LANDSAT DATA CONTINUITY MISSION

LDCM Environmental Verification Requirements

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Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

CM Foreword

This document is a Landsat Data Continuity Mission (LDCM) Project Configuration Management (CM)-controlled document. Changes to this document require prior approval of the applicable Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted to the LDCM CM Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

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1 GENERAL INFORMATION

1.1 PURPOSE

This document provides requirements and guidelines for the environmental verification program for the Landsat Data Continuity Mission (LDCM) observatory, instrument(s), spacecraft bus, subsystems and components and describes methods for implementing those requirements. It contains a baseline for demonstrating by test or analysis the satisfactory performance of hardware in the expected mission environments, and that minimum workmanship standards have been met. It elaborates on those requirements, gives guideline test levels, provides guidance in the choice of test options, and describes acceptable test and analytical methods for implementing the requirements.

For procurement purposes, the instrument is treated as a subsystem, and the spacecraft bus is treated as a module. There will be environmental verification plans to address requirements specified within this document at the instrument and observatory levels.

This document, the LEVR, was created from the General Environmental Verification Specification (GEVS, GSFC-STD-7000), and tailored to create the LDCM project specific environmental verification requirements. For the LDCM project, the GEVS does not apply.

1.2 APPLICABILITY AND LIMITATIONS

These requirements apply to LDCM hardware and associated software that is to be launched on an Atlas V model 401 rocket.

These requirements apply to all space flight hardware, including interface hardware, that is developed as part of the LDCM project.

These Requirements are written in accordance with the current GSFC practice of using a single protoflight observatory to qualify for space flight (see definition of hardware, 1.8). The protoflight verification program, therefore, is given as the nominal test program.

1.3 THE LDCM VERIFICATION APPROACH

The entire LDCM observatory instrument, subsystems, and components will be verified under conditions that simulate the launch operations, flight operations and flight environment as realistically as possible.

LEVR-2183 Units powered on for launch, shall be powered on and their performance monitored during test. However, it is recognized that there may be unavoidable exceptions, or conditions which make it preferable to perform the verification activities at lower levels of assembly. For example, testing at lower levels of assembly may be necessary to produce sufficient environmentally induced stresses to uncover design and workmanship flaws.

Environmental verification of hardware is only a portion of the total assurance effort for LDCM that establishes confidence that the observatory will function correctly and fly a successful mission. The environmental test program provides confidence that the design will perform when subjected to environments more severe than expected during the mission, and provides environmental stress screening to uncover workmanship defects.

The total verification process also includes the development of models representing the hardware, tests to verify the adequacy of the models, analyses, alignments, calibrations, functional/performance tests to verify proper operation, and finally end-to-end tests and simulations to show that the total system will perform as specified.

The level, procedure, and decision criteria for performing any additional tests will beincluded in the LDCM system verification plan.

1.4 OTHER ASSURANCE REQUIREMENTS

In addition to the verification program, the assurance effort includes parts and materials selection and control, reliability assessment, quality assurance, software assurance, design reviews, and system safety per the LDCM Mission Assurance Requirements (MAR).

1.5 RESPONSIBILITY FOR ADMINISTRATION

The responsibility and authority for decisions in waving the requirements rest with the GSFC LDCM Project Manager.

The requirements thus derived and deviations from the requirements of this document are subject to review and approval by the GSFC LDCM Project Office.

1.6 LEVR CONFIGURATION CONTROL AND DISTRIBUTION

This document is controlled and maintained by the GSFC LDCM Project Office.

2 Documents

2.1 APPLICABLE DOCUMENTS

The following documents are needed in formulating the environmental test program.

LEVR-2184 The Contractor shall use the current version in effect at the time of procurement, except as identified in specific requirement(s).

2.1.1 Atlas V Payload User Manual

The most recent version of the launch vehicle user manual and requirements are applicable in accordance with the launch vehicle and can be acquired from the service provider.

2.1.2 Spacecraft Tracking and Data Network Simulation

STDN No. 101.6, Portable Simulation System and Simulations Operation Center Guide for TDRSS & GSTDN, describes the Spacecraft Tracking and Data Network (STDN) and the Tracking and Data Relay Satellite (TDRS)/Ground STDN network simulation programs, and the Simulations Operations Center (SOC). It also discusses end-to-end simulation techniques. STDN No. 408, TDRS and GSTDN Compatibility Test Van Functional Description and Capabilities, describes the equipment and the compatibility test system.

2.1.3 NASA Standards

The following standards provide supporting information:

a. NASA-STD 7002, Payload Test Requirements

b. NASA-STD-7001, Payload Vibroacoustic Test Criteria

c. NASA-STD-7003, Pyroshock Test Criteria

d. NASA-HDBK-7004, Force Limited Vibration Testing

e. NASA-HDBK-7005, Dynamic Environmental Criteria

f. NASA-STD-5001, Structural Design and Test Factors of Safety for Space Flight Hardware

g. NASA-STD-5002, Load Analyses of Spacecraft and Observatories

2.1.4 Standards for EMC Testing

Pertinent sections of the following standards are needed to conduct the EMC tests:

a. MIL-STD-461C, Electromagnetic Interference Characteristics Requirements for Equipment.

b. MIL-STD-462, Electromagnetic Interference Characteristics, Measurement of, as amended by Notice l.

c. IEEEC63.14, Definitions and Systems of Units, Electromagnetic Interference Technology.

2.1.5 Standards for Non-Destructive Evaluation

a. MIL-HDBK-6870, Inspection Program Requirements, Non-Destructive Testing for Aircraft and Missile Materials and Parts.

b. NAS-410, Certification and Qualification of Nondestructive Test Personnel.

c. MSFC-STD-1249, Standard NDE Guidelines and Requirements for Fracture Control Programs.

d. MIL-HDBK-728, Nondestructive Testing.

2.2 DEFINITIONS

The following definitions apply within the context of this specification:

Acceptance Tests:

The verification process that demonstrates that hardware is acceptable for flight. It also serves as a quality control screen to detect deficiencies and, normally, to provide the basis for delivery of an item under terms of a contract.

Configuration:

The functional and physical characteristics of the observatory and instrument, and all its integral parts, components, assemblies and systems that are capable of fulfilling the fit, form and functional requirements defined by performance specifications and engineering drawings.

Contamination:

The presence of materials of molecular or particulate nature which degrade the performance of hardware.

Design Qualification Tests:

Tests intended to demonstrate that the test item will function within performance specifications under simulated conditions more severe than those expected from ground handling, launch, and orbital operations. Their purpose is to uncover deficiencies in design and method of manufacture. They are not intended to exceed design safety margins or to introduce unrealistic modes of failure. The design qualification tests will be to "prototype" or "protoflight" test levels.

Design Specification:

Generic designation for a specification that describes functional and physical requirements for an article, usually at the component level or higher levels of assembly. In its initial form, the design specification is a statement of functional requirements with only general coverage of physical and test requirements. The design specification evolves through the project life cycle to reflect progressive refinements in performance, design, configuration, and test requirements. In many projects the end-item specifications serve all the purposes of design specifications for the contract end-items. Design specifications provide the basis for technical and engineering management control.

Electromagnetic Compatibility (EMC):

The condition that prevails when various electronic devices are performing their functions according to design in a common electromagnetic environment.

Electromagnetic Interference (EMI):

Electromagnetic energy which interrupts, obstructs, or otherwise degrades or limits the effective performance of electrical equipment.

Electromagnetic Susceptibility:

Undesired response by a component, subsystem, or system to conducted or radiated electromagnetic emissions.

End-to-End Tests:

Tests performed on the integrated ground and flight system, including all elements of the observatory, its control, stimulation, communications, and data processing to demonstrate that the entire system is operating in a manner to fulfill all mission requirements and objectives.

Failure:

A departure from specification that is discovered in the functioning or operation of the hardware or software. See nonconformance.

Fracture Control Program:

A systematic project activity to ensure that a observatory intended for flight has sufficient structural integrity as to present no critical or catastrophic hazard. Also to ensure quality of performance in the structural area for any observatory (spacecraft) project.

Fracture Control Analysis:

Central to the program is fracture control analysis, which includes the concepts of fail-safe and safe-life, defined as follows:

a. Fail-safe: Ensures that a structural element, because of structural redundancy, will not cause collapse of the remaining structure or have any detrimental effects on mission performance.

b. Safe-life: Ensures that the largest flaw that could remain undetected after non-destructive examination would not grow to failure during the mission.

Functional Tests:

The operation of a unit in accordance with a defined operational procedure to determine whether performance is within the specified requirements.

Hardware:

As used in this document, there are two major categories of hardware as follows:

a. **Prototype Hardware**: Hardware of a new design; it is subject to a design qualification test program. Where the prototype hardware is tested at qualification test levels and qualification test durations;it is not intended for flight.

b. **Flight Hardware**: Hardware to be used operationally in space. It includes the following subsets:

(1) **Protoflight Hardware**: Flight hardware of a new design; it is subject to a qualification test program that combines elements of prototype and flight acceptance verification; that is, the application of design qualification test levels and flight acceptance test durations.

(2) **Follow-On Hardware**: Flight hardware built in accordance with a design that has been qualified as prototype hardware; follow-on hardware is subject to a flight acceptance test program.

(3) **Spare Hardware**: Hardware the design of which has been proven in a design qualification test program; it is subject to a flight acceptance test program and is used to replace flight hardware that is no longer acceptable for flight.

Level of Assembly:

The environmental test requirements of LEVR generally start at the component or unit level assembly and continue hardware/software build through the system level (referred to in LEVR as the observatory or spacecraft level). The assurance program includes the part level. Verification testing may also include testing at the assembly and subassembly levels of assembly; for test record keeping these levels are combined into a "subassembly" level. The verification program continues through launch, and on-orbit performance. The following levels of assembly are used for describing test and analysis configurations:

Assembly:

A functional subdivision of a component consisting of parts or subassemblies that perform functions necessary for the operation of the component as a whole. Examples are a power amplifier and gyroscope.

Bus:

An integrated assemblage of modules, subsystems, etc., designed to accommodate the instrument(s) to perform the specified mission in space; i.e. the observatory with no instruments. Another term used to designate this level of assembly is Spacecraft Bus.

Component:

A functional subdivision of a subsystem and generally a self-contained combination of items performing a function necessary for the subsystem's operation. Examples are electronic box, transmitter, gyro package, actuator, motor, battery. For the purposes of this document, "component" and "unit" are used interchangeably.

Instrument:

An observatory subsystem consisting of sensors and associated hardware for making measurements or observations in space. For the purposes of this document, an instrument is considered a subsystem (of the observatory).

Module:

A major subdivision of the observatory that is viewed as a physical and functional entity for the purposes of analysis, manufacturing, testing, and recordkeeping. Examples include spacecraft bus, science instrument, and upper stage vehicle.

Observatory:

An integrated assemblage of modules, subsystems, etc., designed to perform a specified mission in space. For the purposes of this document, "payload" and "observatory" are used interchangeably. Other terms used to designate this level of assembly are Laboratory, Satellite and System Segment.

Part:

A hardware element that is not normally subject to further subdivision or disassembly without destruction of design use. Examples include resistor, integrated circuit, relay, connector, bolt, and gaskets.

