to the acceptance acoustic levels and durations.

7.2.5 Shock Development Tests

Since shock responses are difficult to predict by analytical techniques, shock development testing of the launch, upper stage, and space vehicles may be necessary to verify the adequacy of the dynamic design criteria for units. Vehicle units that are not installed at the time of the test shall be dynami-

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cally simulated with respect to mass, center of gravity, moments of inertia, interface stiffness, and geometric characteristics. All explosive ordnance devices and other mechanisms capable of imparting a significant shock to the vehicle and its mounted assemblies shall be operated to demonstrate functionality and survivability. Where practical, the shock test shall involve physical separation of elements being deployed or released. When a significant shock is expected from interfacing subsystems not included on the vehicle under test (such as when a fairing separation causes shock responses on an upper stage under test), the adaptor subsystem or suitable simulation shall be attached and appropriate explosive ordnance devices or other means used to simulate the shock imposed. The pyroshock environment may vary significantly from one ordnance activation to another. Therefore, the statistical basis given in 3.28 shall be used for estimating maximum predicted environment. Multiple activations of ordnance devices may be necessary to provide data for better estimates.

7.2.6 Payload Thermal Development Tests

Prior to space vehicle integration, payloads should be subjected to thermal development testing. The payload thermal vacuum test should include a thermal balance test for thermal model correlation and demonstration of thermal control hardware. Thermal tests may also be performed to measure the thermal conductance across important interfaces and the heat loss through critical thermal blankets. Special tests may also be necessary to verify heat pipe performance in complex configurations or when heat pipes are in a non-horizontal orientation in system-level thermal testing. Heat pipe operation shall be verified in subsystem and vehicle ground thermal testing. Heat pipes shall be oriented such that they operate in ground test orientations. Reflux testing is allowed provided that flight-like performance is verified at a lower level of assembly. In the case of heat pipes with three-dimensional bends, a surrogate heat pipe with identical two-dimensional bends may be tested to verify performance. Heat pipe operation of each three-dimensional flight pipe may be verified in reflux at the unit level. Because workmanship is not completely demonstrated for three-dimensional heat pipes, every effort should be made to use two-dimensional heat pipes.

7.3 Test Program for Subsystems

These tests demonstrate that the subsystem will meet its performance and interface requirements. The baseline is shown in Tables 7.3-1 and 7.3-2. Additional guidance may be found in Reference 32.

7.3.1 Subsystem Performance Test

7.3.1.1 Purpose

The performance test verifies that the mechanical and electrical performance of the subsystem meet the specification requirements, including compatibility with other subsystems and ground support equipment, and validates all test techniques and software. Proper operation of all redundant units or mechanisms must be demonstrated.

7.3.1.2 Mechanical Test

Mechanical devices, valves, deployables, and separation subsystems shall be functionally tested at the subsystem level in the launch, orbital, or recovery configuration appropriate to the function. Alignment checks shall be made where appropriate and feasible. Fit checks shall be made of the subsystem interfaces using master gages or interface assemblies. The test shall validate that the subsystem performs within maximum and minimum limits under worst-case conditions, including environments, time, and other applicable requirements. Tests shall demonstrate specified margins of strength,

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torque, and related kinematics and clearances. Where operation in Earth gravity or in an operational temperature environment cannot be performed, a suitable ground test fixture may be used to permit operation and performance evaluation. The pass-fail criteria shall be adjusted as appropriate to account for worst-case maximum and minimum limits that have been modified to adjust for subsystem and ground test conditions. See Reference 7 for further details regarding MMAs.

7.3.1.3 End-to-End Performance Test

These tests shall be performed in accordance with the general requirements stated above. The subsystem should be in its flight configuration with all units and subsystems connected, except explosive-ordnance elements. The test shall verify the integrity of end-to-end circuits, including functions, redundancies, deployment circuitry, end-to-end paths, and at least nominal performance, including radio frequency and other sensor inputs. End-to-end sensor testing may be accomplished with self-test or coupled inputs.

The test shall be designed to operate all units, primary and redundant, and to exercise all commands and operational modes to the extent practical. The operation of all thermally controlled units, such as heaters and thermostats, shall be verified by test. Where control of such units is implemented by sensors, electrical or electronic devices, coded algorithms, or a computer, end-to-end performance testing shall be conducted. The test shall demonstrate that all commands having precondition requirements (such as enable, disable, a specific equipment configuration, and a specific command sequence) cannot be executed unless the preconditions are satisfied. Equipment performance parameters that might affect end-to-end performance, such as command and data rates, shall be varied over specification ranges to demonstrate the performance. Autonomous functions shall be verified. Continuous monitoring of perceptive parameters, including input and output parameters, and the vehicle main bus by a power transient-monitoring device and a current monitoring device, shall be provided to detect intermittent failures.

The subsystem shall be operated through a mission profile with all events occurring in actual flight sequence. This sequence shall include the final countdown, launch, ascent, separation, upper-stage operation, all appropriate orbital operational modes, and return from orbit, as appropriate. This sequence shall include live disconnecting of electrical circuits from cable-cutting or connector separation. All explosive-ordnance-firing circuits shall be energized and monitored during these events to verify that the proper energy density is delivered to each device and in the proper sequence. All measurements that are telemetered shall also be monitored and trended during appropriate portions of these events to verify proper operations. As a minimum, “a day in the life of the mission test” shall be run. A portion of this test shall be run with antenna hats removed.

7.3.1.4 Supplementary Requirements

Performance tests shall be conducted before and after the environmental subsystem tests program to detect equipment anomalies and to assure that performance meets specification requirements. These tests do not require the mission profile sequence. Sufficient data shall be analyzed to verify the adequacy of the testing and the validity of the data before any change is made to an environmental test configuration, so that any required retesting can be readily accomplished. During these tests, the maximum use of telemetry shall be employed for data acquisition, problem identification, and problem isolation.

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7.3.2 Subsystem Static Load Test

7.3.2.1 Purpose

Static load tests demonstrate the adequacy of structural systems to meet requirements of strength and stiffness, with the specified test factors, when subjected to simulated critical environments predicted to occur during their service life (such as temperature, humidity, pressure, and loads).

7.3.2.2 Test Description

Requirements are the same as 6.3.11.2.

7.3.2.3 Test Levels and Duration

Qualification:

a. **Level.** Unless otherwise specified, the load level for the static load test is 1.4 times limit load (see 3.21) for manned systems and 1.25 times limit load for unmanned systems.

b. **Temperature.** Critical flight temperature and load combinations shall be simulated or taken into account.

c. **Duration.** The dwell time at each load level shall be sufficient to achieve stable structural response and record test data such as strain, load, displacement, and temperature.

Protoqualification:

Same as qualification except the load level for static test is 1.25 limit load (3.21) for manned and unmanned systems.

Acceptance:

A subsystem proof load test shall be conducted for all structural units made of composite materi-als or having adhesively bonded parts that have not been proof tested at the unit level. The proof load test is intended to detect material, process, and workmanship defects that could lead to structural failure. The requirement for the proof load test may be deleted if 6.3.11.3.c is satisfied.

a. **Level.** Unless otherwise specified, the proof load for flight items shall be1.1 times limit load (see 3.21).

b. **Duration.** The dwell time at each load level shall be sufficient to achieve stable structural response and record test data such as strain, load, displacement, and temperature.

7.3.2.3.1 Test Success Criteria

Requirements are the same as 6.3.11.3.1.

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7.3.2.4 Supplementary Requirements

Other structural test requirements are specified in Reference 6. Static testing is the preferred means of structural testing. When this is not practical, equivalent tests, such as sine dwell, sine burst, and centrifuge, may be used provided such tests induce similar loading/stress states. Use of alternate tests, such as sine vibration/sweep, may also be used with approval from the procuring authority provided these tests generate similar loading/stress state and structural analysis models are correlated.

7.3.3 Subsystem Pressure Test

7.3.3.1 Purpose

A pressurized subsystem is comprised of units that have all been qualified per the above sections. Qualification testing is not required for lines and fittings that are fabricated using common aerospace materials and manufacturing processes. With this approach there is no qualification or protoqualification required for the assembled pressurized subsystem in regard to pressure design capability. Proof pressure testing of a pressurized subsystem is required as part of acceptance testing. The proof pressure test detects material and workmanship defects that could result in failure of the pressurized subsystem.

7.3.3.2 Test Descriptions

Preliminary tests shall be performed, as necessary, to verify compatibility with the test setup and to ensure proper control of the equipment and test functions. Where pressurized subsystems are assembled with other than brazed or welded connections, the specified torque values for these connections shall be verified prior to testing.

In addition to the proof pressure test, the subsystem shall be tested for leakage under propellant servicing conditions including evacuated internal pressures.

Flow tests at pressure are considered part of performance testing (see 7.3.1).

7.3.3.3 Test Level and Duration

Proof pressure testing is to be followed by leak testing at MEOP per the following requirements:

a. For launch and upper-stage vehicles that contain pressurized structures, the pressurized subsystem shall be pressurized to a proof pressure that is 1.1 times the maximum expected operating pressure (MEOP) and held constant for a short dwell time, sufficient to assure that the proper pressure was achieved within the allowed test tolerance. The test pressure shall then be reduced to the MEOP for leakage inspection.

b. For space vehicles, each isolated zone of a pressurized subsystem may have an individual proof pressure level. For zones including pressure vessels, the subsystem zone shall be pressurized to a proof pressure, which is 1.25 times the MEOP. For zones without pressure vessels, the proof pressure shall be 1.5 times the MEOP. In each case, the proof pressure shall be maintained for a time just sufficient to assure that the proper pressure was achieved, and then the pressure shall be reduced to the MEOP. This sequence shall be followed by inspection for leakage at the MEOP.

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c. The duration of evacuated propulsion subsystem leakage tests, matching the pressure levels of propellant servicing conditions, shall not exceed the time that this condition is normally experienced during propellant loading.

7.3.3.4 Supplementary Requirements

Applicable safety standards shall be followed in conducting all tests. Tests for detecting external leakage shall be performed at such locations as joints, fittings, plugs, and lines. The acceptable leakage rate to meet mission requirements shall be based upon an appropriate analysis. In addition, the measurement technique shall account for leakage rate variations with pressure and temperature and have the required threshold, resolution, and accuracy to detect any leakage equal to, or greater than, the acceptable leak rate. If appropriate, the leakage rate measurement shall be performed at the MEOP and at operational temperature, with the representative fluid commodity, to account for dimensional and viscosity changes. Times to achieve thermal and pressure equilibrium, test duration, and temperature sensitivity shall be determined by an appropriate combination of analysis and development test, and the results documented. Leakage detection and measurement procedures may require vacuum chambers, bagging of the entire vehicle or localized areas, or other special techniques to achieve the required accuracies. See Reference 18 for further guidance on integration of pressure components and subsystems.

7.3.4 Subsystem Vibration Test

7.3.4.1 Purpose

Requirements are the same as for vehicles. 8.3.6.1

7.3.4.2 Test Description

Requirements are the same as for vehicles. 8.3.6.2

7.3.4.3 Test Levels and Duration

Requirements are the same as for vehicles. 8.3.6.3

7.3.4.4 Supplementary Requirements

Requirements are the same as for vehicles. 8.3.6.4

In addition, subsystems designed for operation during ascent that are exposed to multiple worst-case environments such as thermal and vibration are candidates for combined environmental testing. When such testing is employed, the subsystem shall be tested as close to worst-case flight temperature as is practical and monitored for temperature performance during vibration exposure.

7.3.5 Subsystem Acoustic Test

7.3.5.1 Purpose

Requirements are the same as for vehicles. 8.3.5.1

7.3.5.2 Test Description

Requirements are the same as for vehicles. 8.3.5.2

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7.3.5.3 Test Levels and Duration
Requirements are the same as for vehicles. 8.3.5.3

7.3.5.4 Supplementary Requirements
Requirements are the same as for vehicles. 8.3.5.4

7.3.6 Subsystem Shock Test

7.3.6.1 Purpose
Requirements are the same as for vehicles. 8.3.4.1

7.3.6.2 Test Description
Requirements are the same as for vehicles. 8.3.4.2

7.3.6.3 Test Activations
Requirements are the same as for vehicles. 8.3.4.3

7.3.6.4 Supplementary Requirements
Requirements are the same as for vehicles. 8.3.4.4

7.3.7 Subsystem Thermal Vacuum Test
Subsystems and functional modules shall be temperature cycled in vacuum with the following requirements:

a. Those subsystems or portions thereof that cannot be tested as a standalone unit to performance specifications at the unit level shall be tested at the subsystem level to unit temperature requirements.

b. Those subsystems or payloads that, at the vehicle level, cannot be tested to their appropriate thermal environments or cannot meet performance testing requirements either due to configuration requirements or interaction with other subsystems, shall be tested at the subsystem level to system temperature requirements.

c. Subsystems that have an external interface shall have their external unit interfaces tested to performance at temperature extremes in the subsystemt thermal vacuum test requirements.

7.3.7.1 Purpose
Requirements are the same as for vehicles, 8.3.8.1. For cases where vehicle thermal vacuum testing is not effective for workmanship screening due to small temperature changes from hot to cold cycles, then thermal cycle testing at the subsystem level shall be applied. See A.1. When a subsystem thermal vacuum test is a more effective environment for meeting test objectives specified for the vehicle thermal vacuum test (such as for payloads and instruments), thermal vacuum testing at the subsystem level shall be applied. The same shall be applied for thermal balance testing. When

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thermal balance testing is performed at the subsystem level, the approach and requirements of 8.3.7 shall apply.

7.3.7.2 Test Description

Requirements are the same as for vehicles, 8.3.8.2. For cases where the thermal cycle test is applied, see Section A.1.1.

7.3.7.3 Test Levels and Duration

Requirements are the same as for vehicles, 8.3.8.3, except as noted in 7.3.7. Thermal cycles shall be added per A.1.1 when system thermal vacuum testing is not effective for workmanship screen.

7.3.7.4 Performance Testing

Requirements are the same as for vehicles, 8.3.8.2. For cases where the thermal cycle test is applied, see A.1.

7.3.7.5 Supplementary Requirements

Requirements are the same as for vehicles, 8.3.8.2. For cases where the thermal cycle test is applied, see Section A.1.1.