Spacecraft:

See Observatory. Other terms used to designate this level of assembly are Laboratory and satellite.

Section:

A structurally integrated set of components and integrating hardware that form a subdivision of a subsystem, module, etc. A section forms a testable level of assembly, such as components/units mounted into a structural mounting tray or panel-like assembly, or components that are stacked.

Subassembly:

A subdivision of an assembly. Examples are wire harness and loaded printed circuit boards.

Subsystem:

A functional subdivision of an observatory consisting of two or more components. Examples are structural, attitude control, electrical power, and communication subsystems. Also included as subsystems of the observatory are the science instruments.

Unit:

A functional subdivision of a subsystem, or instrument, and generally a self-contained combination of items performing a function necessary for the subsystem's operation. Examples are electronic box, transmitter, gyro package, actuator, motor, battery. For the purposes of this document, "component" and "unit" are used interchangeably.

Limit Level:

The maximum expected flight level (consistent with the minimum probability levels of Table 3-6).

Margin:

The amount by which hardware capability exceeds requirements.

Nonconformance:

A condition of any hardware, software, material, or service in which one or more characteristics do not conform to specified requirements.

Offgassing:

The emanation of volatile matter of any kind from materials into a manned pressurized volume.

Outgassing:

The emanation of volatile materials under vacuum conditions resulting in a mass loss and/or material condensation on nearby surfaces.

Performance Verification:

Determination by test, analysis, or a combination of the two that the observatory element can operate as intended in a particular mission; this includes being satisfied that the design of the observatory or element has been qualified and that the particular item has been accepted as true to the design and ready for flight operations.

Redundancy (of design):

The use of more than one independent means of accomplishing a given function.

Temperature Cycle:

A transition from some initial temperature condition to temperature stabilization at one extreme and then to temperature stabilization at the opposite extreme and returning to the initial temperature condition.

Temperature Stabilization:

The condition that exists when the rate of change of temperatures has decreased to the point where the test item may be expected to remain within the specified test tolerance for the necessary duration or where further change is considered acceptable.

Thermal Balance Test:

A test conducted to verify the adequacy of the thermal model, the adequacy of the thermal design, and the capability of the thermal control system to maintain thermal conditions within established mission limits.

Thermal-Vacuum Test:

A test conducted to demonstrate the capability of the test item to operate satisfactorily in vacuum at temperatures based on those expected for the mission. The test, including the gradient shifts induced by cycling between temperature extremes, can also uncover latent defects in design, parts, and workmanship.

Vibroacoustics:

An environment induced by high-intensity acoustic noise associated with various segments of the flight profile; it manifests itself throughout the observatory in the form of directly transmitted acoustic excitation and as structure-borne random vibration.

Workmanship Tests:

Tests performed during the environmental verification program to verify adequate workmanship in the construction of a test item. It is often necessary to impose stresses beyond those predicted for the mission in order to uncover defects. Thus random vibration tests are conducted specifically to detect bad solder joints, loose or missing fasteners, improperly mounted parts, etc. Cycling between temperature extremes during thermal-vacuum testing and the presence of electromagnetic interference during EMC testing can also reveal the lack of proper construction and adequate workmanship.

2.3 CRITERIA FOR UNSATISFACTORY PERFORMANCE

Deterioration or any change in performance of any test item that does or could in any manner prevent the item from meeting its functional, operational, or design requirements throughout its mission is reason to consider the test item as having failed. Other factors concerning failure are considered in the following paragraphs. Further elaboration of project requirements are contained in the LDCM MAR.

2.3.1 Failure Occurrence

When a failure (non-conformance or trend indicating that an out of spec condition will result) occurs, a determination will be made as to the feasibility and value of continuing the test to its specified conclusion.

If corrective action is taken, the test will be repeated to the extent necessary to demonstrate that the test item's performance is satisfactory.

2.3.2 Failures with Retroactive Effects

If corrective action taken as a result of failure, e.g. redesign of a component, affects the validity of previously completed tests, prior tests will be repeated to the extent necessary to demonstrate satisfactory performance as deemed required by the MRB.

2.3.3 Failure Reporting

Every failure will be recorded and reported in accordance with the failure reporting provisions of the GSFC LDCM MAR.

2.3.4 Wear Out

If during a test sequence a test item is operated in excess of design life and wears out or becomes unsuitable for further testing from causes other than deficiencies, a spare may be substituted.

LEVR-2187 If, however, the substitution affects the significance of test results, the test during which the item was replaced and any previously completed tests that are affected shall be repeated to the extent necessary to demonstrate satisfactory performance.

2.4 TEST SAFETY RESPONSIBILITIES

The following paragraphs define the responsibilities shared by the Contractor and facility management for planning and enforcing industrial safety measures taken during testing for the protection of personnel, the observatory, and the test facility.

2.4.1 Operations Hazard Analysis, Responsibilities For

It is the Contractor's responsibility of to ensure that environmental tests and associated operations present no unacceptable hazard to the test item, facilities, or personnel.

LEVR-1922 A test operations hazard analysis (OHA) shall be performed by the Contractor to consider and evaluate all hazards presented by the interaction of the observatory or instrument, and the facility for each environmental test.

LEVR-1923 All hazards discovered in the OHA shall be tracked to an agreed-upon resolution.

LEVR-1924 The safety measures to be taken as a result of the OHA, as well as the safety measures between tests, shall be specified as requirements in the verification plan and verification specification.

2.4.2 Treatment of Hazards

As hazards are discovered, a considered attempt must be made to eliminate them. This may be accomplished by redesign, controlling energy sources, revising the test, or by some other method.

If the hazard cannot be eliminated, automatic safety controls will be applied, for example: pressure relief devices, electrical circuit protection devices, or mechanical interlocks.

If that is not possible or is too costly, warning devices should be considered.

If none of the foregoing methods are practicable, control procedures will be developed and applied. In practice, a combination of all four methods may be the best solution to the hazards posed by a complex system.

Before any test begins, the Contractor and test facility management will agree on the hazard control method(s) that are to be used.

2.4.3 Facility Safety

The test facility manager will verify that the test facility and normal operations present no unacceptable hazard to the test item, test and support equipment, or personnel.

He will ensure that facility personnel abide by all applicable regulations, observe all appropriate industrial safety measures, and follow all requirements for protective equipment.

He will ensure that all facility personnel are trained and qualified for their positions.

Training will include the handling of emergencies by the simulation of emergency conditions.

Analyses, tests, and inspections will be performed to verify that the safety requirements are satisfied.

2.4.4 Safety Responsibilities During Tests

The Contractor will appoint a safety officer to work closely with a safety officer designated by the GSFC LDCM project.

The Contractor safety officer will ensure that the facility meets applicable Occupational Safety & Health Act (OSHA) and other requirements, that appropriate industrial safety measures are observed, and that protective equipment is provided for all personnel involved.

The Contractor safety officer will ensure that the Contractor personnel use the equipment provided and that the test operation does not present a hazard to the facility, space hardware, equipment, or personnel.

2.5 TESTING OF SPARE HARDWARE

A supply of selected spares is often maintained in case of the failure of flight hardware.

As a minimum, spares will undergo a verification program equal to that required for follow-on hardware.

Spares are to be treated as follows:

2.5.1 Extent of Testing

The extent and type of testing will be determined as part of the flight hardware test program. A spare unit may be used for qualification of the hardware by subjecting it to protoflight testing, and testing the flight hardware to acceptance levels.

2.5.2 Spares From Failed Elements

If a flight element is replaced for reasons of failure and is then repaired and redesignated as a spare, appropriate retesting will be conducted.

2.5.3 Caution on the Use of Spares

When the need for a spare arises, immediate analysis and review of the failed hardware will be made. If failure occurs in a hardware item of which there are others of identical design, the fault may be generic and may affect all hardware of that design.

2.5.4 "One-Shot" Items

Some items may be degraded or expended during the integration and test period and replaced by spares.

LEVR-1938 The spare that is used shall have met the required quality control standards or auxiliary tests for such items and shall be of qualified design. Examples are pyrotechnic devices, yo-yo despin weights, and elements that absorb impact energy by plastic yielding.

LEVR-1939 When the replacement entails procedures that could jeopardize mission success, the replacement procedure shall be successfully demonstrated with the hardware in the same configuration that it will be in when final replacement is to be accomplished.

2.6 TEST FACILITIES, CALIBRATION

The facilities and fixtures used in conducting tests will be capable of producing and maintaining the test conditions prescribed with the test specimen installed and operating or not operating, as required.

LEVR-1940 In any major test, facility performance shall be verified prior to the test either by a review of its performance during a test that occurred a short time earlier or by conducting a test with a substitute test item.

All equipment used for tests must be in current calibration and so noted by tags and stickers.

2.7 TEST CONDITION TOLERANCES

LEVR-201 In the absence of a rationale for other test condition tolerances, the following shall be used; the values include measurement uncertainties:

Table 2 - 1 Test Condition Tolerances

Acoustics	Overall Level: 1/3 Octave Band Tolerance:	≤1 db Frequency (Hz) f≤40 40<F<3150 f≥3150	 Tolerance (db) +3, -6 ±3 +3, -6
Antenna Pattern Determination		±2 db	
Electromagnetic Compatibility	Voltage Magnitude: Current Magnitude: RF Amplitudes: Frequency: Distance:	 ± 5% of the peak value ±2 db ±2 % ± 5% of specified distance or ± 5 cm, whichever is greater	
Humidity		± 5% RH	
Loads	Steady-State(Acceleration): Static:	± 5% ± 5%	

Mass Properties	Weight: Center of Gravity: Moments of Inertia:	± 0.2% ±0.15 cm (±0.06 in.) ±1.5%	
Mechanical Shock	Response Spectrum: Time History:	+25%,-10% ±10%	
Pressure Pa	Greater than 1.3 X 104 (Greater than 100mm Hg): 1.3 X l04 to 1.3 X l02 Pa (l00 mm Hg to 1 mm Hg): 1.3 X l02 to 1.3 X 101 Pa (1 mm Hg to 1 micron): Less than 1.3 X 101 Pa (less than 1 micron):	±5% ±10% ±25% ±80%	
Temperature		±2°C	
Vibration	Sinusoidal: Amplitude Frequency Random: RMS level Accel. Spectral Density	 ±10% ±2% ±10% ± 3 dB	

3 VERIFICATION PROGRAM

3.1 SYSTEM PERFORMANCE VERIFICATION

This section applies to the entire LDCM observatory its instrument/subsystems, spacecraft bus and components.

3.1.1 Documentation Requirements

The documentation requirements associated with this LEVR as applies to the LDCM Project are called out in the LDCM Contract Data Requirements List for both the observatory and instrument(s). They are listed below:

System Performance Verification Plan and System Performance Verification Matrix

Provides the overall approach for accomplishing the verification program. Defines the specific tests, analyses, calibrations, alignments, hardware models, etc. that will demonstrate that the flight hardware complies with the mission requirements. The System Performance Verification Matrix will summarize the activities in the plan.

Environmental Verification Plan and the Environmental Test Matrix

The Environmental Verification Plan documents the approach for environmental qualification and acceptance tests. The Environmental Test Matrix summarizes the tests performed. This also satisfies the environmental verification requirements of the launch services provider.