7.3.8 Subsystem Separation and Deployment Tests

7.3.8.1 Purpose

The separation subsystem test shall be performed as a qualification test to validate the adequacy of the separation subsystem to meet its performance requirements on such parameters as separation velocity, acceleration, angular motion, time to clear, clearances, flexible-body distortion and loads, amount of debris, and shock levels. For a payload fairing, the test also demonstrates the structural integrity of the fairing and its generic attachments under the separation shock loads environment. The data from the separation test are also used to validate the analytical method and basic assumptions used in the separation analysis. The validated method is then used to verify that requirements are met under worst-case flight conditions.

For deployable subsystems, such as payloads, instruments, etc., qualification and acceptance deployment tests shall be performed to validate the adequacy of each subsystem to meet its performance requirements, such as the release function, separation velocity, acceleration, and angular motion, clearances, flexible-body distortion and loads, amount of debris, and shock levels.

7.3.8.2 Test Description

The test fixtures, including gravity off-loaders, shall duplicate the interfacing structural sections to simulate the separation subsystem or separating body boundary conditions existing in the flight article. The remaining boundary conditions for the separating bodies shall simulate the conditions in flight, unless the use of other boundary conditions permits an unambiguous demonstration that subsystem requirements can be met. The test article shall include all attached flight hardware that could pose a debris threat if detached. When ambient atmospheric pressure may adversely affect the test results, such as for large fairings, the test shall be conducted in a vacuum chamber, duplicating the altitude condition encountered in flight at the time of separation. Critical conditions of temperature,

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pressure, or loading due to acceleration shall be simulated or taken into account. For separation subsystem qualification testing, instrumentation shall include high-speed cameras to record the motion of specially marked target locations, accelerometers to measure the structural response, and other environmental data and strain gages to verify load levels in structurally critical attachments. Critical clearances shall be verified by appropriate measurements. Additional guidelines for moving mechanical assemblies are provided in Reference 7.

7.3.8.3 Test Activations

Separation and deployment tests shall be conducted to demonstrate that requirements on performance parameters are met under predicted flight conditions. When critical conditions exist that cannot be modeled with confidence, additional testing shall be performed to determine the effect of those conditions on the separation or deployment. To validate force or torque margin requirements, tests shall be conducted to demonstrate that the static and dynamic force margins satisfy the requirements described in Reference 7. Such a test may occur at a lower level of assembly where the driving and resisting components are tested for their respective contributions. However, for separating subsystems involving fracture of structural elements, the demonstrated qualification force margin to cause fracture shall be at least 50%. In addition, debris risk shall be evaluated by conducting a test encompassing the most severe conditions that can occur in flight.

7.3.8.4 Supplementary Requirements

A post-test inspection for debris shall be conducted on and around the test article.

7.3.9 Subsystem Electromagnetic Compatibility (EMC) Test

7.3.9.1 Purpose

The electromagnetic compatibility test shall demonstrate that the electromagnetic interference characteristics (emission and susceptibility) of the subsystem, under normal operating conditions, do not result in malfunction of the subsystem. It also demonstrates that the subsystem does not emit, radiate, or conduct interference, which could result in malfunction of other subsystems.

7.3.9.2 Test Description

The test shall be conducted in accordance with the requirements of Reference 21. All tests shall be conducted at the payload and bus level on the subsystem external EMC interfaces. Acceptance tests shall be performed when there is less than a 12 dB qualification margin, or the radiated emissions requirement is more stringent than 10 dBuV/m, or the subsystem has a passive intermodulation requirement.

The EMC margin is to be incorporated into the test levels. No additional margin is required if the Reference 21-1 levels already have the required margin for the interface. Qualification margins of 6 dB are acceptable if the combined test uncertainty, part variation, part degradation at end-of-life, and workmanship variation is less than 6 dB. Electroexplosive devices and bridge wires have a 20 dB margin requirement below the DC no-fire value and a 6 dB margin requirement below the RF no-fire value.

7.3.9.3 Test Levels and Duration

The test levels shall be as follows:

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Qualification:	12 dB
Protoqualification:	6 dB
Acceptance:	6 dB

The test duration shall be 20 minutes at each space vehicle transmitter frequency for radiated susceptibility. Otherwise, the duration is the greater of three seconds or the unit response time for susceptibility requirements and 15 milliseconds duration for emission requirements.

7.3.10 Mode Survey Test

A mode survey test shall be conducted to obtain data needed to develop dynamic models for loads analyses. It may be conducted at the subsystem or at the vehicle level. Reference 17 defines the scope, application, and test requirements.

7.3.10.1 Purpose

The mode survey test is conducted to experimentally derive a structural dynamic model of a vehicle or to provide a basis for test-verification of an analytical model. After upgrading analytically to the flight configuration (such as different propellant loading and differences between flight and test unit mass properties), this model is used in analytical simulations of flight loading events. The computed loads are used to determine structural margins and adequacy of the structural static test loading conditions (7.3.2). They are, therefore, critical for verification of vehicle structural integrity and qualification of the structural subsystem as flight-ready. Where practical, a mode survey test is also performed to define or verify models used in the final preflight evaluation of structural dynamic effects on control subsystem precision, stability, and pointing performance.

7.3.10.2 Test Description

The test article shall consist of flight-quality structure with assembled units, payloads, and other major subsystems, and shall contain actual or simulated liquids. For large vehicles, complexity and testing practicability may dictate that tests be performed at the subsystem level. Mass simulators may be used to represent flight items when their attachment-fixed resonances have been demonstrated by test to occur above the frequency range of the mode survey test. Dynamic simulators may be used for items that have resonances within the frequency range of interest if they are accurate dynamic representations of the flight item. Alternatively, mass simulators may be used if flight-quality items are subjected separately to mode survey testing that meet test requirements. All mass simulators are to include realistic simulation of interface attach structure, and artificial stiffening of the test structure shall be avoided.

The data obtained in the modal survey shall be adequate to define the mode shapes, natural frequencies, and damping values for all modes that occur in the frequency range of interest, typically up to 70 Hz. In addition, the first two modes in each lateral coordinate plane, the first axial mode and the first torsional mode, shall be acquired even if their frequencies lie outside the specified test range. The quality of the measured modes must be judged by computing the mass-weighted orthogonality of the

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mode shapes. As a goal, the off-diagonal terms of the unit normalized generalized mass matrix should be equal to or less than 0.10.

7.3.10.3 Test Levels

The test is generally conducted at response levels that are low compared to the expected flight levels. Limited testing shall be conducted to evaluate nonlinear behavior, with a minimum of three levels used when significant nonlinearity is identified.

7.3.10.4 Supplementary Requirements

Because of their criticality to achieving a successful test, appropriate pretest analyses and experimentation shall be performed to:

a. Establish test instrumentation requirements.

b. Evaluate the test stand and fixturing to preclude any boundary condition uncertainties that could compromise test objectives.

c. Verify that mass simulators have no resonances within the frequency range of interest.

d. Establish flexibility to add or modify instrumentation during test to account for unexpected modes.

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8. Vehicle Test Requirements

8.1 General Requirements

The vehicle-level test baseline assumes that all unit-level and subsystem tests have been performed in accordance with this document. Tests that are conducted as acceptance tests for vehicle elements (such as alignments, instrument calibrations, antenna patterns, and mass properties) shall also have been conducted. All flight equipment and software shall be installed prior to beginning vehicle-level testing.

The sequence of tests performed at the vehicle level is shown in Table 8.3-1 for qualification and protoqualification vehicles and in Table 8.3-2 for acceptance vehicles. An overview of vehicle test level margins and durations described in this section is shown in Table 8.3-3.

System-level tests shall be the same as subsystem tests for end-to-end performance, configuration change, command and telemetry performance, and external interfaces to the ground and LV component, except that the actual compatibility interface testing to the other external system components need not be done at temperature if testing against a simulator at temperature was accomplished at a lower level of assembly.

Table 8.3-1. Vehicle Qualification and Protoqualification Test Summary

Test	Section	Suggested Sequence	Launch Vehicle	Upper-stage Vehicle	Space Vehicle
Inspection	4.6	1, 13	R	R	R
Performance (1)(4)	8.3.1	2, 12	R	R	R
Pressure and Leak (5)	8.3.2	3, 7, 10	R	R	R
EMC(2)	8.3.3	4 or 11 (2)	R	R	R
Shock(7)	8.3.4	6	R	R	R
Acoustic or Random Vibration (3)	8.3.5 8.3.6	5	ER	R	R
Thermal Balance	8.3.7	8	--	ER	R
Thermal Vacuum	8.3.8	9	--	ER	R
Mode Survey (6)	8.3.9	Any	ER	ER	R

R Required
ER Evaluation required (see 6.3)
(1) Performance tests conducted prior to, during, and following each environmental test as appropriate.
(2) EMC testing, sequence 11, shall be conducted when there are radiated emission requirements below 10 dBuV/m or there is a requirement on passive intermodulation levels.
(3) In some cases, vibration may be used in place of acoustics for vehicle weights under 400 lbs. (180 Kg).
(4) Deployments and critical clearance shall be verified (see 7.3.8).
(5) Requirement is met by subsystem-level testing unless a modification or repair has occurred.
(6) Mode Survey may be performed at the subsystem level if the test is not feasible at the system level. See Table 7.3-1.
(7) Preferred at the vehicle level; if not feasible, performed at the subsystem level.

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Table 8.3-2 Vehicle Acceptance Test Summary

Test	Reference Paragraph	Suggested Sequence	Launch Vehicle	Upper Stage Vehicle	Space Vehicle
Inspection	4.6	1, 12	R	R	R
Performance (1) (4)	8.3.1	2, 11	R	R	R
Pressure and Leak (5)	8.3.2	3, 7, 9	R	R	ER
EMC(2)	8.3.3	4 or 10 (2)	ER	ER	ER
Shock	8.3.4	6	ER	ER	R
Acoustic or Vibration (3)	8.3.5 8.3.6	5	ER	R	R
Thermal Vacuum	8.3.8	8	--	ER	R

R Required
ER Evaluation required (see 6.3)
(1) Performance tests shall be conducted prior to, during, and following each environmental test as appropriate.
(2) EMC testing (sequence 4 or 10) required when the qualification margin is not met, or there are radiated emission requirements below 10 dBuV/m, or there is a requirement on passive intermodulation levels.
(3) In some cases, vibration may be used in lieu of acoustics for vehicles under 400 lbs (180 Kg).
(4) Deployments and critical clearance shall be verified (see 7.3.8).
(5) Requirement is met by subsystem level testing unless a modification or repair has occurred

Table 8.3-3 Vehicle Test Level Margins and Duration

Test	Qualification	Protoqualification	Acceptance
Shock	1 activation of all shock-producing events; 2 additional activations of significant events	1 activation of all shock-producing events; 1 additional activation of significant events	1 activation of significant shock-producing events
Acoustic(1)	6 dB above acceptance for 3 min	3 dB above acceptance for 2 min	Envelope of MPE and minimum spectrum (Figure 6.3.6-1) for 1 minute
Vibration(1)	6 dB above acceptance for 3 min in each of 3 axes	3 dB above acceptance for 2 min in each of 3 axes	Envelope of MPE and minimum spectrum (Figure 8.3.7-1) for 1 min in each of 3 axes
Thermal Vacuum(2)	±10°C beyond acceptance for 8 cycles	±5°C beyond acceptance for 4 cycles	MPT for 4 cycles
Pressure(3)	Not applicable	Not applicable	Proof pressure as specified in 7.3.3.3 for pressurized subsystems(3). Leak tests at MEOP per 7.3.3.3
EMC	12 dB minimum duration same as acceptance	6 dB minimum duration same as acceptance	6 dB minimum 20 minutes at each space vehicle transmitter frequency for radiated susceptibility

(1) See B.1.3 for vehicles with effective duration greater than 15 seconds.
(2) See A.1.1 if vehicle thermal cycle testing is performed.
(3) Requirement met by subsystem level testing unless a modification or repair has occurred

8.2 Vehicle Development Tests

Vehicles are subjected to development tests and evaluations using structural and thermal development models as may be required to confirm dynamic and thermal environmental criteria for design of subsystems, to verify mechanical interfaces, and to assess functional performance of deployment mechanisms and thermal control subsystems. Vehicle-level development testing also provides an opportu-

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nity to develop handling and operating procedures as well as to characterize interfaces and interactions.

8.2.1 Mechanical Fit Development Tests

For launch and upper-stage vehicles, a mechanical fit, assembly, and operational interface test with the facilities at the launch or test site is recommended. Flight-weight hardware should be used if practical; however, a facsimile or portions thereof may be used to conduct the development tests at an early point in the schedule in order to reduce the impact of hardware design changes that may be necessary.

8.2.2 Mode Survey Development Tests

A development mode survey test should be conducted at the vehicle level when uncertainty in analytically predicted structural dynamic characteristics is judged to be excessive for purposes of structural or control subsystem design, and an early identification of problem areas is desired. The test article may be the full vehicle or one or more substructures depending on size and complexity. Such a development test does not replace the mode survey test(s) required for the Verification Load Cycle (Reference 17), and the requirements as summarized in 8.3.9.

8.2.3 Structural Development Tests

Structural tests may be required to verify the stiffness and strength properties and to measure member loads, stress distributions, deflections, and thermal distortion. Typical examples are structures with redundant load paths or new technology implementation. This development test does not replace the structural static load test that is required for subsystem qualification.

8.2.4 Acoustic Development Tests

Since high-frequency vibration responses are difficult to predict by analytical techniques, acoustic development testing of the launch, upper-stage, and space vehicles may be necessary to verify the adequacy of the dynamic design criteria for units. Vehicle units that are not installed at the time of the test should be dynamically simulated with respect to mass, center of gravity, moments of inertia, interface stiffness, and geometric characteristics. The test article should be exposed to the maximum predicted flight levels and instrumented at unit and other points of interest to obtain vibration responses for use in verifying unit predictions. Supporting structures such as payload or upper-stage adapters should be included, and responses evaluated to understand structurally borne energy that contributes to the response at nearby units.

8.2.5 Shock Development Tests

Since high-frequency shock responses are difficult to predict by analytical techniques, shock development testing of the launch, upper stage, and space vehicles may be necessary to verify the adequacy of the dynamic design criteria for units. Vehicle units that are not installed at the time of the test should be dynamically simulated with respect to mass properties, interface stiffness, and geometry. All explosive ordnance devices and other mechanisms capable of imparting a significant shock to the vehicle and its mounted assemblies should be operated to demonstrate functionality and survivability. Where practical, the shock test should involve physical separation of elements being deployed or released. When a significant shock is expected from interfacing subsystems not included on the vehicle under test (such as when a fairing separation causes shock responses on an upper stage under test),

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the adaptor subsystem or suitable simulation shall be attached and appropriate explosive ordnance devices or other means used to simulate the shock imposed. The pyroshock environment may vary significantly between ordnance activations. Therefore, the statistical basis given in 3.28 shall be used for estimating maximum expected and extreme spectra. Multiple activations of ordnance devices may be necessary to provide data for improved estimates.