Test Procedures

A test procedure documents each verification test activity containing the appropriate details to perform the test.

Test Reports

Test reports will provide a summary of each integration and test result, conformance, non-conformance, and trend data. A Verification Report for all verification types indicated in the System Performance Verification Plan (Test, Analysis, Inspection, Demonstration) will be generated. Multiple requirements may be verified in a single report.

3.2 ENVIRONMENTAL VERIFICATION

For the purposes of this document, an spacecraft is considered an observatory, an instrument is considered to be a subsystem, a spacecraft bus is considered to be a module when determining the environmental verification requirements. In general, the environmental tests are not performed at the fully integrated flight spacecraft bus level. Functional and performance tests are done at the bus level prior to instrument integration.

The basic provisions are written assuming protoflight hardware. They are, in general, also applicable to prototype hardware. Acceptance requirements are also given for the flight acceptance of previously qualified hardware. This applies to follow-on hardware (multiple copies of the same item) developed for the program, or hardware (from another program) qualified by similarity.

3.2.1 Test Sequence and Level of Assembly

The verification activities herein are grouped by discipline; they are not in a recommended sequence of performance. The recommended order of testing is electrical, mechanical and thermal at the end of the testing sequence.

No specific environmental test sequence is required, but the test program will be arranged in a way to best disclose problems and failures associated with the characteristics of the hardware and the mission objectives.

Table 3-1 provides a hierarchy of levels of assembly for the flight hardware, with examples. These level designators are based on those used in the Space Systems Engineering Database developed by The Aerospace Corporation for the Air Force, and agreed to by NASA Headquarters, GSFC, and JPL. The LEVR environmental test requirements generally start at the "unit" level and end at the "system segment" level. However, screening and life-tests often occur at lower levels, and overall system verification continues beyond the "system segment" level.

This document assumes that the observatory is of modular design and can be tested at the unit/component, subsystem/instrument, and observatory system levels of assembly.

The Contractor will develop a verification program as stated in the SOW that satisfies the intent of the required verification program while taking into consideration the specific characteristics of the mission and the hardware. For example:

An observatory subsystem, or instrument, may be a functional subdivision of the spacecraft, but it may be distributed throughout the spacecraft rather than being a physical entity.

In this case, the environmental tests, and associated functional tests, will be performed as a minimum at the component, instrument and observatory levels. Performance tests and calibrations may still be performed on the functional subsystem or instrument.

The physical size of the system may necessitate testing at other levels of assembly. Facility limitations may not allow certain environmental tests to be performed at the system level.

LEVR-1945 In this case, testing shall be performed at the highest practicable level. Also, for very large systems or subsystems/instruments, tests at additional levels of assembly may be added in order to adequately verify the hardware design, workmanship and/or performance.

LEVR-1946 These decisions shall be made with the approval of the LDCM GSFC project office, especially regarding bypassing lower level testing for instruments, because of the increased risk to the program (schedule, cost, etc.) of finding problems late in the planned schedule.

In some cases, because of the hardware configuration it may be reasonable to test more than one component at a time. The components may be stacked in their flight configuration, and may therefore be tested as a "section".

Part of the decision process will consider the physical size and mass of the hardware.

The test configuration will allow for adequate dynamic or thermal stress inputs to the hardware to uncover design errors and workmanship flaws.

Some test requirements stated as subsystem/instrument requirements may be satisfied at a higher level of assembly if approved by the GSFC project. For example, externally induced mechanical shock test requirements may be satisfied at the system level by firing the environment-producing pyro. A simulation of this environment is difficult, especially for large subsystems or instruments.

Aspects of the design and/or mission may negate certain test conditions to be imposed.

The same process will be applied when developing the test plan for an instrument. While testing is required at the instrument component and all-up instrument levels of assembly, additional test levels may be called for because of hardware complexity or physical size.

Table 3 - 1 Flight System Hardware Levels of Assembly

LEVEL OF ASSEMBLY	EXAMPLES
Space System	NASA Spacecraft
Project or Program	TDRS TIROS GOES
Operating System	Operating Space System
Integrated Systems	Integrated Flight System (Spacecraft + Upperstage + Launch Vehicle)
System Segment (Satellite, Payload, Spacecraft, Laboratory, Observatory, Space Vehicle, etc.)	(Spacecraft Bus + Science Payload) Launch Vehicle IUS
Module	Spacecraft Bus Science Payload Payload Fairing
Subsystem	Instrument/Experiment, Structure, Attitude Control, C & DH, Thermal Control, Electrical Power, TT & C, Propulsion
Section (group of units/components not a subsystem)	Electronic Tray or Palette, Stacked Units/Components, Electronic Boxes Mounted on Panel, Solar Array Sections
Unit (Component)	Electronic Box, Gyro Package, Motor, Actuator, Battery, Receiver, Transmitter, Antenna, Solar Panel, Valve Regulator
Subassembly (combines assembly and subassembly)	Assembly (Power Amplifier, Gyroscope) Subassembly (Wire Harness, Loaded Printed Circuit Card)
Part	Resistor, Capacitor, IC, Switch, Connector, Bolt, Screw, Gasket, Bracket, Valve Stem

3.2.2 Qualification of Hardware by Similarity

There are cases in which hardware qualified for one flight program is to be built and used on another program. Hardware that has been previously qualified may be considered qualified for use on a new program by showing that the hardware is sufficiently similar to the original hardware and that the previous qualification program has adequately enveloped the new mission environments.

The details for performing this comparison will be defined by the Contractor with the approval of the Project Office.

As a minimum the following areas will be reviewed and documented:

LEVR-266 (1) Design and test requirements shall be shown to envelope the original requirements.

LEVR-1951 This shall include a review of the test configuration and of all waivers and deviations that may have occurred during testing of the original hardware.

LEVR-267 (2) Manufacturing information shall be reviewed to determine if changes have been made that would invalidate the previous hardware qualification.

LEVR-1952 This review shall cover parts, materials, packaging techniques as well as changes to the assembly process or procedures.

LEVR-268 (3) Test experience with the previous flight build shall be reviewed to verify that no significant modifications were made to the hardware during testing to successfully complete the test program.

LEVR-1953 Any significant change shall be identified and shown to be implemented on the current flight hardware.

If the review of the above criteria by the GSFC LDCM project shows that the hardware is of sufficiently similar design as the first build and that the previous test requirements envelope any new environmental requirements, then the hardware can be, with GSFC LDCM project office approval, treated as qualified and need only to be subjected to the same acceptance level test requirements as the original flight hardware.

The Contractor will include the review documents as part of the verification package.

3.2.3 Test Factors/Durations

LEVR-271 Test factors for prototype, protoflight, and acceptance shall be applied as given in Table 3-2.

3.2.4 Structural Analysis/Design Factors of Safety

LEVR-273 Structural and mechanical verification testing shall be supported by structural analysis to provide confidence that the hardware will not experience failure or detrimental permanent deformation under test or launch conditions.

LEVR-1680 The factors of safety that shall be applied to limit loads in order to calculate structural margins are shown in Table 3-3. These factors of safety have been selected to be consistent with the test factors shown in Table 3-2. The yield factor of safety ensures that a prototype or protoflight test can be conducted with low risk of the hardware experiencing detrimental yielding. The ultimate factor of safety provides adequate separation between yield and ultimate failure modes and ensures that the hardware will not experience an ultimate failure under expected loading conditions.

Table 3 - 2 Test Factors/Durations

Test	Prototype Qualification	Protoflight Qualification	Acceptance

Structural Loads[1] Level Duration Centrifuge/Static Load Sine Burst	 1.25 x Limit Load 1 minute 5 cycles @ full level per axis	 1.25 x Limit Load 30 seconds 5 cycles @ full level per axis	 1.0 x Limit Load 30 seconds 5 cycles @ full level per axis
Acoustics Level[2] Duration	Limit Level + 3dB 2 minutes	Limit Level + 3dB 1 minute	Limit Level 1 minute
Random Vibration Level[2] Duration	Limit Level + 3dB 2 minutes/axis	Limit Level + 3dB 1 minute/axis	Limit Level 1 minute/axis
Sine Vibration[3] Level Sweep Rate	1.25 x Limit Level 2 oct/min	1.25 x Limit Level 4 oct/min	Limit Level 4 oct/min
Mechanical Shock Actual Device Simulated	2 actuations 1.4 x Limit Level 2 x Each Axis	2 actuations 1.4 x Limit Level 1 x Each Axis	1 actuations Limit Level 1 x Each Axis
Thermal-Vacuum	Max./min. predict. ± 10°C	Max./min. predict. ± 10°C	Max./min. predict. ± 5°C
Thermal Cycling[4]	Max./min. predict. ± 25°C	Max./min. predict. ± 25°C	Max./min. predict. ± 20°C
EMC & Magnetics	As Specified for Mission	Same	Same

LEVR-321 1 - If qualified by analysis only, positive margins shall be shown for factors of safety of 2.0 on yield and 2.6 on ultimate. Beryllium and composite materials cannot be qualified by analysis alone.

LEVR-322 1- Test levels for beryllium structure shall be 1.4 x Limit Level for both qualification and acceptance testing.

LEVR-2211 1- Composite structure, including metal matrix, shall be acceptance tested to 1.25 x Limit Level.

LEVR-323 2 - As a minimum, the test level shall be equal to or greater than the workmanship level.

LEVR-324 3 - The sweep direction shall be evaluated and chosen to minimize the risk of damage to the hardware. If a sine sweep is used to satisfy the loads or other requirements, rather than to simulate an oscillatory mission environment, a faster sweep rate may be considered, e.g., 6-8 oct/min to reduce the potential for over stress.

LEVR-325 4 - The number of thermal cycles and dwell times shall be increased by 50% for thermal cycle(ambient pressure) testing. (Thermal cycle tests to be approved by the LDCM Project.

Table 3 - 3 Flight Hardware Design/Analysis Factors of Safety Applied to Limit Loads

Type (note 1,2)	Static	Sine	Random/Acoustic[4]
Metallic Yield	1.25[3]	1.25	1.6
Metallic Ultimate	1.4[3]	1.4	1.8
Stability Ultimate	1.4	1.4	1.8
Beryllium Yield	1.4	1.4	1.8
Beryllium Ultimate	1.6	1.6	2.0
Composite Ultimate	1.5	1.5	1.9
Bonded Inserts/Joints Ultimate	1.5	1.5	1.9
Other (note 1 and 2)	*	*	*

LEVR-368 1 - Factors of safety for pressurized systems shall be compliant with AFSPCMAN 91-710 (Range Safety).

LEVR-369 2 - Factors of safety for glass and structural glass bonds shall be as specified in NASA-STD-5001

LEVR-370 3 - If qualified by analysis only, positive margin shall be shown for factors of safety of 2.0 on yield and 2.6 on ultimate. See section 3.4.1.1.1

LEVR-371 4 - Factors shown shall be applied to statistically derived peak response based on RMS level.

LEVR-1681 As a minimum, the peak response shall be calculated as a 3-sigma value.

3.3 ELECTRICAL FUNCTION AND PERFORMANCE

The following paragraphs describe the required electrical functional and performance tests that verify the observatory's operation before, during, and after environmental testing.