8.2.6 Thermal Balance Development Tests

A thermal balance development test is performed to verify the analytical thermal modeling of launch, upper-stage, or space vehicles, and demonstrate the ability of the thermal control subsystem to maintain temperature limits. For vehicles in which thermally induced structural distortions are critical to mission success, the thermal balance test also evaluates alignment concerns. The test vehicle should consist of flight hardware or a thermally equivalent structure with addition of equipment panels, thermal control insulation, finishes, and thermally equivalent models of electrical, electronic, pneumatic, and mechanical units. Testing should be conducted in a space simulation test chamber capable of simulating the ascent, transfer orbit, and orbital thermal vacuum conditions as may be appropriate. The test consists of simulating different environmental and operational modes and collecting steady-state and transient thermal data to correlate the thermal analytic model and verify performance of the thermal control hardware.

8.2.7 Transportation and Handling Development Tests

The handling and transport of launch, upper-stage, space vehicles, or their sub-tier elements is normally conducted to result in dynamic environments well below those expected for launch and flight. However, since these environments are difficult to predict, it is often necessary to conduct a development test of potentially significant handling and transportation configurations to determine worst-case dynamic inputs. Such a test should use a development model of the item or a simulator that has at least the proper mass properties and RFI shielding effectiveness, instrumented to measure responses of the item. In particular, a drop test representative of a maximum credible operational occurrence should be conducted to demonstrate protection of the item in the handling apparatus and validate design of the shipping container. The data should be sufficient to determine whether the environments are benign relative to the design requirements, or to provide a basis for an analysis to demonstrate lack of damage, or to augment qualification and acceptance testing, if necessary.

8.2.8 Wind Tunnel Development Tests

Flight vehicle aerodynamic and aero-thermal data are needed to establish that the vehicles survive flight, and function properly under the imposed loads. For flight vehicles with a new or significantly changed aerodynamic design, the following wind tunnel tests shall be conducted:

a. **Force and Moment Tests.** These tests provide the resultant aerodynamic forces and moments acting on the vehicle during the high-dynamic-pressure region of flight. Data from these tests are used in both structural and control subsystem design and in trajectory analysis.

b. **Steady-State Pressure Tests.** These tests determine the spatial distribution of the steady-state component of the pressures imposed on the vehicle's external surfaces during the high-dynamic-pressure region of flight. These data are used to obtain the axial air load distributions, which are used to evaluate the static-elastic characteristics of the vehicle. These data along with fluctuating pressures of the external skin environment are also used in com-

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partment venting analyses to determine burst and collapse pressures imposed on the vehicle structure. The design and testing of the payload fairing structure are particularly dependent upon high-quality definition of these pressures.

c. **Aerodynamic Heating Tests.** These tests determine the heating effects due to fin and fuselage junctures, drag (friction), angle of attack, flow transition, shock wave impingement, proximity effects for multibody vehicles, and surface discontinuities.

d. **Base Heating Tests.** These tests determine the heating effects due to thermal radiation, multiplume recirculation convection, plume-induced flow separation on the vehicle body, and the base flow field.

e. **Thruster Plume-Impingement Heating Tests.** These tests determine the heating effects and contamination due to impingement of the thruster plumes.

f. **Transonic and Supersonic Buffet and Aerodynamic Noise Tests.** These tests define the spatial distribution of the unsteady or fluctuating component of the pressures imposed on the vehicle external surfaces during the high-dynamic-pressure region of flight. These data are used to obtain the dynamic airloads acting to excite the various structural modes of the vehicle and are used in aeroelastic, flutter, and vibroacoustic analyses. These data are also used in compartment venting analyses to determine burst and collapse pressures imposed on the vehicle structure.

g. **Ground-Wind-Induced Oscillation Tests.** These tests define the resultant forces and moments acting on the vehicle prior to launch when it is exposed to the ground-wind environment. Flexible models or elastically mounted rigid models are used to simulate at least the first cantilever-bending mode of the vehicle. Nearby structures or terrain, which may influence the flow around the vehicle, shall also be simulated.

h. **Aerodynamic Staging Tests.** These tests determine the forces and moments acting on the core vehicle and solid rocket motors (SRM) that are oriented in a series of representative positions encountered during SRM booster separation. Data from these tests are used in stage performance analysis.

8.3 Test Program for Flight Vehicles

Testing at the system level is composed of performance tests that are performed under ambient conditions and during or after environmental exposure.

The vehicle configuration shall contain all of its flight subsystems with flight software, and shall interface with external hardware and facilities and or simulators for external interface verification. Additional guidance may be found in Reference 32.

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8.3.1 Vehicle Performance and Functional Tests

8.3.1.1 Purpose

Performance and functional testing verify that the mechanical and electrical operations of the vehicle meet requirements, including interoperability with ground support equipment, and ground station assets.

8.3.1.2 Mechanical Test

Mechanical devices, valves, deployables, and separation subsystems shall be functionally tested at the vehicle level in the launch, orbital, or recovery configuration appropriate to the function. Alignment checks shall be made where appropriate and feasible. Fit checks shall be made of the vehicle physical interfaces. Testing shall validate that the vehicle performs within maximum and minimum limits under worst-case conditions, including environments, time, and other applicable requirements. Tests shall demonstrate positive margins of strength, force/torque, and related kinematics and clearances. Where operation in earth gravity or in an operational temperature environment cannot be performed, a suitable ground test fixture may be used to permit operation and performance evaluation. The pass-fail criteria shall be adjusted, as appropriate, to account for worst-case maximum and minimum limits that have been modified to adjust for ground test conditions. For additional details concerning deployment testing, see 7.3.8 and Reference 7.

8.3.1.3 End-to-End Performance Test

Vehicle performance testing is conducted to verify that the vehicle satisfies performance and functional requirements before and after exposure to environmental testing, hardware and software changes, hardware removal, and replacements. The vehicle shall be in its flight configuration with all units and subsystems connected. The test shall verify the integrity of end-to-end circuits, including functions, redundancies, deployment circuitry, end-to-end paths, and performance, including radio frequency and other sensor inputs. End-to-end sensor testing may be accomplished with self-test or coupled inputs.

The test shall be designed to operate all units, primary and redundant, and to exercise all commands and operational modes to the maximum extent practical. The operation of all thermally controlled units, such as heaters and thermostats, shall be verified by test. Where control of such units is implemented by sensors, electrical or electronic devices, coded algorithms, or a computer, end-to-end performance testing shall be conducted. The test shall demonstrate that all commands having precondition requirements (such as enable, disable, a specific equipment configuration, and a specific command sequence) cannot be executed unless the preconditions are satisfied. Equipment performance parameters that might affect end-to-end performance, such as command and data rates, shall be varied over specification ranges to demonstrate the performance. Autonomous functions shall be verified. Continuous monitoring of perceptive parameters, including input and output parameters, and the vehicle main bus by a power transient and a current monitoring device, shall be provided to detect intermittent failures.

The vehicle shall be operated through a mission profile with all events occurring in actual flight sequence. This sequence shall include the final countdown, launch, ascent, separation, upper-stage operation, all appropriate orbital operational modes, and return from orbit as appropriate. All explosive ordnance firing circuits shall be energized and monitored during these events to verify that the

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proper energy density is delivered to each device and in the proper sequence. Telemetry shall be monitored and trended during appropriate portions of these events to verify proper operations. Sufficient data shall be analyzed to verify the adequacy of the testing and the validity of the data before any change is made to an environmental test configuration so that any required retesting can be readily accomplished. The final software testing shall demonstrate that the hardware and software configuration can meet the defined functional and performance specifications in a worst-case stressing environment.

During one test in the acceptance flow, the vehicle shall be subjected to a "plugs-out" test. The purpose of this test is to demonstrate that all vehicle systems are in an "as near-flight configuration" as is practical. At the start of the test, umbilicals are disconnected and the vehicle is on flight batteries or flight-like batteries. The vehicle shall be operated through a basic set of functional checkouts and telemetry responses.

8.3.1.4 Supplementary Requirements

An end-to-end mission readiness test should be performed with the space vehicle in the factory operating under ground station control. This test should demonstrate that the combined space/ground system can perform the mission before flight, and to detect anomalies unique to this architecture. This end-to-end test should be run on the mission timeline and in the mission sequence. This test should be associated with the final integrated system test so that final flight hardware and flight/ground software loads are tested together. The test should also include mission tasking and data dissemination. The synergistic effects of combined environmental stresses and stressing mission scenarios should be considered.

8.3.2 Vehicle Pressure and Leakage Test

8.3.2.1 Purpose

These tests demonstrate the capability of pressurized subsystems to meet the specified pressure and leakage rate requirements. Vehicle-level testing for proof pressure need only include those zones or portions of the pressure system that are not fully assembled until the vehicle is complete or the integrity of which is suspect after the completion of the subsystem level testing. Leak testing at MEOP in pressurized subsystems shall be conducted.

Flow tests at pressure are considered part of performance testing (see 8.3.1).

8.3.2.2 Test Description

See 7.3.3.2

8.3.2.3 Test Levels and Durations

Pressurized subsystems shall have a capability to repeat testing of 7.3.3.3 at the vehicle level in the event of a modification or repair to the subsystem.

8.3.2.4 Supplementary Requirements

Applicable safety standards shall be followed in conducting all tests. Tests for detecting external leakage shall be performed at such locations as joints, fittings, plugs, and lines. The acceptable leak-

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age rate to meet mission requirements shall be based upon an appropriate analysis. In addition, the measurement technique shall account for leakage rate variations with pressure and temperature and have the required threshold, resolution, and accuracy to detect any leakage equal to or greater than the acceptable leak rate. If appropriate, the leakage rate measurement shall be performed at the MEOP and at operational temperature, with the representative fluid commodity, to account for dimensional and viscosity changes. Times to achieve thermal and pressure equilibrium, test duration, and temperature sensitivity shall be determined by an appropriate combination of analysis and development test, and the results documented. Leakage detection and measurement procedures may require vacuum chambers, bagging of the entire vehicle or localized areas, or other special techniques to achieve the required accuracies. See Reference 4 for further guidance on integration of pressure components and subsystems.

8.3.3 Vehicle Electromagnetic Compatibility Test

8.3.3.1 Purpose

The electromagnetic compatibility test demonstrates electromagnetic compatibility of the vehicle. EMC testing at the vehicle level assumes that full EMC testing in accordance with Reference 21 has been accomplished at the unit and/or subsystem level and that bus and payload EMC testing has also occurred in accordance with the tests described herein.

8.3.3.2 Test Description

The operation of the vehicle and selection of instrumentation shall be suitable for determining the margin against malfunctions and unacceptable or undesired responses due to electromagnetic incompatibilities.

The test shall demonstrate satisfactory electrical and electronic equipment operation in conjunction with the expected electromagnetic radiation from other subsystems or equipment, such as from other vehicle elements and ground support equipment. The vehicle shall be subjected to the required tests while in the launch, orbital, and return-from-orbit configurations, and in all possible operational modes, as applicable. Special attention shall be given to areas indicated to be marginal by unit-level test and analysis. Potential electromagnetic interference between the test vehicle and other subsystems shall be measured. The tests shall be conducted according to the requirements of Reference 21. The tests shall include, but not be limited to, nine main segments:

a. Radio frequency (RF) self-compatibility (all receivers and transmitters receiving and transmitting through flight antennas without antenna hats)

b. Power quality

c. Radiated emissions

d. Radiated susceptibility

e. Conducted emissions

f. Power transients

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g. Magnetic moments

h. Critical circuit margins

i. Umbilical separation test

Explosive-ordnance devices having bridge wires, but otherwise inert, shall be installed in the vehicle and monitored during all tests.

Acceptance tests shall be performed when the qualification margin is not met, or the radiated emissions requirement is more stringent than 10 dBuV/m, or the system has a passive intermodulation requirement.

The EMC margin is to be incorporated in to the test levels. No additional margin is required if the Reference 21 levels already have the required margin for the interface. Qualification margins of 6 dB are acceptable if the combined test uncertainty, part variation, part degradation at end-of-life, and workmanship variation is less than 6 dB. Electroexplosive devices and bridge wires have a 20 dB margin requirement below the DC no-fire value and a 6 dB margin requirement below the RF no-fire value.

8.3.3.3 Test Levels and Duration

The test levels shall be as follows:

Qualification:	12 dB
Protoqualification:	6 dB
Acceptance:	6 dB

The test duration shall be 20 minutes at each space vehicle transmitter frequency for radiated susceptibility. Otherwise, the duration is the greater of three seconds or the unit response time for susceptibility requirements and 15 milliseconds duration for emission requirements.

8.3.3.4 Supplementary Requirements

For guidance on testing rationale for satellite hardness and survivability refer to Reference 29.

8.3.3.4.1 Vehicle Qualification and Protoqualification

EMC testing Sequence 11 in the list of requirements shown in Table 8.3-1 shall be conducted when there are radiated emission requirements below 10 dBuV/m or there is a requirement on passive intermodulation levels. Sequence 4 is the preferred sequence as this minimizes the risk of repeating the mechanical environmental testing in the event of a failure and subsequent rework. If Sequence 11 is performed, conducting Sequence 4, in addition to Sequence 11, should be considered to reduce the risk of repeating the mechanical environmental testing in the event of a failure and subsequent rework.

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8.3.3.4.2 Vehicle Acceptance

EMC acceptance testing Sequence 4 or 10 in the list of requirements shown in Table 8.3-2 shall be conducted when the qualification margin is not met, or there are radiated emission requirements below 10 dBμV/m, or there is a requirement on passive intermodulation levels. EMC testing Sequence 10 shall be conducted when there are radiated emission requirements below 10 dBμV/m or there is a requirement on passive intermodulation levels. Sequence 4 is the preferred sequence as this minimizes the risk of repeating the mechanical environmental testing in the event of a failure and subsequent rework. If Sequence 10 is performed, conducting Sequence 4, in addition to Sequence 10, should be considered to reduce the risk of repeating the mechanical environmental testing in the event of a failure and subsequent rework.

8.3.4 Vehicle Shock Test

8.3.4.1 Purpose

Shock testing demonstrates the capability of the vehicle to withstand or, if appropriate, to operate through the induced shock environments. Shock testing also yields data to validate the maximum expected unit shock requirements.

8.3.4.2 Test Description

The vehicle shall be supported and configured to allow flight-like dynamic response of the vehicle with respect to amplitude, frequency content, and paths of transmission. Support of the vehicle may vary during the course of a series of shock tests in order to reflect the configuration at the time of each shock event. Test setups shall avoid undue influence of test fixtures, and prevent re-contact of separated items.

In the shock test, or series of shock tests, the vehicle shall be subjected to shock transients that cause the extreme expected shock environments to the extent practical. Shock events to be considered include separations and deployments initiated by explosive ordnance or other devices, as well as impacts and suddenly applied or released loads that may be significant for unit dynamic response (such as due to an engine transient, parachute deployment, and vehicle landing). All devices on the vehicle capable of imparting significant shock to the vehicle shall be activated. Those potentially significant shock sources not on the vehicle under test, such as on an adjoining payload fairing or a nearby staging joint, shall also be actuated or simulated and applied through appropriate interfacing structures. Dynamic instrumentation shall be installed to measure shock responses in three orthogonal directions at attachments of selected units.

8.3.4.3 Test Activations

Qualification: All explosive-ordnance devices and other potentially significant shock-producing devices or events, including those from sources not installed on the vehicle under test, shall be activated at least one time, or simulated, as appropriate. The significant shock events shall be activated two additional times to provide for variability in the vehicle test and to provide data for prediction of maximum and extreme expected shock environments for units. Activation of both primary and redundant devices shall be carried out in the same sequence as they are intended to operate in service.

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Protoqualification:	Same as qualification except only one additional activation of significant shock producing events is required.
Acceptance:	One activation of significant shock-producing events is required.

8.3.4.4 Supplementary Requirements

Electrical and electronic units shall be operating and monitored to the maximum extent practical and safe. Continuous monitoring of several perceptive parameters, including input and output parameters, and the vehicle main bus by a power transient-monitoring device, shall be provided to monitor power quality and detect intermittent failures.

8.3.5 Vehicle Acoustic Test

8.3.5.1 Purpose

The acoustic test demonstrates the ability of the vehicle to endure acoustic acceptance testing and meet requirements during and after exposure to the applicable acoustic environment of flight. Except for items whose environment is dominated by structure-borne vibration, the acoustic test also verifies the adequacy of unit vibration qualification levels, and serves as a qualification test and environmental stress screen for items not tested at a lower level of assembly.

8.3.5.2 Test Description

The vehicle in its ascent configuration shall be installed in an acoustic test facility capable of generating sound fields or fluctuating surface pressures that induce vehicle vibration environments sufficient for vehicle qualification. The vehicle shall be mounted on a flight-type support structure. Significant fluid and pressure conditions shall be replicated to the extent practical. Appropriate dynamic instrumentation shall be installed to measure vibration responses at attachment points of critical and representative units. Control microphones shall be placed at a minimum of four well-separated locations, preferably at one-half the distance from the test article to the nearest chamber wall, but no closer than 0.5 m (20 in.) to both the test article surface and the chamber wall. When test article size exceeds facility capability, the vehicle may be appropriately subdivided and acoustically tested as one or more subsystems or assemblies.

8.3.5.3 Test Level and Duration

The basic test levels and duration required for vehicles exposed to the liftoff and ascent acoustic excitation, effective duration of 15 seconds (see 3.12), are as follows:

Qualification:	6 dB above acceptance for 3 min
Protoqualification:	3 dB above acceptance for 2 min
Acceptance:	Envelope of the maximum predicted environment and minimum workmanship level shown in Figure 6.3.6-1 for 1 min

8.3.5.4 Supplementary Requirements

During the test, all electrical and electronic units used during launch, ascent, and on orbit, or that may be especially susceptible to vibroacoustic failure modes, shall be electrically energized and sequenced

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through operational modes to the maximum extent practical, with the exception of units that may sustain damage if energized. Continuous monitoring of appropriate perceptive parameters, including input and output parameters, and the vehicle main bus by a power transient-monitoring device and a current monitoring device, shall be provided to detect intermittent failures.

See B.1.5 for discussion of a damage-based approach to the analysis of flight acoustic data for determining the adequacy of established acceptance and qualification testing when new flight data bring the adequacy of the MPE spectrum into question.

8.3.5.5 Options for Acoustic Testing

8.3.5.5.1 Flightproof Acoustic Test

For program procurements of one or two vehicles, flightproof acoustic tests may be exercised as an option. This approach subjects the vehicle to a flightproof test that is an enhanced acceptance test using protoqualification levels (+3 dB), over the acceptance duration (one minute). Confidence is gained that each flightproof vehicle meets performance requirements in flight after having successfully passed testing beyond the maximum expected flight environments (MPE). Thus, flightproof testing is a check on the adequacy of each flight item, considering build variability or defects introduced due to handling or testing. In addition, flightproof reduces potential fatigue failures for retest due to the reduced exposure time. Since flightproof testing does not validate an acceptance test program (see B.1.2), acoustic testing of subsequent vehicle is performed, again, at flightproof levels.

8.3.5.5.2 Option for Deletion of Acceptance Acoustic Test

For satellite programs in excess of five vehicles with a consistent block design, an option to delete the acceptance acoustic test may be exercised based on the level of accepted residual risk. The contractor shall assess risk and provide documentation of the accepted risk of deleting the acoustic test. The contractor shall provide a report documenting the design and manufacture pedigrees and vehicle test results from the five previous vehicles in block to support the justification for execution of this option. Reference 31 provides information necessary to assess deleting the vehicle acoustic test after five sequential anomaly-free acoustic tests under the following conditions:

1. Consistent dynamic response to acoustics with no Category 1 or 2 anomalies noted and associated with the five preceding and sequential acoustic tests, including state changes identified in post-test functional/performance tests. Category 1 and 2 anomalies are discussed in B.3.

2. No flight anomalies potentially associated with dynamic environments during the first 180 days flight experience.

3. Consistent block design with no primary or secondary structural or harnessing design changes within block.

4. Demonstrated production stability on all vehicles within block. Detailed production stability criteria are discussed in Reference 31.

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5. The contractor shall provide a risk assessment for customer approval prior to executing this option.

Category 1 and 2 anomalies are discussed in B.3

Once these criteria are satisfied and a decision to delete the acoustic test is implemented, it is necessary to continue tracking program stability metrics to ensure the no-test status remains valid across builds. The test should be reinstated when these criteria are violated.

8.3.5.5.3 Alternative Power-On Acoustic Test Configuration

A baseline test requires the vehicle be electrically energized to the maximum extent feasible while maintaining vehicle safety. When this is not feasible or safe, the test may be run in other electrical configurations. In this case the supplier shall provide technical rationale and a risk assessment to the customer for approval. The risk assessment should consider latent defects that require synergistic environmental stress and electrical power for detection, which was not provided during the test.

8.3.5.5.4 Option to Perform Acoustic Test After Thermal Vacuum

As indicated in Tables 8.3-1 and 8.3-2, the suggested sequence shows the acoustic test preceding the thermal vacuum test. On acceptance test programs where schedule and hardware availability suggest a change in the test sequence, the acoustic test may be performed following the thermal vacuum test. This represents an increased risk to the program as the thermal vacuum test, the most perceptive environmental test, is not the last environmental test performed. The risk is due to the possibility of defects escaping that would not be detected without a subsequent thermal vacuum test. The resequencing may involve moving the associated shock test. If the modified test sequence is adopted, the acoustic should be run after shock and before post-test functional tests. The contractor shall conduct and provide a technical justification and a risk assessment to the customer for approval. The risk assessment should consider latent defects that require a subsequent thermal test for detection, which is no longer available.

A major purpose of the protoqualification, or flightproof, testing is design verification requiring maximum test effectiveness. As a result, the modified sequence approach is not available for protoqualification and flightproof vehicle testing.

8.3.6 Vehicle Vibration Test

The vibration test may be conducted instead of an acoustic test for small, compact vehicles that are not sensitive to acoustic excitation. Such vehicles may be excited more effectively via interface vibration. These vehicles should have a weight less than 400 lb.

8.3.6.1 Purpose

The vibration test demonstrates vehicle margin over the launch and ascent environments and assures that a satisfactory workmanship level screen can be applied for follow-on hardware. Except for items whose response is dominated by acoustic excitation, the vibration test also verifies the adequacy of unit vibration qualification levels and serves as a qualification test and environmental stress screen for items that have not been tested at a lower level of assembly.

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8.3.6.2 Test Description

The vehicle and a flight-type adapter, in the ascent configuration, shall be vibrated using one or more shakers through appropriate vibration fixtures. Vibration shall be applied in each of three orthogonal axes, one direction being parallel to the vehicle thrust axis. Instrumentation shall be installed to measure, in those same three axes, the vibration inputs and the vibration responses at attachment points of critical and representative units.

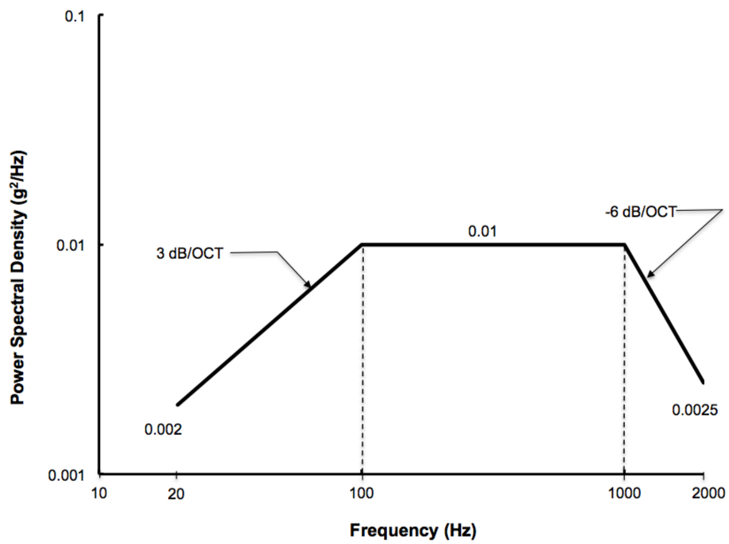
8.3.6.3 Test Levels and Durations

The basic test levels and duration required for vehicles exposed to the liftoff and ascent vibration, effective duration of 15 seconds (see 3.12), are as follows:

Qualification:	6 dB above acceptance for 3 min/axis
Protoqualification:	3 dB above acceptance for 2 min/axis
Acceptance:	Envelope of the maximum predicted environment and minimum workmanship level shown in Figure 8.3.7-1 for 1 min/axis

Notching is allowed based on impedance differences between the test and flight interface.

Test time should be divided approximately equally between redundant functions. When insufficient test time is available at the full test level to test redundant circuits, functions, and modes, extended testing using a spectrum no lower than 6 dB below the qualification spectrum shall be conducted as necessary to complete functional testing.



Spectrum Values	
Frequency (Hz)	Minimum PSD (g^2/Hz)
20	0.002
20 to 100	+3 dB per octave slope
100 to 1000	0.01
1000 to 2000	-6 dB per octave slope
2000	0.0025
The overall acceleration level is 3.8 grms.	

Figure 8.3.7-1. Minimum random vibration spectrum, vehicle acceptance test.

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8.3.6.4 Supplementary Requirements

During the test, all electrical and electronic units used during launch, ascent, and on-orbit, or that may be especially susceptible to vibroacoustic failure modes, shall be electrically energized and sequenced through operational modes to the maximum extent practical. Continuous monitoring of appropriate perceptive parameters, including input and output parameters, and the vehicle main bus by a power transient-monitoring device, shall be provided to detect intermittent failures.

See B.1.5 for discussion of a damage-based approach to the analysis of flight vibration data for determining the adequacy of established acceptance and qualification test requirements when new flight data are outside the experience base used to derive the preflight MPE spectrum.

8.3.6.5 Option for Vehicle Random Vibration Testing

8.3.6.5.1 Flightproof Random Vibration Test

For program procurements of a single vehicle of less than 400 lb. weight, a flightproof random vibration test may be executed for vehicles meeting criteria of 8.3.6. This approach subjects the vehicle to a flightproof test that is an enhanced acceptance test using protoqualification levels (+3 dB), over the acceptance duration (one minute). Confidence is gained that each flightproof vehicle meets performance requirements in flight after having successfully passed testing beyond the maximum expected flight environments (MPE). Thus, flightproof testing is a check on the adequacy of each flight item, considering build variability or defects introduced due to handling or testing. In addition, flightproof reduces potential fatigue failures for retest due to the reduced exposure time. Since flightproof testing does not validate an acceptance test program (see B.1.2), random vibration testing of any subsequent vehicle shall be performed at flightproof levels and durations.

8.3.7 Vehicle Thermal Balance Test

8.3.7.1 Purpose

The thermal balance test provides the data necessary to verify the analytical thermal model and demonstrates the ability of the vehicle thermal control subsystem to maintain specified temperature limits of units for various operational scenarios throughout the entire vehicle. The thermal balance test can be combined with the thermal vacuum test.

8.3.7.2 Test Description

The qualification or protoqualification vehicle shall be exposed to thermal environments expected by the vehicle during its service life in a thermal balance test. Test instrumentation shall be installed that produces data that can be correlated to the thermal model over the full range of seasons, equipment duty cycles, ascent conditions, solar angles, maximum and minimum unit thermal dissipations, including effects of bus voltage variations, and eclipse combinations. As a minimum, three test conditions shall be imposed: a hot operational case, a cold operational case, and a cold non-operational case. Two additional cases should be imposed: a transient case and a case chosen to check the validity of the correlated model. Other cases that are commonly simulated include eclipse, ascent, safe mode, and “day-in-the-life” conditions.

Thermal balance test phases need not be worst-case-expected flight conditions, but they should not be significantly different from these conditions. Special emphasis shall be placed on defining the test

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conditions expected to produce the maximum and minimum temperatures of sensitive units such as batteries. Sufficient measurements shall be made on the vehicle internal and external units to verify the vehicle thermal design, hardware, and analyses. The operation and power requirements of all thermostatically or electronically controlled heaters and coolers shall be verified during the test, and appropriate control authority demonstrated, both on the primary and redundant circuits.