These tests along with all other calibrations, functional/performance tests, measurements/ demonstrations, alignments (and alignment verifications), end-to-end tests, mission readiness tests, simulations, etc., that are part of the overall verification program will be described in the LDCM Mission Integration and Test Plan, GSFC 427-10-01.

3.3.1 Electrical Interface Tests

LEVR-375 Before the integration of an assembly, component, or subsystem into the next higher hardware assembly, electrical interface tests shall be performed to verify that all interface signals are within acceptable limits of applicable performance specifications.

LEVR-376 Prior to mating with other hardware, electrical harnessing shall be tested to verify proper characteristics; such as, routing of electrical signals, impedance, isolation, and overall workmanship.

LEVR-377 The following parameters shall be verified as a minimum:

LEVR-378 Accuracy (signals on correct pins and nowhere else),

LEVR-379 Inputs and outputs (unloaded and loaded),

LEVR-380 Specified range (high/low extremes as well as nominal),

LEVR-381 Range impacts (how range extremes of one signal affect related signals),

LEVR-2407 Verify grounding continuity between the mating boxes and harness.

3.3.1.1 Aliveness Tests

LEVR-383 Aliveness tests shall be performed as necessary to verify that the subsystem and/or observatory and its major components are functioning.

3.3.2 Comprehensive Performance Tests

LEVR-385 A comprehensive performance test (CPT) shall be conducted on each hardware element after each stage of assembly: component, subsystem/instrument, spacecraft bus and observatory.

When environmental testing is performed at a given level of assembly, additional comprehensive performance tests will be conducted during the hot and cold extremes of the temperature or thermal-vacuum test for both maximum and minimum input voltage, and at the conclusion of the environmental test sequence, as well as at other times prescribed in the verification plan, specification, and procedures.

LEVR-386 The comprehensive performance test shall be a detailed demonstration that the hardware and software meet their performance requirements within allowable tolerances.

LEVR-1684 The test shall demonstrate operation of all redundant circuitry and satisfactory performance in all operational modes within practical limits of cost, schedule, and environmental simulation capabilities.

The initial CPT will serve as a baseline against which the results of all later CPTs can be readily compared.

LEVR-387 At the observatory level, the comprehensive performance test shall demonstrate that, with the application of known stimuli, the observatory will produce the expected responses.

At lower levels of assembly, the test will demonstrate that, when provided with appropriate inputs, internal performance is satisfactory and outputs are within acceptable limits.

3.3.3 Limited Performance Tests

LEVR-389 Limited performance tests (LPT) shall be performed before, during, and after environmental tests, as appropriate, in order to demonstrate that functional capability has not been degraded by the tests. The limited tests are also used in cases where comprehensive performance testing is not warranted or not practicable.

LPTs will demonstrate that the performance of selected hardware and software functions is within acceptable limits.

Specific times when LPTs will be performed will be prescribed in the verification specification.

3.3.4 Performance Operating Time and Failure-Free Performance Testing

LEVR-391 One-thousand (1000) hours of operating/power-on time shall be accumulated on all flight electronic hardware, and spares prior to launch.

LEVR-392 The instrument(s) shall accumulate at least 300 hrs of operation that includes 100 hrs of operation in vacuum, and the last 50 hours of operation being failure-free prior to shipment to the observatory for integration and test.

LEVR-393 At the conclusion of the performance verification program, the observatory shall have demonstrated failure-free performance testing for at least the last 350 hours of operation.

LEVR-2351 Failure-free operation during the thermal-vacuum test exposure is included as part of the demonstration with 100 hours of the trouble-free operation shall be logged at the hot-dwell temperatures.

LEVR-2352 Failure-free operation during the thermal-vacuum test exposure is included as part of the demonstration with 100 hours of the trouble-free operation shall be logged at the cold-dwell temperatures.

LEVR-1690 Major hardware changes during or after the verification program shall invalidate previous failure free demonstration test.

3.3.5 Limited-Life Electrical Elements

LEVR-395 A life test program shall be performed for electrical elements that have limited lifetimes.

The verification plan will address the life test program, identifying the electrical elements that require such testing, describing the test hardware that will be used, and the test methods that will be employed.

3.3.6 Long Duration and Failure Free System Level Test of Flight Software

LEVR-397 Ground test of the fully integrated FSW system shall include demonstration of error-free operations-like scenarios over an extended time period. The minimum duration uninterrupted FSW system-level test (on the highest fidelity FSW testbed) is 72 hours (Class B).

3.4 STRUCTURAL AND MECHANICAL VERIFICATION REQUIREMENTS

A series of tests and analyses will be conducted to demonstrate that the flight hardware is qualified for the expected mission environments and that the design of the hardware complies with the specified verification requirements such as factors of safety, interface compatibility, structural reliability, workmanship, and associated elements of system safety.

LEVR-400 Structural and mechanical verification activities shall be as in Table 3-4.

When the tests and analyses are planned, consideration will be given to the expected environments of structural loads, vibroacoustics, sine vibration, mechanical shock, and pressure profiles induced during all phases of the mission; for example, during launch, insertion into final orbit, preparation for orbital operations.

Verification will also be accomplished to ensure that the transportation and handling environments are enveloped by the expected mission environments.

Mass properties and proper mechanical functioning will also be verified.

Of equal importance with qualifying the hardware for expected mission environments are the testing for workmanship and structural reliability, which are intended to provide a high probability of proper operation during the mission. In some cases, the expected mission environment is rather benign and produces test levels insufficient to expose workmanship defects.

The verification test will envelope the expected mission levels, with appropriate margins added for qualification, and impose sufficient stress to detect workmanship faults. Flight load and dynamic environment levels are probabilistic quantities.

LEVR-1696 Selection of probability levels for flight limit level loads/environments to be used for observatory design and testing is the responsibility of the Contractor, but in no event shall the probability levels be less than the minimum levels in Table 3-5. Specific structural reliability requirements regarding fracture control for ELV payloads, beryllium structure, composite structure, bonded structural joints, and glass structural elements are given in 3.4.1.4.

The program outlined in Table 3-4 assumes that the observatory is sufficiently modularized to permit realistic environmental exposures at the subsystem level. In general, mechanical subsystem tests are at the instrument and spacecraft structure levels, except for the mechanical function tests.

LEVR-1697 When the test program outlined in Table 3-4 is not possible, then with the GSFC LDCM project office's approval, compliance with the subsystem requirements shall be accomplished at a higher or lower level of assembly.

For example, structural load tests of some components may be necessary if they cannot be properly applied during testing at higher levels of assembly.

LEVR-403 Ground handling, transportation and test fixtures shall be analyzed and tested for proper strength as required by safety, and shall be verified for stability for applicable configurations as appropriate.

3.4.1 Structural Loads Qualification

Qualification of the observatory for the structural loads environment requires a combination of test and analysis.

LEVR-1698 A test-verified finite element model of the observatory and instrument shall be developed and a coupled loads analysis of the observatory/launch vehicle performed.

The analytical results define the limit loads for the observatory (subsystems and components) and show compatibility with the launch vehicle for all critical phases of the mission.

Structural and Mechanical analysis and test will be performed per Table 3-4 and the associated annotations.

Table 3 - 4 Structural and Mechanical Verification Analysis and Test Requirements

Requirement	Observatory	Subsystem/ Instrument	Components
Structural Loads			
Modal Survey	*	T^2	*
Design Qualification	*	$A,T/A^1$	*
Structural Reliability			
Primary & Secondary Structure	*	$(A,T)^1$	*
Vibroacoustics			
Acoustics	T	T^2	T^2
Random Vibration	T^2	T^2	T
Sine Vibration	T^3,T^4	T^3,T^5	T^3,T^6
Mechanical Shock	T	T^7	T^7
Mechanical Function	A,T	A,T	-
Pressure Profile	-	A,T^2	A
Mass Properties	A/T	A,T^2	*

* = May be performed at observatory or component level of assembly if appropriate.

A = Analysis required.

T = Test required.

A/T = Analysis and/or test.

A,T/A1 = Analysis and Test or analysis only if no-test factors of safety given in 3.4.1.1.1 are used.

(A,T)1 = Combination of fracture analysis and proof tests on selected elements, with special attention given to beryllium, composites, and bonded joints.

T2 = Test required unless assessment justifies deletion.

T3 = Test required to simulate any sustained periodic mission environment, or to satisfy other requirement (loads, low frequency transient vibration).

T4 = Test required to simulate transient and any sustained periodic vibration mission environment.

T5 = Test required for instruments and spacecraft bus if not performed at observatory level of assembly due to test facility limitations; to simulate sine transient and any sustained periodic vibration mission environment.

T6 = Test required for observatory, instruments, and components to simulate sine transient and any sustained periodic vibration mission environment.

T^7 = Test required for self-induced shocks, but may be performed at observatory level of assembly for externally induced shocks.

Table 3 - 5 Minimum Probability-Level Requirementsfor Flight Limit Level

Requirement	Minimum Probability Level
	ELV Observatory
Structural Loads	97.72/50 (1),(2)
Vibroacoustics Acoustics Random Vibration	95/50 (3)
Sine Vibration	97.72/50 (1)
Mechanical Shock	95/50
Notes:	
(1) When parametric statistical methods are used to determine the limit level, the data shall be tested to show a satisfactory fit to the assumed underlying distribution.	
(2) 97.72% probability of not exceeding level, estimated with 50% confidence. Equal to the mean plus two-sigma level for normal distributions.	

(3) Equal to, or greater than, the ninety-fifth percentile value, estimated with 50% confidence.

LEVR-537 A modal survey shall be performed for each observatory (at the spacecraft /instrument or other appropriate level of assembly) to verify that the analytical model adequately represents the dynamic behavior of the hardware.

LEVR-1699 The test-verified model shall then be used to predict the maximum expected load for each critical loading condition, including handling and transportation, vibroacoustic effects during lift-off, insertion into final orbit, orbital operations, etc., as appropriate for the particular mission.

LEVR-1700 If the observatory configuration is different for various phases of the mission, the structural loads qualification program, including the modal survey, shall consider the different configurations.

LEVR-1701 The maximum loads resulting from the analysis shall define the limit loads.

The launch loads environment is made up of a combination of steady-state, low-frequency transient, and higher-frequency vibroacoustic loads.

LEVR-541 When determining the limit loads for ELV launches, consideration shall be given to the timing of the loading events.

LEVR-1703 Also, the frequency band of the vibroacoustic energy to be combined shall be evaluated on a case-by-case basis.

LEVR-1704 Flight events which shall be considered for inclusion in the coupled loads analysis for various ELVs are lift-off, maximum dynamic pressure, Mach 1 and staging.

LEVR-1705 If the verification cycle analysis or observatory test-verified model is not available, the latest analytical data shall be used in conjunction with an uncertainty factor to be approved by the GSFC LDCM project office.

LEVR-542 Each subsystem/instrument shall then be qualified by loads testing to 1.25 times the limit loads defined above.

LEVR-1706 The loads test shall be accompanied by stress analysis showing positive margins of safety at 1.4 times the limit load for all ultimate failure modes such as fracture or buckling. In some cases, qualification by analysis may be allowed.

Special design and test factors of safety are required for beryllium structure (see Section 3.4.1.3.1).

3.4.1.1 Coupled Load Analysis

LEVR-545 A coupled load analysis, combining the launch vehicle and observatory, shall be performed to support the verification of positive stress margins and sufficient clearances during the launch.

3.4.1.1.1 Analysis - Strength Verification

LEVR-547 A finite element model shall be developed (and verified by test) that analytically simulates the observatory's mass and stiffness characteristics, for the purpose of performing a coupled loads analysis.

LEVR-1707 The model shall be of sufficient detail to make possible an analysis that defines the observatory's modal frequencies and displacements below a specified frequency that is dependent on the fidelity of the launch vehicle finite element model. For ELV all significant modes below 70 Hz are sufficient unless higher-frequency modes are required by the launch vehicle manufacturer.

The model is then coupled with the model of the ELV and any upper-stage propulsion system. The combined coupled model is used to conduct a coupled loads analysis that evaluates all potentially critical loading conditions.

LEVR-1708 Forcing functions used in the coupled loads analysis shall be defined at the flight limit level consistent with the minimum probability levels of Table 3-5.

LEVR-1709 The results of the coupled loads analysis shall be reviewed to determine the worst-case loads. These constitute the set of limit loads that are used to evaluate member loads and stresses.

LEVR-549 The coupled loads analysis shall consider all flight events required by the ELV provider.

LEVR-1710 None of the flight events shall be deleted from the coupled loads analysis unless it is shown by base drive analysis of the cantilevered observatory and adapter that there are no significant observatory vibration modes in frequency bands of significant launch vehicle forcing functions and coupled-mode responses.

LEVR-1711 It shall be confirmed that there are no observatory structural components or subsystems (upper platforms, antenna supports, scientific instruments, etc.) which can experience high dynamic responses during flight events such as lift-off or sustained, pogo-like oscillations before deleting these events.

LEVR-1712 For the evaluation of flight events to include in the coupled loads analysis, an appropriate tolerance shall be applied to all potentially significant observatory modal frequencies unless verified by modal survey testing

Normally, the design and verification of observatories is not burdened by transportation and handling environments that exceed stresses expected during launch, orbit. Rather, shipping containers are designed to prevent the imposition of such stresses.

LEVR-1714 A documented analysis shall be prepared on shipping and handling equipment to define the loads transmitted to flight hardware.

LEVR-1715 When transportation and handling loads are not enveloped by the maximum expected flight loads, the transportation and handling loads shall be included in the set of limit loads.

LEVR-551 For those hardware items that will later be subjected to a strength qualification test, a stress analysis shall be performed to provide confidence that the risk of failing the strength test is small and to demonstrate compliance with the launch vehicle (ELV) interface verification and safety requirements.

LEVR-1716 The analysis shall show positive margins at stresses corresponding to a loading of 1.4 times the limit load for all ultimate failure modes such as fracture or buckling.

LEVR-1717 In addition, the analysis shall show that for a loading equal to the limit load, the maximum allowable loads at the ELV flight adapter are not exceeded, that no detrimental permanent deformations will occur, and that no excessive deformations occur that might constitute a hazard to the launch vehicle. See Section 3.4.1.4 for special requirements for beryllium structure.

For observatories, or observatory elements, whose strength is qualified by analysis, the objective of the stress analysis is to demonstrate with a high degree of confidence that there is essentially no chance of failure during flight.

LEVR-1718 For all elements that are to be qualified by analysis, positive strength margins on yield shall be shown to exist at stresses equal to 2.0 times those induced by the limit loads.

LEVR-2214 Positive margins on ultimate shall be shown to exist at stresses equal to 2.6 times those induced by the limit loads. For exceptions, see Section 3.4.1.3.

LEVR-1719 When qualification by analysis is used, the upper frequency of the modal survey shall be increased by a value as agreed to by the GSFC LDCM project office.

LEVR-1720 In addition, at stresses equal to the limit load, the analysis shall show that the maximum allowable loads at the ELV flight adapter are not exceeded, that no detrimental permanent deformations will occur, and that no excessive deformations occur that might constitute a hazard to the launch vehicle.

3.4.1.1.2 Analysis - Clearance Verification

LEVR-554 Analysis shall be conducted to verify adequate dynamic clearances between the observatory and launch vehicle and between members within the observatory for all significant ground test and flight conditions.

3.4.1.1.2.1 During Powered Flight

LEVR-556 The coupled loads analysis shall be used to verify adequate clearances during flight within the ELV payload fairing.

LEVR-1721 One part of the coupled loads analysis output transformation matrices shall contain displacement data that will allow calculation of loss of clearance between critical extremities of the observatory and adjacent surfaces of the ELV.

LEVR-1722 For ELV observatories, the analysis shall consider clearances between the observatory and ELV payload fairing (and its acoustic blankets if used, including blanket expansion due to venting) and between the observatory and ELV attach fitting, as applicable.

LEVR-1723 For the clearance calculations the following factors shall be considered:

LEVR-557 1. Worst-case observatory and vehicle manufacturing and assembly tolerances as derived from as-built engineering drawings.

LEVR-558 2. Worst-case observatory/vehicle integration "stacking" tolerances related to interface mating surface parallelism, perpendicularity and concentricity, plus bolt positional tolerances, ELV payload fairing ovality, etc.

LEVR-559 3. Quasi-static and dynamic flight loads, including coupled steady-state and transient sinusoidal vibration, vibroacoustics and venting loads, as applicable. Typically, either liftoff or the transonic buffet and maximum airloads cause the greatest relative deflections between the vehicle and observatory.

3.4.1.1.2.2 During ELV Payload Fairing Separation

LEVR-561 A fairing separation analysis based on ground separation test of the fairing, shall be used to verify adequate clearances between the separating fairing sections and observatory extremities.

LEVR-1724 Effects of fairing section shell-mode oscillations, fairing rocking, vehicle residual rates, transient coupled-mode oscillations, thrust accelerations, and vehicle control-jet firings shall be considered, as applicable.

3.4.1.1.2.3 During Payload Separation

LEVR-563 A payload separation analysis shall be used to verify adequate clearances between the observatory and ELV during separation.

LEVR-1725 The analysis shall include effects of factors such as vehicle residual rates, forces and impulses imparted by the separation system (including lateral impulses due to separation clampbands) and vehicle retro-rocket plumes impinging on the observatory, as applicable.

LEVR-1726 The same analysis shall be utilized to verify acceptable payload separation velocity and tip-off rates.

LEVR-564 Analysis shall also be performed to verify adequate critical dynamic clearances between members within the observatory during ground vibration and acoustic testing, and flight.

LEVR-1727 Additionally, a deployment analysis shall be used to verify adequate clearances during observatory appendage deployment. Refer to Section 3.4.5.2 regarding mechanical function clearances.

LEVR-565 For all of the above clearance analyses and conditions, adequate clearances shall be verified assuming worst-case static clearances due to manufacturing, assembly and vehicle integration tolerances (unless measured on the launch stand), and quasi-static and dynamic deflections due to 1.4 times the applicable flight limit loads or flight-level ground test levels. Depending on the available static clearance, the clearance analysis requirements may be satisfied in many cases by simple worst-case estimates and/or similarity.

3.4.1.2 Modal Survey

LEVR-567 A modal survey test shall be performed for observatories and subsystems, including instruments, that do not meet requirements on minimum fundamental frequency.

The minimum fundamental frequency requirement is dependent on the launch vehicle and is discussed below for ELV launch vehicles.

LEVR-1728 In order to determine if the hardware meets the frequency requirement, an appropriate test, or tests, shall be performed to identify the fundamental frequency. A low level sine survey is generally an appropriate method for determining the fundamental frequency.

The frequency below which a modal test is required is dependent on the specific launch vehicle. The determination will be made on a case-by-case basis and specified in the design and test requirements.

LEVR-1729 Modal tests shall be performed at the subsystem/instrument level of assembly unless assessment justifies deletion. It may be required at other levels of assembly such as the observatory or component level depending on LDCM project office determination.

LEVR-569 In general, the support of the hardware during the test shall duplicate the boundary conditions expected during launch. When that is not feasible, other boundary conditions are employed and the frequency limits of the test are adjusted by a value as agreed to by the GSFC LDCM project office.

The effects of interface flexibilities will be included when other than normal boundary conditions are used.

The results of the modal survey are required to identify any inaccuracies in the mathematical model used in the observatory analysis program so that modifications can be made if needed. Such an experimental verification is required because a degree of uncertainty exists in unverified models owing to assumptions inherent in the modeling process. These lead to uncertainties in the results of the flight dynamic loads analysis, thereby reducing confidence in the accuracy of the set of limit loads derived therefrom.

LEVR-571 All significant modes (those with greater than 5% effective modal mass) up to the required frequency shall be determined both in terms of frequency and mode shape.

LEVR-1731 Cross-orthogonality checks of the test and analytical mode shapes, with respect to the analytical mass matrix, shall be performed with the goal of obtaining at least 0.9 on the diagonal and no greater than 0.1 off-diagonal. Any test method that is capable of meeting the test objectives with the necessary accuracy may be used to perform the modal survey. The input forcing function may be transient, fixed frequency, swept sinewave, or random in nature.

3.4.1.3 Design Strength Qualification

The preferred method of verifying adequate strength is to apply a set of loads that will generate forces in the hardware that are equal to 1.25 times limit loads.

LEVR-1732 The strength qualification test shall be shown to produce forces equal to 1.25 times limit at structural interfaces as well as in structural elements which have been shown to have the lowest margins for all identified failure modes of the hardware.

As many test conditions as necessary will be applied to achieve the appropriate loads for qualification.

LEVR-1734 Structural qualification testing shall be performed at the lowest level of assembly as possible to reduce overtest and to limit the risk of damage to other components/subsystems should structural failure occur.

LEVR-1735 After structural testing, the hardware shall be capable of meeting its performance criteria (see Section 3.4.1.3.1 for special requirements for beryllium structure).

LEVR-1736 No detrimental permanent deformation shall be allowed to occur as a result of applying the loads, and all applicable alignment requirements shall be met following the test.

LEVR-574 The strength qualification test shall be accompanied by a stress analysis that demonstrates a positive margin on ultimate at loads equal to 1.4 times the limit load for all ultimate failure modes such as fracture or buckling. See Section 3.4.1.3.1 for special requirements for beryllium structure.

LEVR-575 In addition, the analysis shall show that at stresses equal to the limit load, the maximum allowable loads at the launch vehicle interface points are not exceeded and that no excessive deformations occur that might constitute a hazard to the mission.

LEVR-1737 This analysis shall be performed prior to the start of the strength qualification tests to provide minimal risk of damage to hardware. When satisfactory qualification tests have been conducted on a representative structural model, the strength qualification testing of the protoflight unit may not be necessary.

a. Selection of Test Method

LEVR-577 The qualification load conditions shall be applied by acceleration testing, static load testing, or vibration testing (either transient, fixed frequency or swept sinusoidal excitation).

Random vibration is generally not acceptable for loads testing.