The test chamber, with the test item installed, shall provide a pressure of no higher than 13.3 mPa (10^{-4} Torr) for space and upper-stage vehicles, or a pressure commensurate with service altitude for launch vehicles. Where appropriate, provisions should be made to prevent the test item from "viewing" warm chamber walls, by using black-coated cryogenic shrouds of sufficient area and shape that are capable of approximating liquid-nitrogen temperatures. The vehicle thermal environment may be supplied by one of the following methods:

a. **Absorbed Flux.** The absorbed solar, albedo, and planetary irradiation is simulated using heater panels or infrared (IR) lamps with their spectrum adjusted for the external thermal coating properties, or using electrical resistance heaters attached to vehicle surfaces.

b. **Incident Flux.** The intensity, spectral content, and angular distribution of the incident solar, albedo, and planetary irradiation are simulated.

c. **Equivalent Radiation Sink Temperature.** The equivalent radiation sink temperature is simulated using infrared lamps and calorimeters with optical properties identical to those of the vehicle surface.

d. **Combination.** The thermal environment is supplied by a combination of the above methods.

The selection of the method and fidelity of the simulation depends upon details of the vehicle thermal design, such as vehicle geometry, the size of internally produced heat loads compared with those supplied by the external environment, and the thermal characteristics of the external surfaces. Instrumentation shall be incorporated down to the unit level to evaluate total vehicle performance within operational limits as well as to identify unit problems. The vehicle shall be operated and monitored throughout the test. Dynamic flight simulation of the vehicle thermal environment should be provided unless the external vehicle temperature does not vary significantly with time.

Temperature measurement channels used to define thermal equilibrium shall have stabilities with time (noise level evidenced by varying readings at constant temperature, including bias and precision) commensurate with the time rate of change of temperature (dT/dt) used to define equilibrium. This capability shall be defined as a requirement and demonstrated before test.

8.3.7.3 Levels and Duration

Test conditions and durations for the thermal balance test are dependent upon the vehicle configuration, design, and mission details. Boundary conditions for evaluating the thermal control hardware and design shall include the following:

a. Maximum external absorbed flux plus maximum internal dissipation

b. Minimum external absorbed flux plus minimum internal power dissipation

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c. Minimum external absorbed flux plus minimum non-operating or stand-by power dissipation

Temperature stabilization shall be achieved when the unit having the largest thermal time constant has a temperature rate of change of less than 1°C measured over five hours. The thermal time constant of the subsystems and mission profile both influence the time required for the vehicle to achieve thermal equilibrium and, hence, the test duration.

8.3.8 Vehicle Thermal Vacuum Test

8.3.8.1 Purpose

The qualification thermal vacuum test demonstrates the ability of the vehicle to meet design requirements and establishes the thermal design margin and vehicle performance under thermal vacuum conditions and temperature extremes. Acceptance thermal vacuum testing demonstrates the ability to withstand the thermal stressing environment with margin on temperature range and number of cycles. It also detects material, process, and workmanship defects that would respond to thermal vacuum and thermal stress conditions.

8.3.8.2 Test Description

The vehicle shall be placed in a thermal vacuum chamber, and a performance test conducted to assure readiness for chamber closure. The vehicle shall be divided into separate equipment zones based on the thermal limits of the temperature-sensitive units and similar unit qualification temperatures within each zone. Units that operate during ascent shall be operating and monitored for the effects of corona and multipacting, as applicable, as the pressure is reduced to the lowest specified level. The rate of chamber pressure reduction shall be no greater than during ascent, and may have to be slower to allow sufficient time to monitor for the effects of corona and multipacting. Typically, this test does not simulate launch depressurization; therefore, consideration shall be given to any hardware susceptible to a rapid change in pressure. Equipment that does not operate during launch shall have electrical power applied after the lowest specified pressure level has been reached. A thermal cycle begins with the vehicle at ambient temperature. The temperature is raised to the specified high level and stabilized. Following the high-temperature soak, the temperature shall be reduced to the lowest specified level and stabilized. Following the low-temperature soak, the vehicle shall be returned to ambient temperature to complete one thermal cycle. Performance tests shall be conducted during the first and last thermal cycle at both the hot and cold temperature limits with functional operation and monitoring of perceptive parameters during all other cycles. If simulation of the ascent environment is desirable at the beginning of the test, the first cycle may begin with a transition to a cold thermal environment rather than a hot thermal environment.

In addition to the thermal cycles for an upper-stage or space vehicle, the chamber may be programmed to simulate various orbital flight operations. Execution of operational sequences shall be coordinated with expected environmental conditions, and a complete cycling of all equipment shall be performed, including the operating and monitoring of redundant units and paths. Vehicle electrical equipment shall be operating and monitored continuously throughout the test. Temperature monitors shall assure attainment of temperature limits. Strategically placed witness plates, quartz-crystal microbalances, or other instrumentation shall be installed in the test chamber to measure the outgassing from the vehicle and test equipment.

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Performance tests shall be conducted after unit temperatures have stabilized at the hot and cold temperatures on the first and last cycle. Before the first cycle and following the last cycle, the test shall also be performed at ambient. For any intermediate cycles, abbreviated performance tests at hot and cold temperatures shall be performed. During these tests, electrical and electronic units, including all redundant circuits and paths, shall be cycled through all operational modes. Perceptive parameters shall be monitored for failures and intermittent conditions. All electrical circuits and all paths should be verified for circuit performance and continuity. Performance tests may be conducted during temperature transitions.

In some cases, vehicle performance and workmanship objectives may require a vehicle thermal cycle test in addition to a vehicle thermal vacuum test. If payload performance or workmanship screening requires a temperature range that cannot be achieved in ground vacuum testing, then a vehicle thermal cycle test over the desired temperature range shall also be performed as an alternative strategy (A.1.1).

8.3.8.3 Test Levels and Durations

The vehicles shall be tested to the temperature ranges and cycles as shown:

Qualification:	10°C beyond acceptance temperatures for 8 cycles
Protoqualification:	5°C beyond acceptance temperatures for 4 cycles
Acceptance:	Minimum and maximum predicted temperatures for 4 cycles

Temperatures in various equipment areas shall be controlled by the external test environment and internal heating resulting from equipment operation. During the hot and cold half-cycles, the test temperature is reached as soon as one unit in each equipment area is at its hot or cold temperature. Temperature stabilization shall be achieved when the test article temperature is within the allowed test tolerance on the specified test temperature and the temperature rate of change is less than 3°C per hour. Unit temperatures shall not be allowed to go outside their applicable qualification, protoqualification, or acceptance range at any time during the test. The pressure shall be maintained at no higher than 13.3 mPa (10^{-4} Torr) for service above 100,000 meters, or the pressure commensurate with the highest possible service altitude for lower altitudes.

The rate of temperature change shall equal or exceed the maximum predicted mission rate of change. The thermal soak shall be at least eight hours at each temperature extreme during the first and last cycles. For intermediate cycles, the thermal soak duration shall be at least four hours. Operating time shall be divided approximately equally between primary and redundant units.

8.3.9 Mode Survey Test

Mode survey testing shall be conducted to obtain data required to develop or verify a dynamic model for load analyses. It may be conducted as a system test, or a combination of subsystem tests, as appropriate. Reference 17 defines the requirements for the test.

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8.3.9.1 Purpose

The mode survey test is conducted to experimentally derive a structural dynamic model of a vehicle or to provide a basis for test verification of an analytical model. After upgrading analytically to the flight configuration, the model is used in the Verification Load Cycle defined in Reference 17. The Verification Load Cycle loads are used to determine structural margins and the adequacy of the structural static strength test (7.3.2). Mode survey tests are, therefore, critical for verification of vehicle structural integrity and qualification of the structural subsystem as flight-ready. Where practical, a mode survey test is also performed to define or verify models used in the final preflight evaluation of structural dynamic effects on control subsystem precision, stability, and pointing performance.

8.3.9.2 Test Description

The data obtained in the mode survey test shall be adequate to define the mode shapes, natural frequencies, and damping values, for all modes of vibration that occur in the frequency range of interest, typically up to 70 Hz. The first two modes in each lateral coordinate plane, the first axial mode, and the first torsional mode shall be acquired, even if their frequencies lie outside the specified test range. The quality of the measured modes shall be judged by computing the mass-weighted orthogonality of the mode shapes, i.e., the off-diagonal terms of the unit normalized generalized mass matrix should be equal to or less than 0.10.

8.3.9.3 Test Levels

The test is generally conducted at response levels that are low compared to the expected flight levels. Limited testing shall be conducted to evaluate nonlinear behavior, with a minimum of three levels used when significant nonlinearity is identified.

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9. Prelaunch Validation and Operational Tests

9.1 Prelaunch Validation Tests, General Requirements

Prelaunch validation testing is accomplished at the factory and at the launch base, with the objective of demonstrating launch system and on-orbit system readiness. Prelaunch validation testing is usually divided into two phases:

Phase A. Integrated system tests (Step 3 tests, Reference 2 as guidance)

Phase B. Initial operational tests and evaluations (Step 4 tests, Reference 2 as guidance)

During Phase A, the test series establishes the vehicle baseline data in the factory preshipment acceptance tests. When the launch vehicle(s), upper-stage vehicle(s), and space vehicle(s) are first delivered to the launch site, tests shall be conducted as required to assure vehicle readiness for integration with the other vehicles. These tests are intended to identify any changes that may have occurred in vehicle parameters as a result of handling and transportation to the launch base. The launch vehicle(s), upper stage vehicle(s), and space vehicle(s) may each be delivered as a complete vehicle, or they may be delivered as separate stages and first assembled at the launch site as a complete launch system. The prelaunch validation tests are unique for each program in the extent of the operations necessary to ensure that all interfaces are properly tested. For programs that ship a complete vehicle to the launch site, these tests primarily confirm vehicle performance, check for transportation damage, and demonstrate interface compatibility.

During Phase B, initial operational tests and evaluations (Step 4 tests) are conducted following the integrated system tests to demonstrate successful integration of the vehicles with the launch facility, and that compatibility exists between the vehicle hardware, ground equipment, computer software, and within the entire launch system and on-orbit system. The point at which the integrated system tests end and the initial operational tests and evaluations begin is somewhat arbitrary since the tests may be scheduled to overlap in time. To the greatest extent practical or as dictated by the procuring agency, the initial operational tests in the launch vehicle and launch upper stage shall exercise every operational mode in order to ensure that all mission requirements are satisfied. These Step 4 tests shall be conducted in an operational environment, with the equipment in its operational configuration, by the operating personnel, in order to test and evaluate the effectiveness and suitability of the hardware and software. These tests should emphasize reliability, contingency plans, maintainability, supportability, and logistics. These tests should assure compatibility with scheduled range operations including range instrumentation.

9.2 Prelaunch Validation Test Flow

Step 4 testing (Reference 2 as guidance) of new or modified ground facilities, ground equipment, or software should be completed prior to starting the prelaunch validation testing of the vehicles at the launch base. The prelaunch validation test flow shall follow a progressive growth pattern to ensure proper operation of each vehicle element prior to progressing to a higher level of assembly and test.

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In general, tests should follow the launch base buildup cycle. As successive vehicles or subsystems are verified, assembly proceeds to the next level of assembly. Following testing of the vehicles and their interfaces, the vehicles are electrically and mechanically mated and integrated into the launch system. Upper-stage vehicles and space vehicles employing a recoverable flight vehicle shall utilize a flight vehicle simulator to perform mechanical and electrical interface tests prior to integration with the flight vehicle. Following integration of the launch vehicle(s), upper-stage vehicle(s), and space vehicle(s), performance tests of each of the vehicles shall be conducted to ensure its proper operation following the handling operations involved in mating. Vehicle cleanliness shall be monitored. In general, the Step 4 testing of the launch system is conducted first. Bus and Payload testing shall be in accordance with appropriate verification and test plans.

9.3 Prelaunch Validation Test Configuration

During each test, the applicable vehicle(s) shall be in their flight configuration to the maximum extent practical, consistent with safety, control, and monitoring requirements. For programs utilizing a recoverable flight vehicle, the test configuration shall include any airborne support equipment required for the launch, ascent, and space vehicle deployment phases. This equipment shall be mechanically and electrically mated to the space vehicle in its launch configuration. All ground equipment shall be validated prior to being connected to any flight hardware. Test provisions shall be made to verify integrity of circuits into which flight jumpers, arm plugs, or enable plugs have been inserted.

9.4 Prelaunch Validation Test Descriptions

The prelaunch launch vehicle and upper stage validation tests shall exercise and demonstrate satisfactory operation of each of the vehicles through all of their mission phases, to the maximum extent practical. Test data shall be compared to corresponding data obtained in factory tests to identify trends in performance parameters.

9.4.1 Performance Tests

Performance tests shall be conducted to validate integrated hardware and software performance and flightworthiness. Mechanical tests shall be conducted for leakage, valve and mechanism operability, and fairing clearance.

9.4.1.1 Simulators

When simulators are employed, the flight interfaces shall be validated when reconnected.

9.4.1.2 Explosive Ordnance and Non-Explosive Firing Circuits

Prior to final connection of the firing circuit to electro-explosive devices (EED) and non-explosive actuators (NEA), the ignition energy levels and redundant circuit isolation shall be validated. Circuit continuity and stray energy checks shall be made prior to connection of a firing circuit to ordnance devices, and this check shall be repeated whenever that connection is opened and prior to reconnection.

9.4.1.3 Transportation and Handling Monitoring

Monitoring for shock, vibration, temperature, and humidity shall be performed at a minimum at the forward and aft interfaces between the shipping container transporter and the article being shipped,

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and on the top of the article. Three-axis monitoring shall cover the entire shipment period and the data evaluated as part of the receiving process.

9.4.1.4 Late Removal and Replacement of Flight Hardware

A performance test shall be performed when flight hardware or interfaces have been removed and/or replaced. The performance test shall verify performance of all affected hardware and software and potentially affected interfaces.

9.4.2 Propulsion Subsystem Leakage and Functional Tests

Performance tests of the launch vehicle propulsion subsystem(s) shall be conducted to verify the proper operation of all units to the maximum extent practical.

9.4.3 Launch-critical Ground Support Equipment Tests

Hardware associated with ground subsystems that are flight critical and non-redundant (such as umbilicals) shall have been subjected to appropriate tests under simulated functional and environmental conditions of launch. These tests shall include an evaluation of radio frequency (RF) interference between system elements, electrical power interfaces, and the command and control subsystems. For further guidance on Range Safety see Reference 3.