Consideration will be given to the following when the method to be employed for verification tests is selected:

(1) The method most closely approximates the flight-imposed load distribution,

(2) Application of flight load distribution with the greatest accuracy,

(3) Method for deriving information for design verification and for predicting design capability for future observatory or launch vehicle modifications, and

(4) Posing the least risk to the hardware in terms of handling and test equipment.

b. Test Setup

LEVR-585 The test item shall be attached to the test equipment by a fixture whose mechanical interface simulates the mounting of the test item into the observatory with particular attention paid to duplicating the actual mounting contact area.

LEVR-1738 In mating the test item to the fixture, a flight-type mounting (including vibration isolators or kinematic mounts if part of the design) and fasteners shall be used.

LEVR-586 Components that are normally sealed shall be pressurized during the test to their prelaunch pressure.

LEVR-1739 In cases when significant changes in strength, stiffness, or applied load result from variations in internal and external pressure during the launch phase, a special test shall be considered to cover those effects.

LEVR-587 When acceleration testing is performed, the centrifuge shall be large enough so that the applied load at the extreme ends of the test item does not differ by more than 10 percent from that applied to the center of gravity.

LEVR-1740 In addition, when the proper orientation for the applied acceleration vector is computed, ambient gravity effects shall be included.

c. Performance

LEVR-589 Before and after the strength qualification test, the test item shall be examined and functionally tested to verify compliance with all performance criteria.

LEVR-1741 During the tests, performance shall be monitored in accordance with the verification specification and procedures.

If appropriate development tests are performed to verify accuracy of the stress model, stringent quality control procedures are invoked to ensure conformance of the structure (materials, fasteners, welds, processes, etc.) to the design, and the structure has well-defined load paths, then strength qualification may (with LDCM project concurrence) be accomplished by a stress analysis that demonstrates that the hardware has positive margins on yield at loads equal to 2.0 times the limit load, and positive margin on ultimate at loads equal to 2.6 times the limit load.

If warranted, factors of safety lower than 2.0 on yield and 2.6 on ultimate will be considered for approval by the GSFC LDCM project office.

LEVR-1742 Justification for the lower factors of safety shall be based on the merits of a particular combination of test and analysis and a correlation of the two.

Such alternative approaches will be reviewed and approved on a case-by-case basis.

LEVR-1744 In addition, at stresses equal to the limit load, the analysis shall show that the maximum allowable loads at the launch vehicle interface points are not exceeded and that no excessive deformations occur.

LEVR-591 Structural elements fabricated from composite materials or beryllium shall not be qualified by analysis alone.

3.4.1.3.1 Strength Qualification - Beryllium

LEVR-593 All beryllium primary and secondary structural elements shall undergo a strength test to 1.4 times limit load.

LEVR-1745 No detrimental permanent deformation shall be allowed to occur as a result of applying the loads, and applicable alignment requirements shall be met following the test. In addition:

LEVR-594	a. When using cross-rolled sheet, the design shall preclude out-of-plane loads and displacements during assembly, testing, or service life.
LEVR-595	b. In order to account for uncertainties in material properties and local stress levels, a design factor of safety of 1.6 on ultimate material strength shall be used.
LEVR-596	c. Stress analysis shall properly account for the lack of ductility of the material by rigorous treatment of applied loads, boundary conditions, assembly stresses, stress concentrations, thermal cycling, and possible material anisotropy.
LEVR-1749	d. The stress analysis shall take into account worst-case tolerance conditions.
LEVR-597	e. All machined and/or mechanically disturbed surfaces shall be chemically milled to ensure removal of surface damage and residual stresses.
LEVR-598	f.All parts shall undergo penetrant inspection for surface cracks and crack-like flaws per MIL-STD-6866.

3.4.1.4 Structural Reliability (Residual Strength Verification)

Structural reliability requirements are intended to provide a high probability of the structural integrity of all flight hardware. They are generally covered by the selection of materials, process controls, selected analyses (stress, and fracture mechanics/crack growth), and loads/proof tests. All structural materials contain defects such as inclusions, porosity, and cracks.

LEVR-1752	To ensure that adequate residual strength (strength remaining after the flaws are accounted for) is present for structural reliability at launch, a fracture control program, or a combination of fracture control and specific loads tests shall be performed on all flight hardware as specified below.

The use of materials that are susceptible to brittle fracture or stress-corrosion cracking require development of, and strict adherence to, special procedures to prevent problems.

If materials are used for structural application that are not listed in Table 1 of MSFC-STD-3029, a Materials Usage Agreement (MUA) will be negotiated with the project office. Refer to project Materials and Processes Control Requirements for applicable requirements.

3.4.1.4.1 Primary and Secondary Structure:

ELV Payloads - The following requirements regarding beryllium, nonmetallic-composite, and metallic-honeycomb structural elements (both primary and secondary), and bonded structural joints apply to ELV payloads:

LEVR-605 a. Beryllium Primary and Secondary Structure: The requirements of section 3.4.1.3.1, Strength Verification-Beryllium, shall apply for structural reliability.

b. Nonmetallic Composite Structural Elements (including metal matrix): All flight structural elements will be proof tested to 1.25 times limit load (even if previously qualified on valid prototype hardware).

However, if this is not feasible, and with approval from the GSFC LDCM Project Office, then it is acceptable to proof test a representative set of structural elements to 1.25 times the highest limit load for that type of structure. The remainder of the structural elements may then be considered qualified by similarity.

LEVR-1755 In order to use this approach, the allowables used to assess structural margins shall be developed based on coupon testing and standard statistical techniques.

LEVR-1756 As a minimum, B-basis allowables shall be used. In addition:

LEVR-607 (1) A process control plan shall be developed and implemented to ensure uniformity of processing among test coupons, test articles, and flight hardware as required by the project Materials and Processes Control Requirements.

LEVR-608 (2) A damage control plan shall be implemented to establish procedures and controls to prevent and/or identify nonvisible impact damage which may cause premature failure of composite elements.

c. Metallic Honeycomb (both facesheets and core) Structural Elements:

LEVR-610 (1) Appropriate process controls and coupon testing shall be implemented to demonstrate that the honeycomb structure is acceptable for use as observatory flight structure as required by the project Materials and Processes Control Requirements.

LEVR-611 (2) Metallic honeycomb shall not be considered to be a composite material.

d. Bonded Structural Joints (either metal-metal or metal-nonmetal):

LEVR-613 (1) Every bonded structural joint in a flight article shall be proof tested (by static loads test) to 1.25 times limit load.

For example, proof loads testing will be performed to demonstrate that inserts will not tear out from honeycomb under protoflight loads. However, in cases where this approach is not feasible, and with approval from the GSFC LDCM Project Office, it is acceptable to test a representative sample of the bonded structural joints in the flight article.

LEVR-1758 As a minimum, at least one of each type of bonded joint in the flight article shall be tested to 1.25 times the maximum predicted limit load for that joint type. The remainder of the bonded joints may then be considered to be qualified by similarity. The use of this approach requires that bonded joint allowables be developed based on coupon testing or testing of sample joints and standard statistical techniques.

LEVR-1759 As a minimum, B-basis allowables shall be used.

(2)A process control plan will be developed and implemented as required by applicable project Materials and Processes Control Requirements to ensure uniformity of processing among test coupons, test articles, and flight hardware.

LEVR-615 Fracture control requirements (per GSFC 731-0005-83) shall apply to the following elements only:

a. Pressure vessels, dewars, lines, and fittings (per NHB-8071.1),

LEVR-617 b. Castings (unless hot isostatically pressed and the flight article is proof tested to 1.25 times limit load),

LEVR-618 c. Weldments,

LEVR-619 d. Parts made of materials on Tables II or III of MSFC-SPEC-522B if under sustained tensile stress.

LEVR-1760 All structural applications of these materials requires that a Materials Usage Agreement (MUA) will be negotiated with the GSFC LDCM Project Office; (refer to project Materials and Processes Control Requirements),

LEVR-620 e. Parts made of materials susceptible to cracking during quenching,

LEVR-621 f. Nonredundant, mission-critical preloaded springs loaded to greater than 25 percent of ultimate strength.

LEVR-622 g. All glass elements, that are stressed above 10% of their ultimate tensile strength, shall also be shown by fracture analysis to satisfy "Safe-life" or "Fail-safe" conditions or be subjected to a proof loads test at 1.0 times limit level.

3.4.1.5 Acceptance Requirements

All of the structural reliability requirements of Section 3.4.1.4 apply for the acceptance of all flight hardware.

LEVR-625 The following acceptance/proof loads tests shall be performed unless equivalent load-level testing was performed on the actual flight hardware as part of a protoflight test program:

LEVR-627 (1)Beryllium structure (primary and secondary) shall be proof tested to 1.4 times limit load.

LEVR-628 (2)Nonmetallic composites (including metal matrix) structural elements shall be proof tested to 1.25 times limit load.

LEVR-629 (3)Bonded structural joints shall be proof tested (by static loads test) to 1.25 times limit load.

LEVR-630 When a follow-on observatory receives structural modifications or a new complement of instruments, it shall be requalified for the loads environment if analysis so indicates.

Generally, structural design loads testing is not required for flight structure that has been previously qualified for the current mission as part of a valid prototype or protoflight test.

3.4.2 Vibroacoustic Qualification

Qualification for the vibroacoustics environment generally requires an acoustics test at the observatory level of assembly and random vibration tests on all components, instruments, and on the observatory, when appropriate, to better simulate the structure borne inputs.

LEVR-1761 In addition, random vibration tests shall be performed on all subsystems unless an assessment of the expected environment indicates that the subsystem will not be exposed to any significant vibration input.

LEVR-633 Similarly, an acoustic test shall be performed on subsystems/instruments and components unless an assessment of the hardware indicates that they are not susceptible to the expected acoustic environment or that testing at higher levels of assembly provides sufficient exposure at an acceptable level of risk to the program. Irrespective of the above stated conditions, these additional tests may be required to satisfy delivery requirements.

It is understood that for some observatory projects, the vibroacoustic qualification program may have to be modified. For example, for very large observatories it may be impracticable because of test facility limitations to perform testing at the required level of assembly.

LEVR-1762 In that case, testing at the highest practicable level of assembly shall be performed, and additional tests and/or analyses added to the verification program per approval by the GSFC LDCM project office.

LEVR-1763 Also, the risk to the program associated with the modified test program shall be assessed and documented in the System Verification Plan.

Similarly, for very large components, the random vibration tests may have to be supplemented or replaced by an acoustic test. If the component level tests are not capable of inducing sufficient excitation to internal electric, electronic, and electromechanical devices to provide adequate workmanship verification, it is recommended that an environmental stress screening test program be conducted at lower levels of assembly (subassembly or board level).

LEVR-636 For the vibroacoustic environment, limit levels shall be used which are consistent with the minimum probability levels of Table 3-5. The protoflight qualification level is defined as the flight limit level plus 3 dB.

LEVR-1764 When random vibration levels are determined, responses to the acoustic inputs plus the effects of vibration transmitted through the structure shall be included.

The random vibration test levels to be used for hardware containing delicate optics, sensors/detectors, etc., may be notched in frequency bands known to be destructive to the hardware with project concurrence. A force-limiting control strategy is recommended. This requires a dual control system which will automatically notch the input so as not to exceed design/expected forces in the area of rigid, shaker mounted resonances while maintaining acceleration control over the remainder of the frequency band.

LEVR-1765 The control methodology shall be approved by the GSFC LDCM project office. More information on implementing the force-limiting control strategy can be found in Force Limited Vibration Testing NASA Technical Handbook, NASA-HDBK-7004.

As a minimum, the vibroacoustic test levels will be sufficient to demonstrate acceptable workmanship.

LEVR-638 During test, the test item shall be in an operational configuration, both electrically and mechanically, representative of its configuration at lift-off.

The vibroacoustic (acoustics plus random vibration) environmental test program will be included in the environmental verification plan and environmental verification specification.

3.4.2.1 Fatigue Life Considerations

The nature of the protoflight test program prevents a demonstration of hardware lifetime because the same hardware is both tested and flown.

LEVR-1767 When hardware reliability considerations demand the demonstration of a specific hardware lifetime, a prototype verification program shall be employed, and the test durations shall be modified accordingly.

LEVR-642 Specifically, the duration of the vibroacoustic exposures shall be extended to account for the life that the flight hardware will experience during its mission.

LEVR-1768 In order to account for the scatter factor associated with the demonstration of fatigue life, the duration of prototype exposures shall be at least four times the intended life of the flight hardware.

LEVR-1769 For ELV observatories, the duration of the exposure shall be based on both the vibroacoustic and sine vibration environments.

LEVR-643 If there is the possibility of thermally induced structural fatigue (examples include solar arrays, antennas, etc.), thermal cycle testing shall be performed on prototype hardware. For large solar arrays, a representative smaller qualification panel shall be used for test which contains all of the full scale design details (including at least 100 solar cells) susceptible to thermal fatigue.

LEVR-2383 For large solar arrays, a representative smaller qualification panel shall be used for test which contains all of the full scale design details (including at least 100 solar cells) susceptible to thermal fatigue.

LEVR-1770 The life test shall normally be performed at the worst case (limit level) predicted temperature extremes for a number of thermal cycles corresponding to the required mission life. However, if required by schedule considerations, the test program may be accelerated by increasing the temperature cycle range (and possibly the temperature transition rate) provided that stress analysis shows no unrealistic failure modes are produced by the accelerated testing.

3.4.2.2 Observatory Acoustic Test

LEVR-645 At the observatory level of assembly, protoflight hardware shall be subjected to an acoustic test in a sound pressure field to verify its ability to survive the lift-off acoustic environment and to provide a final workmanship acoustic test.

LEVR-1771 The test specification is dependent on the observatory-launch vehicle configuration and shall be determined on a case-by-case basis and approved by the GSFC LDCM project office.

LEVR-1772 The minimum overall test level shall be at least 138 dB.

LEVR-1773 If the test specification derived from the launch vehicle expected environment, including fill-factor, is less than 138 dB, the test profile shall be raised to provide a 138 dB test level.

LEVR-1774 The planned test and specification levels shall be confirmed by the launch vehicle program office.

LEVR-646 a. Facilities and Test Control - The acoustic test shall be conducted in an area large enough to maintain a uniform sound field at all points surrounding the test item. The sound pressure level is controlled at one-third octave band resolution. The preferred method of control is to average four or more microphones with a real-time device that effectively averages the sound pressure level in each filter band.

LEVR-1776 When real-time averaging is not practicable, a survey of the chamber shall be performed to determine the single point that is most suitable for control of the acoustic test.

LEVR-647 Regardless of the control method employed, a minimum of four microphones shall be positioned around the test chamber at sufficient distance from all surfaces to avoid absorption or re-radiation effects.

LEVR-1777 One of the microphones shall be located above the test item for a free-field test. A distance from any surface of at least l/4 the wavelength of the lowest frequency of interest is recommended. It is recognized that this cannot be achieved in some facilities, particularly when noise levels are specified to frequencies as low as 25 Hz.

LEVR-1778 In such cases, the microphones shall be located in positions so as to be affected as little as possible by surface effects.

The preferred method of preparing for an acoustic test is to preshape the spectrum of the acoustic field with a dummy test item. If no such item is readily available, it is possible to preshape the spectrum in an empty test area.

LEVR-1779 In that case, however, a low-level test shall be performed after the test item has been placed in the test area to permit final adjustments to the shape of the acoustic spectrum.

LEVR-649 b. Test Setup - The boundary conditions under which the hardware is supported during test shall duplicate those expected during flight.

LEVR-1781 When that is not feasible, the test item shall be mounted in the test chamber in such a manner as to be isolated from all energy inputs on a soft suspension system (natural frequency less than 20 Hz) and a sufficient distance from chamber surfaces to minimize surface effects.

LEVR-1782 During test, the test item shall be in an operational configuration, both electrically and mechanically, representative of its configuration at lift-off.

LEVR-650 c. Performance - Before and after the acoustic exposure, the observatory shall be examined and functionally tested.

LEVR-1784 During the test, performance shall be monitored in accordance with the verification specification.

3.4.2.3 Observatory Random Vibration Tests

LEVR-652 At the observatory level of assembly, protoflight hardware shall be subjected to a random vibration test to verify its ability to survive the lift-off environment and also to provide a final workmanship vibration test, unless assessment justifies deletion.

LEVR-1786 The acoustic environment at lift-off is usually the primary source of random vibration; however, all other sources of random vibration shall be considered. The sources include transonic aerodynamic fluctuating pressures and the firing of retro/apogee motors.

LEVR-653 a. Lift-Off Random Vibration - Protoflight hardware shall be subjected to a random vibration test to verify flightworthiness and workmanship.

LEVR-1788 The test level shall represent the qualification level (flight limit level plus 3 dB).

LEVR-654 The test shall cover the full 20-2000 Hz frequency range.

LEVR-1789 Both lift-off and transonic random vibration shall be considered.

LEVR-655 The observatory in its launch configuration shall be attached to a vibration fixture by use of a flight-type launch-vehicle adapter and attachment hardware.

LEVR-1790 Vibration shall be applied at the base of the adapter in each of three orthogonal axes, one of which is parallel to the thrust axis.

LEVR-1791 The excitation spectrum as measured by the control accelerometer(s) shall be equalized such that the acceleration spectral density is maintained within +/- 3 dB of the specified level at all frequencies within the test range and the overall RMS level is within 10% of the specified level.

LEVR-656 Prior to the observatory test, a survey of the test fixture/exciter combination shall be performed to evaluate the fixture dynamics, the proposed choice of control accelerometer locations, and the control strategy.

LEVR-1792 If a mechanical test model of the observatory is available it shall be included in the survey to evaluate the need for limiting.

LEVR-657 If a random vibration test is not performed at the observatory level of assembly, the feasibility of doing the test at the next lower level of assembly shall be assessed by the Contractor and approved by the GSFC LDCM project office.

LEVR-658 b. Performance - Before and after each vibration test, the observatory shall be examined and functionally tested.

LEVR-1794 During the tests, performance shall be monitored in accordance with the verification specification.

3.4.2.4 Subsystem/Instrument Vibroacoustic Tests

LEVR-660 If subsystems are expected to be significantly excited by structure-borne random vibration, a random vibration test shall be performed. Specific test levels are determined on a case-by-case basis and approved by the GSFC LDCM project office.

LEVR-1795 The levels shall be equal to the qualification level as predicted at the location where the input will be controlled. Subsystem acoustic tests may also be required if the subsystem is judged to be sensitive to this environment or if it is necessary to meet delivery specifications. A random vibration test is generally required for instruments.

3.4.2.5 Component/Unit Vibroacoustic Tests

LEVR-662 As a screen for design and workmanship defects, components/units shall be subjected to a random vibration test along each of three mutually perpendicular axes.

LEVR-1796 In addition, when components are particularly sensitive to the acoustic environment, an acoustic test shall be considered.

LEVR-663 a. Random Vibration - The test item shall be subjected to random vibration along each of three mutually perpendicular axes for one minute each.

LEVR-1798 When possible, the component random vibration spectrum shall be based on levels measured at the component mounting locations during previous subsystem or observatory testing.

LEVR-1799 When such measurements are not available, the levels shall be based on statistically estimated responses of similar components on similar structures or on analysis of the observatory.

Actual measurements will then be used if and when they become available.

LEVR-1801 In the absence of any knowledge of the expected level, the generalized vibration test specification of Table 3-6 shall be used.

LEVR-664 As a minimum, all components shall be subjected to the levels of Table 3-7, which represent a workmanship screening test. The minimum workmanship test levels are primarily intended for use on electrical, electronic, and electromechanical hardware.

LEVR-665 The test item shall be attached to the test equipment by a rigid fixture.

LEVR-1802 The mounting shall simulate, insofar as practicable, the actual mounting of the item in the observatory with particular attention given to duplicating the mounting contact area.

LEVR-1803 In mating the test item to the fixture, a flight-type mounting (including vibration isolators or kinematic mounts, if part of the design) and fasteners shall be used.

LEVR-1804 Normally sealed items shall be pressurized during test to their prelaunch pressure.

LEVR-666 In cases where significant changes in strength, stiffness, or applied load result from variations in internal and external pressure during the launch phase, a special test shall be considered to cover those effects.

LEVR-667 Prior to the test, a survey of the test fixture/exciter combination shall be performed to evaluate the fixture dynamics, the proposed choice of control accelerometer locations, and the control strategy.

LEVR-1805 The evaluation shall include consideration of cross-axis responses.

LEVR-1806 If a mechanical test or engineering model of the test article is available it shall be included in the survey.

For very large components the random vibration tests may have to be supplemented or replaced by an acoustic test if the vibration test levels are insufficient to excite internal hardware.

LEVR-1807 If neither the acoustic nor vibration excitation is sufficient to provide an adequate workmanship test, a screening program shall be initiated at lower levels of assembly; down to the board level, if necessary.

LEVR-1808 The need for the screening program shall be evaluated by the project. The evaluation is based on mission reliability requirements and hardware criticality, as well as budgetary and schedule constraints.

If testing is performed below the component level of assembly, the workmanship test levels of Table 3-7 can be used as a starting point for test tailoring. The intent of testing at this level of assembly is to uncover design and workmanship flaws. The test input levels do not represent expected environments, but are intended to induce failure in weak parts and to expose workmanship errors.

LEVR-1809 The susceptibility of the test item to vibration shall be evaluated and the test level tailored so as not to induce unnecessary failures.

If the test levels create conditions that exceed appropriate design safety margins or cause unrealistic modes of failure, the input spectrum can be notched below the minimum workmanship level. This can be accomplished when flight or test responses at the higher level of assembly are known or when appropriate force limits have been calculated.

LEVR-671 b. Acoustic Test - If a component-level acoustic test is required, the test set-up and control shall be in accordance with the requirements for observatory testing.

LEVR-672 c. Performance - Before and after test exposure, the test item shall be examined and functionally tested.

LEVR-1812 During the test, performance shall be monitored in accordance with the verification specification.

3.4.2.6 Acceptance Requirements

LEVR-674 Vibroacoustic testing for the acceptance of previously qualified hardware shall be conducted at flight limit levels using the same duration as recommended for protoflight hardware.