On a new vehicle design or where significant design changes were made to the telemetry, tracking, or receiving subsystem of an existing vehicle, a test shall be run on the first vehicle to ensure nominal operation and that explosive ordnance devices do not fire when the vehicle is subjected to worst-case electromagnetic interference environment.

9.4.4 Compatibility Test, On-Orbit System

9.4.4.1 Purpose

The compatibility test validates any required compatibility of the upper-stage vehicle, the space vehicle, the on-orbit command and control network, and other elements of the space system.

9.4.4.2 Test Description

Facilities to perform system compatibility tests exist. These facilities can command the launch, upper-stage, and space vehicles, and process telemetry from the vehicles, as well as perform tracking and ranging, thus verifying the system compatibility, the command software, the telemetry processing software, and the telemetry modes. The required tests shall include the following:

a. Verification of the compatibility of the radio frequencies and signal waveforms used by the flight unit's command, telemetry, and tracking links

b. Verification of the ability of the flight units to accept commands from the command and control network(s)

c. Verification of the command and control network(s) capability to receive, process, display, and record the vehicle(s) telemetry link(s) required to monitor the flight units during launch, ascent, and on-orbit mission phases

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d. Verification of the ability of the flight units to support on-orbit tracking as required for launch, ascent, and on-orbit mission phases

e. Verification of all uplink and downlink command and telemetry paths or redundant boxes as well as all keying material on-board the space vehicle and on the ground

f. Verification of all downlink frequencies that contain data

9.4.4.3 Supplementary Requirements

The compatibility test is made with every vehicle to verify system interface compatibility. The test shall be run using the software versions that are integrated into the operational on-orbit software of the vehicle under test. Following the completion of the compatibility test, the on-orbit command and control network configuration of software, hardware, and procedures shall be frozen until the space vehicle is in orbit and initialized.

9.5 Follow-On Operational Tests for Space Vehicles

9.5.1 Follow-On Operational Tests and Evaluations

Follow-on Operational Tests and Evaluations shall be conducted at the launch site in an operational environment with the equipment in its operational configuration. The assigned operating personnel shall identify operational system deficiencies. (See Reference 2.)

9.5.2 On-Orbit Testing

On-orbit testing should be conducted to verify the functional integrity of the space vehicle following launch and orbital maneuvering. Other on-orbit testing requirements are an important consideration in the design of any space vehicle. For example, there may be a need to calibrate on-line equipment or to verify the operational status of off-line equipment while in orbit. However, on-orbit testing is dependent on the built-in design features, and if testing provisions were not provided, the desired tests cannot be accomplished. On-orbit tests are, therefore, so program peculiar that specific requirements are not addressed in this Standard.

9.5.3 Reusable Flight Hardware

Tests of reusable flight hardware shall be conducted as required to achieve a successful space mission. Reusable hardware consists of the vehicles and units intended for repeated missions. Airborne support equipment that performs its mission while attached to a recoverable launch vehicle is an example of a candidate for reuse. The reusable equipment would be subjected to repeated exposure to test, launch, flight, and recovery environments throughout its service life. The accumulated exposure time of equipment retained in a recoverable vehicle and of airborne support equipment is a function of the planned number of missions involving this equipment and the retest requirements between missions. The environmental exposure time of airborne support equipment is further dependent on whether or not its use is required during the acceptance testing of other non-recoverable flight equipment. In any case, the service life of reusable hardware should include all planned reuses and all planned retesting between uses.

The test requirements for reusable space hardware after the completion of a mission and prior to its reuse on a subsequent mission depend heavily upon the design of the reusable item and the allowable

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program risk. For those reasons, specific details are not presented in this Standard. Similarly, orbiting space vehicles that have completed their useful life spans may be retrieved by means of a recoverable flight vehicle, refurbished, and reused. Based on present approaches, it is expected that the retrieved space vehicle would be returned to the contractor's factory for disassembly, physical inspection, and refurbishment. All originally specified acceptance tests shall be conducted before reuse.

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Appendix A. Thermal Test Considerations

A.1 Additional Thermal Test Considerations

A.1.1 Vehicle Alternate Thermal Strategy

In some cases, vehicle performance and workmanship objectives are better addressed in a vehicle thermal cycle test than in a vehicle thermal vacuum test. If payload performance or workmanship screening requires a temperature range that cannot be achieved in ground vacuum testing, then a vehicle thermal cycle test over the desired temperature range shall also be performed.

When a vehicle thermal cycle test is performed, the number of required vehicle thermal vacuum cycles may be reduced from the values given in 8.3.8.3. The test durations and levels of the vehicle thermal cycling test (and the number of thermal vacuum cycles, performed per 8.3.8) shall be:

Qualification:	6 TC cycles over a 70°C minimum temperature range (and 4 TV cycles over the temperature range specified in 8.3.8.3)
Protoqualification:	3 TC cycles over a 60°C minimum temperature range (and 2 TV cycles over the temperature range specified in 8.3.8.3)
Acceptance:	3 TC cycles over a 50°C minimum temperature range (and 2 TV cycles over the temperature range specified in 8.3.8.3)

The vehicle qualification thermal cycle test detects design defects and demonstrates the ability of the vehicle to withstand the stressing environment associated with flight vehicle thermal cycle acceptance testing, with a qualification margin on temperature range and maximum number of cycles. The vehicle acceptance thermal cycle test detects material, process, and workmanship defects. The vehicle shall be placed in a thermal chamber at ambient pressure, and a performance test shall be performed to assure readiness for the test. The vehicle shall be operated and monitored during the entire test, except that vehicle power may be turned off, if necessary, to reach stabilization at the cold temperature. Vehicle operation shall be asynchronous with the temperature cycling, and redundant units shall be operated for approximately equal times.

Temperature cycling shall begin when the relative humidity of inside spaces of the vehicle is below the value at which the cold test temperature would cause condensation. One complete thermal cycle is a period beginning at ambient temperature, then cycling to one temperature extreme and stabilizing, then to the other temperature extreme and stabilizing, and then returning to ambient temperature. Strategically placed temperature monitors installed on units shall assure attainment and stabilization of the expected temperature extremes for all units. Auxiliary heating and cooling may be employed for selected temperature-sensitive units (e.g., batteries). If it is necessary in order to achieve the required temperature rate of change, parts of the vehicle such as solar arrays and passive thermal equipment may be removed for the test.

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Performance tests shall be conducted after unit temperatures have stabilized at the hot and cold temperatures on the first and last cycle. Before the first cycle and following the last cycle, the performance test shall also be performed at ambient. For intermediate cycles, functional tests at hot and cold temperatures shall be performed. During these tests, electrical and electronic units, including all redundant circuits and paths, shall be cycled through all operational modes. Perceptive parameters shall be monitored for failures and electrical intermittences. All electrical circuits and all paths shall be verified for circuit performance and continuity. Performance tests and mission profile testing may be conducted during temperature transitions.

A.1.2 Option for Unit Level Two-Tier Thermal Test

When an electrical or electronic unit's allowable test temperature limits do not comply with the baseline temperature ranges specified in 6.3.8.3b and 6.3.9.3b, the number of cycles may be increased to achieve an equivalent screening stress level. An alternative approach is applicable when operational temperature limits can comply with the baseline temperature ranges, but performance temperature limits cannot. In such cases, a two-tier thermal test profile may be adopted whereby the unit demonstrates operational requirements at the baseline temperature range and performance requirements at a narrower temperature range. A representative two-tier acceptance thermal test profile is shown in Figure A.1.2.

For an acceptance test, the unit shall be taken to the acceptance temperature range (at least -24°C to +61°C) on each cycle of the test and to a narrower performance temperature range on the first and last cycles. Functional tests shall be conducted at acceptance temperatures on each cycle. Performance tests are conducted at the narrower performance hot and cold temperature levels on the first and last cycle. Other test requirements, such as dwell time and parameter monitoring during the test, are as specified in 6.3.8 and 6.3.9.

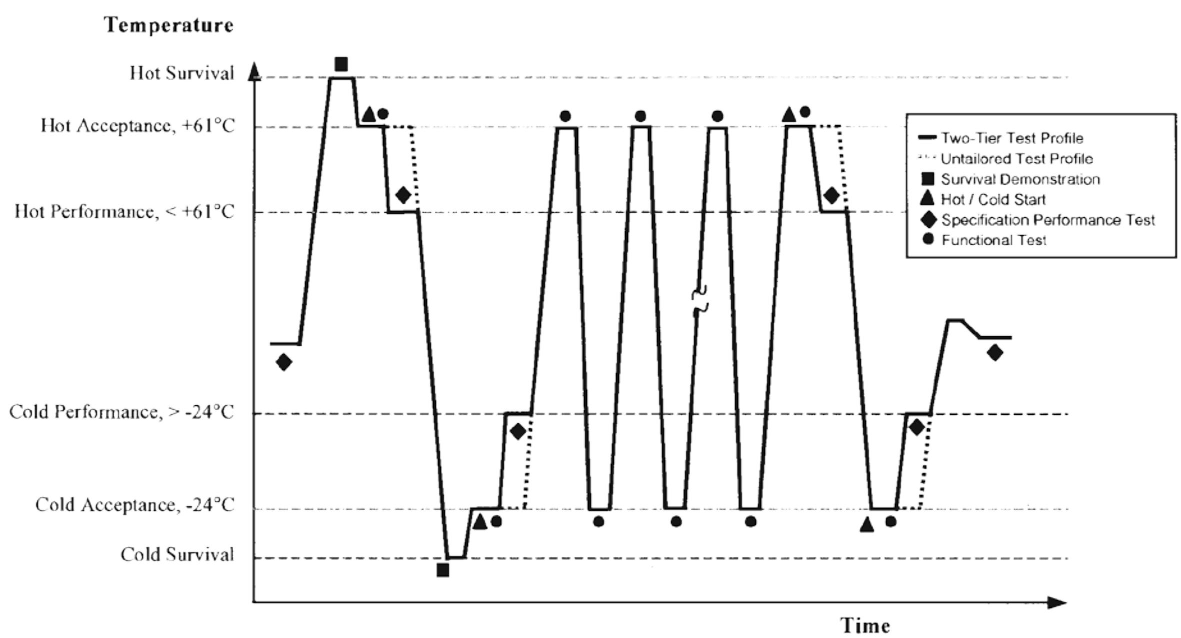

Figure A.1.2. Two-tier acceptance thermal test profile.

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An alternative approach is to conduct performance testing at the acceptance levels with the provision that performance requirements do not need to be met at these wider temperature levels. When the unit is ramped to the subsequent performance temperature range, only those performance tests that did not pass at the acceptance temperature are conducted. Performance testing at the acceptance temperature range permits some performance requirements to be verified at the wider temperature range and a better understanding of performance roll-off or degradation as a function of temperature. Another option is to conduct all performance testing at both the acceptance and the performance temperature levels, allowing performance to degrade at the acceptance level. The advantage of this approach is that it characterizes the unit's performance temperature dependency.

In two-tier testing, the thermal uncertainty margin is demonstrated between the maximum thermal model temperature prediction range and the performance temperature limits. The thermal control subsystem shall be designed (i.e., selection of thermal control hardware, heaters and thermal coatings) to show, for an acceptance unit, an 11°C minimum margin between the maximum model temperature prediction and the hot performance temperatures, and an 11°C minimum margin (or a 25 percent control authority for active thermal control) between the minimum model temperature prediction and the cold performance temperatures. For protoqualification testing, the thermal control subsystem shall show an additional 5°C of temperature margin.

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Appendix B. Dynamic Test Considerations

B.1 Test Considerations for Acoustic, Vibration, and Shock Environments

The following paragraphs describe the considerations for the statistical analysis approach used in this document to derive the Maximum Predicted Environment for acceptance testing and margins for qualification and protoqualification. The approach applies to random vibration, acoustics, and shock environments.

B.1.1 Statistical Basis for Test Level

a. Flight-to-flight variability of the spectral value at a frequency for acoustic, random vibration, shock, and sinusoidal vibration environments (defined in 3.26, 3.27, 3.28, and 3.29 respectively) is baselined to be log-normally distributed. That is, the normal distribution applies to the logarithms of the spectral values at a particular frequency. Consequently, the estimated mean spectrum is the average of the logarithmic values of available spectra. The standard deviation of spectra from the mean is denoted by σ and is baselined to equal 3 dB. The assumption of log-normal distribution with 3 dB standard deviation is based on repeated measurements on 24 static firings and over 40 flights of a launch vehicle (Reference B9).

b. Test levels are generally based on a tolerance interval above the estimated flight mean spectrum. The interval is specified for a probability P that the test spectrum will not be exceeded in flight, estimated with a confidence of C, and will depend on the applicable probability distribution. In the absence of a set of relevant measurements, the analysis presented in the next several paragraphs may be used. It rests on the assumption that the distribution of the spectrum values is normal, centered at the sample or analysis mean, and that the standard deviation of the overall population from which the sample was taken is 3 dB as discussed in item (a) above. This approach has been used in versions of MIL-STD-1540 since 1989. More recently, Womack (Reference B2) documented the applicability of the analysis and set the low sample limit at approximately 14. For larger samples, a rigorous calculation of the tolerance interval should be employed. Reference B10 provides guidance for such cases.

   For the special case where σ is known and the mean spectrum value is estimated from N available flights, the test level L for probability P with confidence C is given by

$$L_{P/C} = \sigma\,[z_P + z_C/N^{1/2}]\ \text{dB} \tag{B.1}$$

   The factor z_P multiplied by σ determines the normal probability limit, and the factor $z_C/N^{1/2}$ multiplied by σ determines the confidence limit for the estimate of the mean spectrum. The factors z_P and z_C are read from a table of the standardized normal density function found in many references, such as Reference B3. On a normal distribution plot, the area P lies to the left of the mean plus z_P times the standard

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deviation σ. Likewise, the area C lies to the left of the mean plus z_C times the standard deviation σ. Note that $z_C = 0$ for 50% confidence since the mean is the 50-percentile estimate. Numerical examples for acceptance, qualification, and protoqualification are included in c, d, and e below.

c. **Acceptance** tests are performed at the P95/50 level, with consideration of the minimum workmanship level, shorthand for the probability P = 0.95 and the confidence C = 0.50. Stated another way, there is a 50-50 chance of one exceedance of the P95/50 spectrum in 20 flights. Reading from the following table that $z_{0.95} = 1.645$ and $z_{0.50} = 0$, acceptance is performed at 4.9 dB above the mean spectrum [from Eq. (B.1), $L_{95/50} = 3(1.645 + 0) = 4.9$ dB]. Note that this value applies no matter how many flights provide data for the estimate of the mean. Also note that minimum spectra from Figures 6.3.5-1, 8.3.6-1, and 6.3.6-1 must be enveloped with the P95/50 spectrum for the final acceptance test levels for random vibration and acoustic tests.

d. **Qualification** is performed at the P99/90 level (P = 0.99 and C = 0.90). Stated another way, there is one chance in ten of exceeding the qualification level once in 100 flights. For the purpose of preflight prediction, a value N = 1 is adopted. Then, since $z_{0.99} = 2.322$ and $z_{0.90} = 1.282$, preflight qualification is performed at 10.8 dB above the mean spectrum [from Eq. (B.1), $L_{99/90} = 3(2.322 + 1.282) = 10.8$ dB]. The preflight qualification spectrum is therefore baselined to be 6 dB above the acceptance spectrum (a rounding of 10.8 – 4.9 = 5.9). The 6-dB qualification margin is the same as in versions A and B of this MIL-STD-1540, where it was based on experience and not on a statistical model.

After N flights are available, updates of the estimates can be made as follows:

1. A revised estimate of the mean spectrum is calculated.

2. The revised estimate of the $L_{95/50}$ is then 4.9 dB above the revised mean. The result is compared to the previously established acceptance spectrum.

3. The revised estimate of the qualification test margin M, the dB difference between the qualification and acceptance levels (from paragraphs c and d above), is

$$M = L_{99/90} - L_{95/50} = 3(2.322 + 1.282 / N^{1/2}) - 3(1.645 + 0)$$
$$= 3(0.677 + 1.282 / N^{1/2}) \text{ dB} \qquad \text{(B.2)}$$

As the number N of flight data samples grows, the margin decreases since the confidence in its estimate increases. The following table summarizes the estimated margin to the number of flights using the relationship of Eq. (B.2):

Table B.1.1-1. Qualification Margin vs. Number of Flights

Number of flights, N	1	2	3	4	5	6	8	12
Margin, M (dB)	5.9	4.8	4.3	4.0	3.8	3.6	3.4	3.2

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The difference is not allowed to fall below 3 dB. When data from a sufficient number of flights, or from ground tests that produce environments that are realistic for flight (for example, engine firings), the tolerance interval of the applicable statistical distribution can be determined using the available data. However, when reducing the qualification margin on the basis of improved confidence in the environment, one must not put at risk the peak stress capability and fatigue life demonstration that comes from the qualification test nor should the margin drop below the maximum allowable tolerance for vibration testing, currently ± 3.0 dB, as indicated in Table 4.7-1.

e. **Protoqualification** is performed at 3 dB above the 95/50 acceptance level, an established practice set to be half the 6 dB increase for baseline qualification. Assuming that the assumed statistical distribution is valid, the protoqualification spectrum is 7.9 dB above the mean (3 dB over the 4.9 dB for acceptance). Since 7.9 dB is 2.63 sigma above the mean (7.9/3), with 50% confidence the probability of exceeding the protoqualification level in flight at any particular frequency is 0.0043 (about 1 in 230); this result is read as the probability of exceeding 2.63 sigma above the mean in a normal density table (Reference B3). For a 90% confidence, the probability of exceeding the protoqualification level for a single flight is 0.088 or exceedance will occur once in 11 flights; this result is obtained from Eq. (B.1), $7.9 = 3[z_P + 1.282/1]$ yielding $z_P = 1.351$ and resulting in a probability of exceedance of 0.088 read from a normal density table.

B.1.2 Acceleration of Acceptance Life for Acoustic and Random Vibration Tests

Spacecraft and many launch vehicle components are exposed to acoustics and random vibration during the liftoff and ascent segments of flight for a nominal period of 15 seconds. Some components may be exposed to these environments in excess of 15 seconds, such as those located on or near engines.

Baseline acoustic and random vibration qualification and protoqualification tests include one minute duration for the liftoff and ascent flight environment with a margin added to the acceptance spectrum. A longer than the baseline 15-second duration of the maximum predicted environment (see 3.12) leads to an increased test time for flight of four times that of the MPE, where four is the duration factor for fatigue life demonstration by test. To ensure that flight capability is maintained after the acceptance program on production hardware, the test duration is increased beyond the time required for flight to serve as a life test for a maximum duration acceptance testing. The assumptions are that fatigue is the life-limiting mechanism, that Miner's Rule for fatigue accumulation applies, and that induced stress is proportional to the applied acceleration. Miner's Rule (Reference B6) states that the summation of the product of the number of cycles times their stress amplitude raised to an exponent "b" is proportional to the fraction of life exhausted. Therefore, if T_A denotes the upper limit on the duration of acceptance testing, $4T_A$ becomes the duration of the life test for acceptance required if performed with the acceptance spectrum.

Since the qualification and protoqualification testing are performed at higher than the acceptance level beyond the duration required for flight, the added testing becomes an accelerated acceptance life test. The time acceleration factor is given by the amplitude factor on the acceptance excitation raised to the fatigue exponent "b." The amplitude factor equals $10^{M/20}$, where M is the margin in dB. So the

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time acceleration factor is $10^{Mb/20}$. Let t_A be the duration of an acceptance test (baseline 1 minute), T_A be the limit on the duration of acceptance testing, and 4 be the life factor, then

$$T_A / t_A = (1/4)10^{Mb/20} \tag{B.3}$$

For conservatism, the exponent on stress is taken to be 4, a conservative value for this purpose. For example, Reference B3 recommends b = 4 for solder.

$$T_A / t_A = (1/4)10^{M/5} \tag{B.4}$$

A table of the acceptance duration limit versus the test margin M follows:

Table B.1.2-1. Allowable Acceptance Test Duration for Various Test Margins

Test margin, M (dB)	3	4	4.5	5	6
Acceptance limit, T_A / t_A	1.0	1.6	2.0	2.5	4.0

As seen above, one minute of 6 dB margin testing demonstrates life for four acceptance tests of one minute each. Since baseline qualification uses a 6 dB margin and a three-minute test (two minutes beyond the one min for flight), adequate remaining life for flight life is demonstrated for up to eight 1one-minute acceptance tests. Note that each minute with a 3 dB margin demonstrates life for a single acceptance test. So, for protoqualification (3 dB margin for two minutes, one of which is for flight), a limit of only one acceptance test is demonstrated. Therefore, under nominal assumptions, there is no demonstrated life remaining to accommodate any retesting.

B.1.3 Margin and Retest Implications of Acoustic and Random Vibration Qualification and Protoqualification Tests

In general, the test margin for qualification or protoqualification is M dB over acceptance, and the upper bound on acceptance testing (per axis for vibration) is T_A. Based on B.1.2, the general requirement for the duration of a qualification or protoqualification test is given by

$$T_Q = 4(T_{MPE} + T_A/10^{Mb/20}) \tag{B.5a}$$

This equation includes the implicit assumption that maximum vibration levels in flight could be as high as the qualification (or protoqualification) environment and, as a result, the flight duration, T_{MPE}, is not accelerated. This is a conservative approach justified by the uncertainty in the true flight environment for future flights.

The nominal qualification strategy employs a three minute per axis test at 6 dB above the acceptance level. The first goal of the qualification test is to demonstrate that the design is robust to the qualification environment. Under the assumption that hardware is designed to survive the full qualification test level, the qualification test hardware is generally not usable without substantial inspection and rework. The subsequent item is typically the first flight hardware. For this item, the life margin of 4 (Eq. B.3) implies that for a nominal 15 second exposure, one minute of the qualification test demonstrates margin for flight, at the qualification or P99/90 level. Table B.1.2-1 shows that the

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remaining two minutes equate to the fatigue experienced in eight one-minute acceptance tests: one for the expected acceptance test and seven more for retest after rework or repair.

In contrast, the nominal protoqualification strategy employs a two-minute-per-axis test at 3 dB above the acceptance level. Referring again to Table B.1.2-1, this test demonstrates fatigue life for two one-minute acceptance tests. The protoqualification unit is flown at risk, relying on analytical margin rooted in confidence in the design and manufacturing processes. The second flight unit then has demonstrated fatigue life for one acceptance test and one flight exposure at the P95/50 level. Life has not been demonstrated for any repeat of any original acceptance test.

An alternative test approach that meets the acceptance life demonstration with less conservatism is described in B.1.4.

In those cases where the hardware is exposed to vibration at or near acceptance levels for long durations, such as engine components, Eq. (B.5a) is modified to accelerate both flight and total acceptance test durations

$$T_Q = 4(T_{MPE} + T_A)/10^{Mb/20} \tag{B.5b}$$

to preclude excessive fatigue accumulation in test. For this approach, the qualification of the affected hardware to demonstrate capability to withstand qualification levels of vibration is performed as a separate test. The duration of that test is determined on a case-by-case basis depending on the application and mission requirements.

B.1.4 Two-Phase Qualification and Protoqualification Test for Vibration and Acoustics

The discussion in the previous section can be used as the basis for a modified test strategy where the demonstration of margin to test level and duration for acceptance testing is separated into different phases of the test. The testing consists of a Phase I for acceptance life performed with the acceptance spectrum and a Phase II for flight with the qualification or protoqualification spectrum. The two-phase test approach can be employed to

a. Reduce the conservatism in the testing for acceptance life that is built into the baseline qualification and protoqualification requirements.

b. In those cases where the hardware is exposed for long durations at or near acceptance levels of vibration.

c. Testing of hardware that is vibration or shock isolated in flight, but acceptance tested without isolators.

In baseline testing, the acceptance life test is accelerated since it is performed at levels higher than acceptance. As indicated earlier, the acceleration of the life test is based on a nominal exponent of 4

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for fatigue, as well as the assumptions of linearity and that all amplitudes contribute to fatigue life (that is, not allowing for amplitudes below an endurance limit). For example, by performing the acceptance life testing at 6 dB higher than acceptance (a factor of 2 in amplitude), a time acceleration factor of 2^4 or 16 is used. If the fatigue exponent were 6, the time acceleration factor would be 2^6 or 64.

For qualification, Figure B.1.1 depicts the baseline approach, consisting of testing at 6 dB above acceptance for three minutes.

A corresponding two-phase test is conducted for 32 minutes at the acceptance level, Phase I, followed by a one-minute test at 6 dB above the acceptance level, Phase II. Figures B.1.2a and B.1.2b provide the graphical representation. Phase I of the testing is an acceptance life test consisting of a normal acceptance test extended in duration to 4 times the set limit on the duration of flight acceptance testing (T_{FLT}). For example, a 32-minute Phase (per axis for vibration) covers a baseline maximum of eight minutes of acceptance testing. Phase II is a baseline qualification test for a duration of 4 times the effective flight duration but not less than 1 min (4.3.2.2) at 6 dB above acceptance

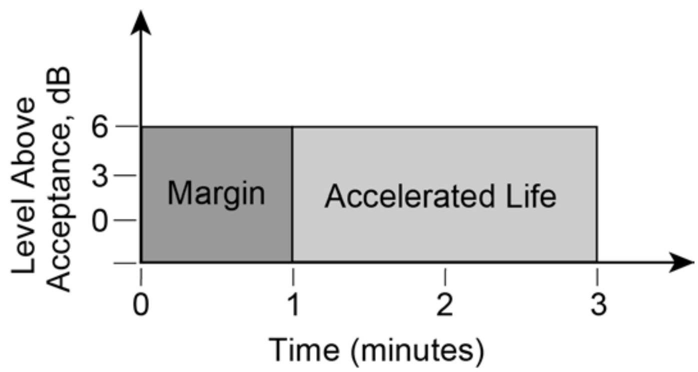

Figure B.1.1. Qualification test (+6 dB, 3 minutes).

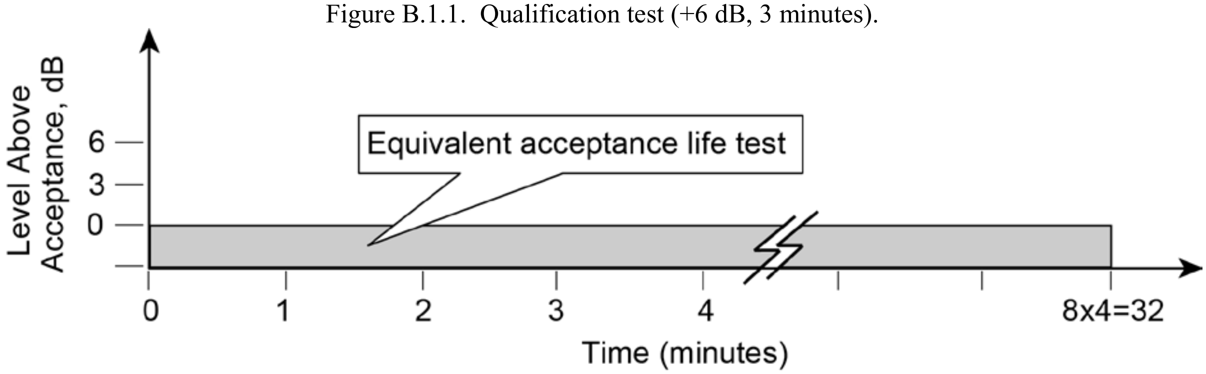

Figure B.1.2a. Phase I qualification test for equivalent acceptance life (0 dB, 32 minutes).

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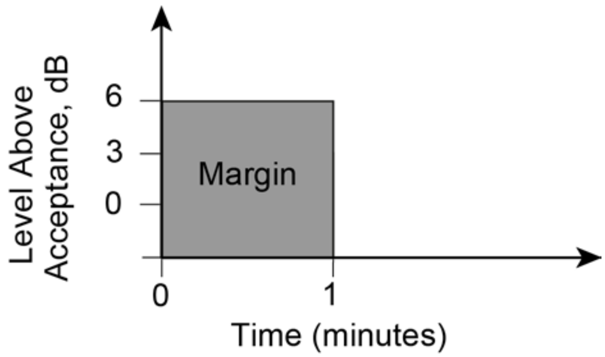

Figure B.1.2b. Phase II test for qualification margin (+6 dB, 1 minute).

For protoqualification, Phase I is an acceptance life test consisting of a normal acceptance test extended in duration to four times the set limit on the duration of flight acceptance testing, the same requirement as for qualification. Phase II is a baseline protoqualification test for a duration of four times the effective duration of the flight acceptance testing (T_{FLT}), but not less than one minute (4.3.3.2). So the only change from qualification is the margin used to qualify the hardware, which now is 3 dB. This test approach is shown graphically in Figures B.1.3, B.1.4a, and B.1.4b.

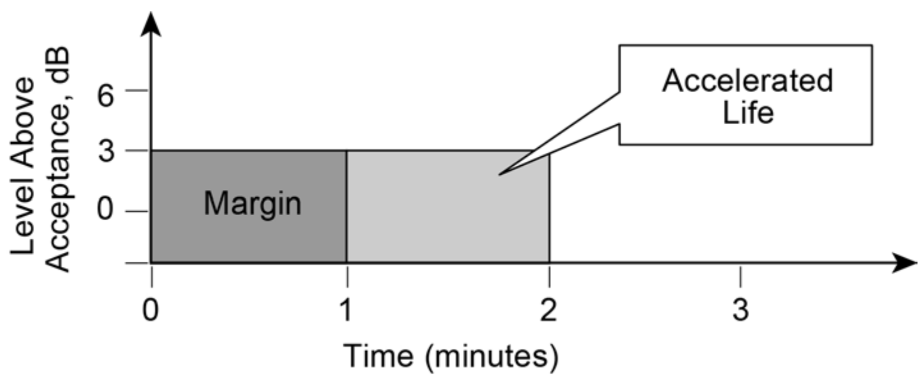

Figure B.1.3. Protoqualification test (+3 dB, 2 minutes).

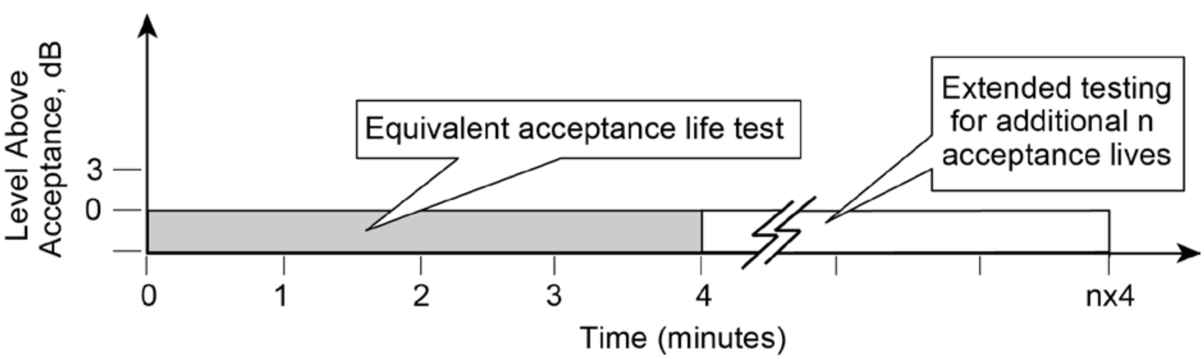

Figure B.1.4a. Phase I protoqualification test for equivalent acceptance life (0 dB, 4 minutes) and possible extension for *n* lives.

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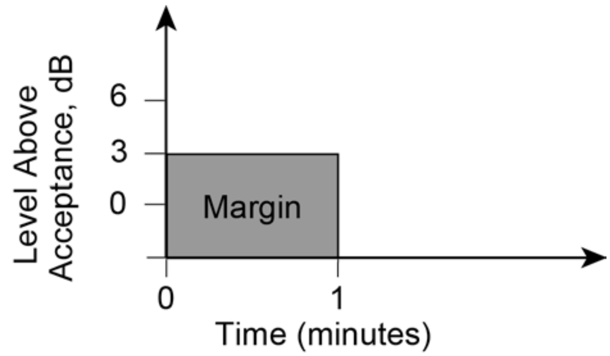

Figure B.1.4b. Phase II test for protoqualification margin (+3 dB, 1 minute).

The accelerated acceptance life segment of the protoqualification test is one minute at 3 dB. The equivalent Phase I duration is four minutes. This part of the test can be extended to demonstrate additional retest capability. Each additional four minutes of testing demonstrates a one minute retest capability. This added flexibility in Phase I testing allows the tailoring of the two phase test to suit program requirements without exposing the hardware to the higher levels of testing at 3 dB above acceptance. Phase II testing is a one-minute test at 3 dB above acceptance level, demonstrating protoqual level capability of the hardware.

When performing two phase testing, the sequence of Phase I and II tests can be tailored to address a program-unique issue. In general, the test phase least likely to damage the hardware should be performed first. Acceptance level testing should be performed first if hardware is more sensitive to peak stress. Qualification, or protoqualification, testing should be performed first if the hardware is sensitive to fatigue damage.

B.1.5 Damage-Based Analysis of Flight Vibroacoustic Data

Traditional maximax spectral analysis of flight vibroacoustic data for space and launch vehicles (3.15 and 3.20) can lead to excessively conservative testing. An alternate data analysis method (Reference B5), based on a simple damage model, employs an extended response spectrum analysis that includes amplitude-cycle counts to deal with fatigue potential. The output is a conservative stationary test specification, but less so than using the maximax basis. The damage-based test specification envelops the damage potential of the non-stationary flight environment for both peak response and fatigue, while recognizing uncertainties in damping and in the fatigue law.

The advanced method enables a more perceptive means for assessing the flightworthiness of units when maximax analysis of new flight data indicates excessive levels. Re-qualification or vibration isolation may then be required. Some experience with the advanced data analysis technique indicates a potential to clear the concern.

B.1.6 Threshold Response Spectrum for Shock Significance

The damage potential of a shock test may be shown to be less than the damage potential from the random vibration acceptance testing over its frequency range, typically 20 to 2000 Hz. For the shock response spectrum values, a modal response velocity criterion can be used to signify a lack of shock

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severity, as long as the unit does not contain any components that are sensitive to shock, such as crystals and ceramic chips (6.3.4.4).

The response spectrum S_{vib} of the random vibration acceptance excitation is given in Reference B4 as,

$$S_{vib} = n[(\pi/2)G_{vib}fQ]^{1/2} \tag{B.6}$$

n = factor on the response standard deviation to yield maximum response

G_{vib} = spectral density of random vibration (g^2/Hz)

f = frequency (Hz)

Q = quality factor

An expression for n with 50% confidence is given in Reference B4 as

$$n = [2\, ln(fT)]^{1/2} \tag{B.7}$$

where *ln* is the natural logarithm and T is the duration of the random test. For a 60-second random vibration test, n is 3.8 at 20 Hz increasing to 4.8 at 2000 Hz. Substituting Eq. (B.7) into Eq. (B.6),

$$S_{vib} = [\pi GfQ\, ln(fT)]^{1/2} = 5.6[Gf\, ln(fT)]^{1/2} \quad \text{for } Q = 10 \tag{B.8}$$

If S_{vib} exceeds the response spectrum for the shock S_{shock} at all frequencies, the random vibration test is judged to have a damage potential greater than that of the shock over the frequency range of the vibration. A response velocity to shock less than 50 in/sec is judged to be non-damaging (Reference B7). This is the case if the shock response spectrum value in g is less than 0.8 times the frequency in Hz.

See 6.3.4 for qualification test exception requirements.

B.2 Response Limiting Criteria for Units Weighing More Than 50 lb (23 kg)

Force or response limiting refers to the practice of notching (reduction of level in frequency bands) of the input acceleration spectrum to a test item to reduce either the applied force spectrum or to reduce the magnitude of the spectrum of test item response at critical locations. In both cases, the reduction is in frequency bands that contain major resonant behavior of the test item or of the test fixture. A justifiable basis for such limiting is necessary in order to avoid excessive reduction of inputs that will result in inadequate acceptance or qualification.

The rationale is that the input motion is reduced because the relatively high mechanical impedance of the test item inhibits the motion of the supporting structure that would occur in the flight configuration and because the test specifications are based on enveloping response data.

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B.2.1 Broadband Reduction

For units exceeding 23 kg (50 lb), the random vibration specification may be reduced using the following relation:

$$\text{Reduced spectrum level } (g^2/\text{Hz}) = 0.04\left(\frac{50}{W}\right) \tag{B.9}$$

where W is the unit weight in pounds. The reduction cannot be more than 6 dB. Figure B.2.2-1 shows the minimum spectra for units weighing 50, 100, and 200 lb, respectively. For each of these weights, the flat portion of the spectrum was extended into the low-frequency regime without reducing the spectrum roll-off level in order to assure adequate excitation of the lower frequency modes resulting from the increased weight.

B.2.2 Narrowband Notching

The input vibration spectrum may be adjusted on a case-by-case basis to limit unit response accelerations. The adjustment takes the form of notching of the input over a narrow frequency band. The notch depth is limited to 10 dB of below the input PSD, with floor not less than 0.01 g^2/Hz. Figure B.2.2-2 shows an example of notching.

In addition, the notch bandwidth shall not exceed ±5% of the notch center band frequency.

As an example, for 200 Hz center band notch frequency, f_c, the notch band is ±10 Hz, i.e., 190 Hz minimum and 210 Hz maximum.

B.3 Anomaly Severity Definitions

Dhallin and Graham define the severity of Category 1, 2, and 3 ground and flight anomalies in Reference B8. In summary:

Category 1: Loss of mission or permanent inability to perform baseline mission

Category 2: Permanent loss of redundancy or loss of reliability; temporary inability of the spacecraft or an operational payload to meet its baseline mission requirements

Category 3: Anomalies that are identified as a nuisance or of negligible impact. This includes anomalies with non-operational payloads: recorded flight observations that have no vehicle impact.

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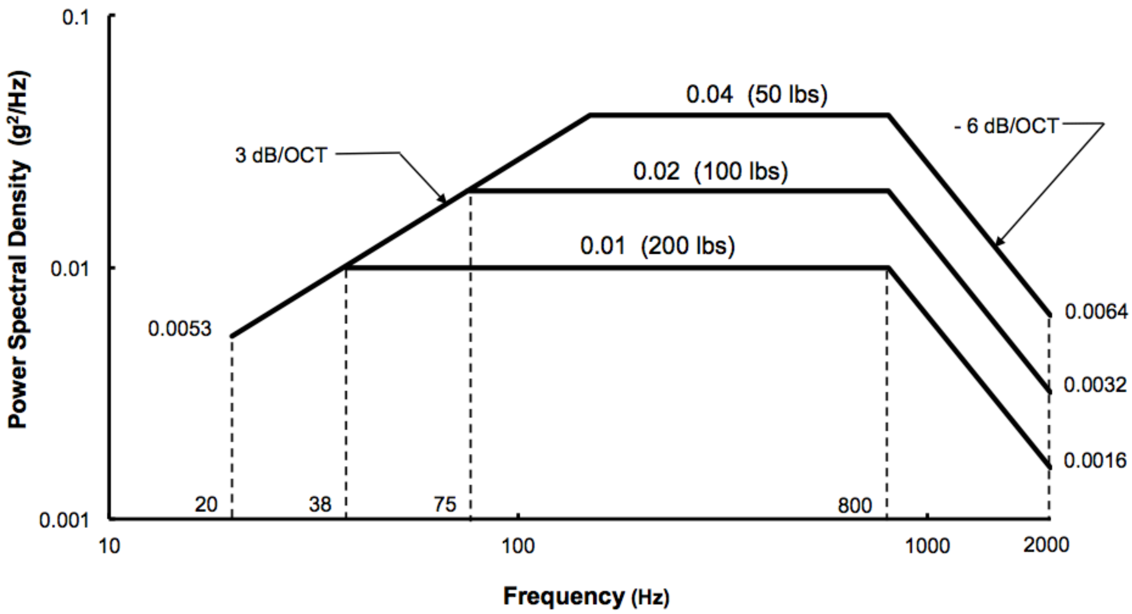
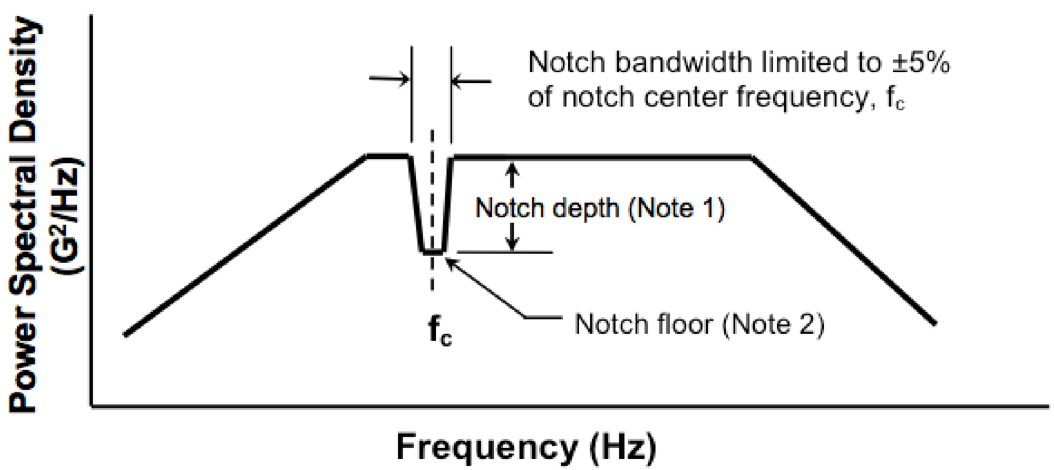


Weight (lb)	Overall Acceleration (Grms)
50	6.90
100	4.87
200	3.52

Figure B.2.2-1. Weight-adjusted minimum random vibration spectrum, unit acceptance test.



Notes: 1. Notch depth limited to –10 dB
2. Notch floor not less than 0.01 g^2/Hz

Figure B.2.2-2. PSD notch.

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SMC Standard Improvement Proposal

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SMC STANDARD CHANGE RECOMMENDATION:	**1. Document Number** SMC-S-016	**2. Document Date** 5 September 2014

3. Document Title	TEST REQUIREMENTS FOR LAUNCH, UPPER-STAGE AND SPACE VEHICLES

4. Nature of Change
(Identify paragraph number; include proposed revision language and supporting data. Attach extra sheets as needed.)

5. Reason for Recommendation

6. Submitter Information

a. Name	**b. Organization**
c. Address	**d. Telephone**
e. E-mail address	**7. Date Submitted**

8. Preparing Activity	Space and Missile Systems Center AIR FORCE SPACE COMMAND 483 N. Aviation Blvd. El Segundo, CA 91245 Attention: SMC/EN