LEVR-1813 As a minimum, the acoustic test level shall be 138 dB, and the random vibration levels shall represent the workmanship test levels.

LEVR-675 The observatory shall be subjected to an acoustic test and/or a random vibration test in three axes.

LEVR-1814 Components shall be subjected to random vibration tests in the three axes. Additional vibroacoustic tests at subsystem/instrument and component levels of assembly are performed in accordance with the environmental verification plan or as required for delivery.

LEVR-2215 Components shall be tested per Table 3-6.

LEVR-676 During the test, performance shall be monitored in accordance with the verification specification.

Table 3 - 6 Generalized Random Vibration Test Levels Components (ELV)

Frequency	ASD Level (g2/Hz) 22.7-kg (50-lb) or less		
(Hz)	Qualification	Acceptance	
20 20-50 50-800 800-2000 2000	0.026 +6 dB/oct 0.16 -6 dB/oct 0.026	0.013 +6 dB/oct 0.08 -6 dB/oct 0.013	
Overall	14.1 Grms	10.0 Grms	
The acceleration spectral density level may be reduced for components weighing more than 22.7-kg (50 lb) according to:			
	Weight in kg	Weight in lb	
dB reduction	= 10 log(W/22.7)	10 log(W/50)	
ASD(50-800 Hz)	= 0.16•(22.7/W)	0.16•(50/W)	for protoflight
ASD(50-800 Hz)	= 0.08•(22.7/W)	0.08•(50/W)	for acceptance

Where W = component weight.

The slopes shall be maintained at + and - 6dB/oct for components weighing up to 59-kg (130-lb). Above that weight, the slopes shall be adjusted to maintain an ASD level of 0.01 g2/Hz at 20 and 2000 Hz.

For components weighing over 182-kg (400-lb), the test specification will be maintained at the level for 182-kg (400 pounds).

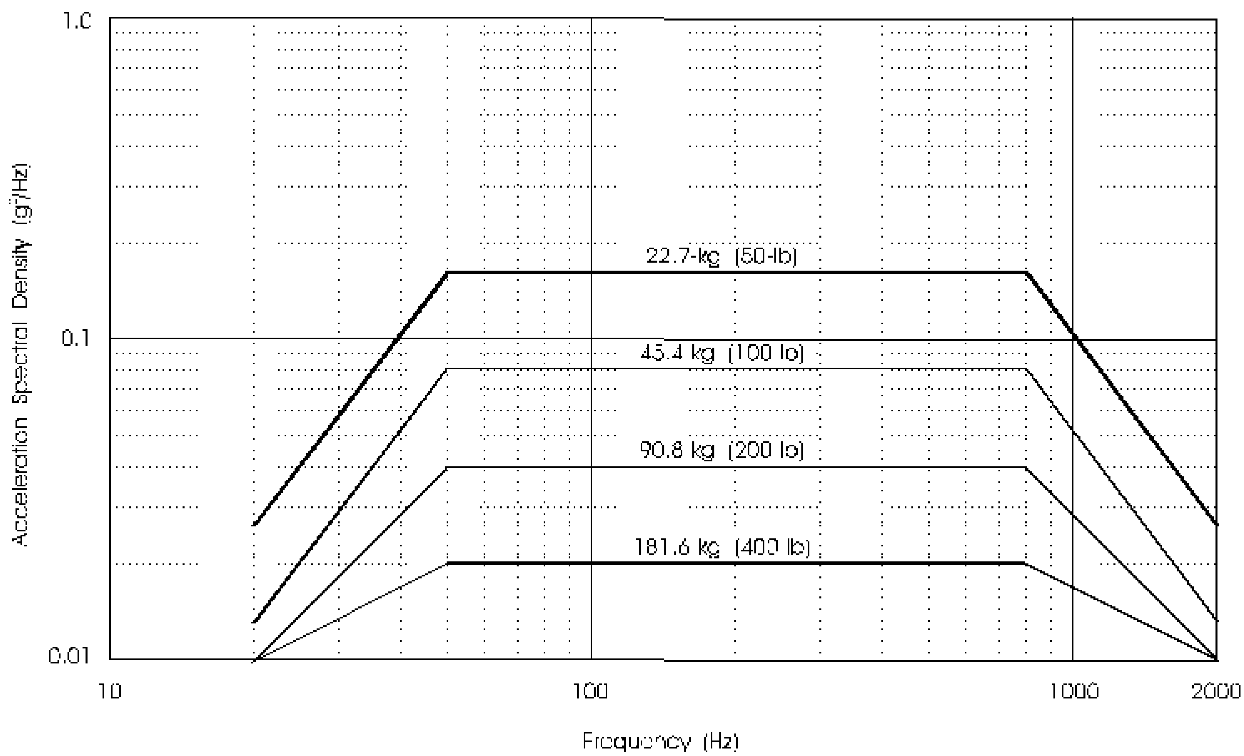


Table 3 - 7 Component Minimum Workmanship Random Vibration Test Levels

Frequency (Hz)	ASD Level (g2/Hz) 45.4-kg (100-lb) or less
20	0.01
20-80	+3 dB/oct
80-500	0.04
500-2000	-3 dB/oct
2000	0.01
Overall	6.8 grms

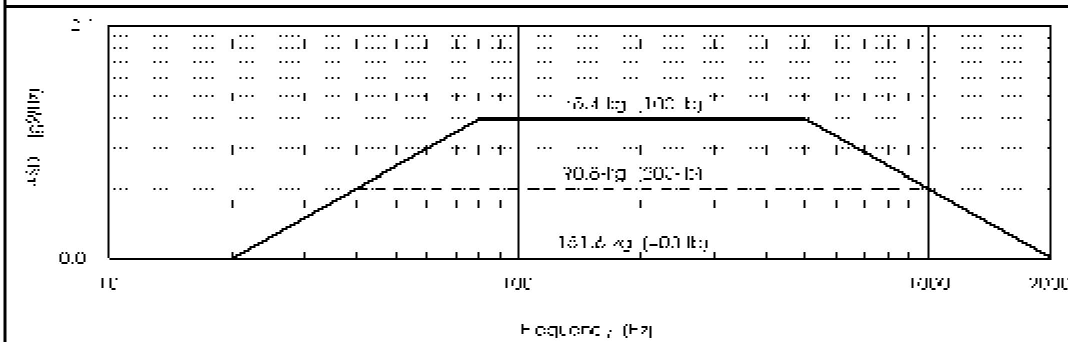
The plateau acceleration spectral density level (ASD) may be reduced for components weighing between 45.4 and 182 kg, or 100 and 400 pounds according to the component weight (W) up to a maximum of 6 dB as follows:

		Weight in kg	Weight in lb
dB reduction	=	10 log(W/45.4)	10 log(W/100)
ASD(plateau) level	=	0.04•(45.4/W)	0.04•(100/W)

The sloped portions of the spectrum shall be maintained at plus and minus 3 dB/oct. Therefore, the lower and upper break points, or frequencies at the ends of the plateau become:

FL	= 80 (45.4/W) [kg] = 80 (100/W) [lb]	FL = frequency break point low end of plateau
FH	= 500 (W/45.4) [kg] = 500 (W/100) [lb]	FH = frequency break point high end of plateau

The test spectrum shall not go below 0.01 g2/Hz. For components whose weight is greater than 182-kg or 400 pounds, the workmanship test spectrum is 0.01 g2/Hz from 20 to 2000 Hz with an overall level of 4.4 grms.



3.4.2.7 Retest of Reworked Hardware

In many cases it is necessary to make modifications to hardware after a unit has been through a complete mechanical verification program. For example, replacing a capacitor on a circuit board in a electronics box that has already been through protoflight vibration testing. For this type of reworked hardware, the amount of additional mechanical testing required depends on the amount of rework done and the amount of disassembly performed as part of the rework. The primary objective of post-rework testing is to ensure proper workmanship has been achieved in performing the rework and in reassembling the component.

LEVR-1977 As a minimum, the reworked component shall be subjected to a single axis workmanship random vibration test to the levels specified in Table 3-7.

LEVR-1978 The determination of axis shall be made based on the direction necessary to provide the highest excitation of the reworked area. Testing may be required in more than one axis if a single axis test cannot be shown to adequately test all of the reworked area. If the amount of rework or disassembly required is significant, then 3-axis testing to acceptance levels may be necessary if they are higher than workmanship levels as deemed necessary by the MRB.

3.4.3 Sinusoidal Sweep Vibration Qualification

Sine sweep vibration tests are performed to qualify prototype/protoflight hardware for the low-frequency transient or sustained sine environments when they are present in flight, and to provide a workmanship test for all observatory hardware which is exposed to such environments and normally does not respond significantly to the vibroacoustic environment at frequencies below 50 Hz, such as wiring harnesses and stowed appendages.

LEVR-684 Each observatory shall be assessed for such applicable sine test requirements. Qualification for these environments requires swept sine vibration tests at the observatory, instrument, and component levels of assembly.

LEVR-685 For a observatory level test, the observatory shall be in a configuration representative of the time the stress occurs during flight, with appropriate flight type hardware used for attachment.

LEVR-686 Observatories shall be subjected to swept sine vibration testing to simulate low-frequency sine transient vibration and sustained, pogo-like sine vibration (if expected) induced by the launch vehicle. Qualification for these environments requires swept sine vibration tests at the observatory, instrument, and component levels of assembly.

It is understood that, for some observatory projects, the sinusoidal sweep vibration qualification program may have to be modified. For example, for very large ELV observatories (with very large masses, extreme lengths, or large c.g. offsets) it may be impracticable because of test facility limitations to perform a swept sine vibration test at the observatory level of assembly. In that case, testing at the highest level of assembly practicable is required.

LEVR-688 For the sinusoidal vibration environment, limit levels shall be used which are consistent with the minimum probability level given in Table 3-5. The qualification level is then defined as the limit level times 1.25.

LEVR-1980 The test input frequency range shall be limited to the band from 5 to 50 Hz. The fatigue life considerations of Section 3.4.2.1 apply where hardware reliability goals demand the demonstration of a specific hardware lifetime.

The sine sweep environmental test program will be included in the environmental verification plan and environmental verification specification.

3.4.3.1 ELV Observatory Sine Sweep Vibration Tests

LEVR-690 At the observatory level of assembly, prototype/protoflight hardware shall be subjected to a sine sweep vibration design qualification test to verify its ability to survive the low-frequency launch environment.

The test also provides a workmanship vibration test for observatory hardware which normally does not respond significantly to the vibroacoustic environment at frequencies below 50 Hz, but can experience significant responses from the ELV low-frequency sine transient vibration and any sustained, pogo-like sine vibration. Guidelines for developing mission-specific test levels are given in Section 3.4.3.1.b.

LEVR-1982 a. Vibration Test Requirements - Protoflight hardware shall be subjected to a sine sweep vibration test to verify flightworthiness and workmanship.

LEVR-1983 The test shall represent the qualification level (flight limit level times 1.25).

The test is intended for all ELV observatories (spacecraft) except those with very large masses, extreme lengths and/or large c.g. offsets, where it is impracticable because of test facility limitations.

LEVR-693 If the sine sweep vibration test is not performed at the observatory level of assembly, it shall be performed at the next lowest practicable level of assembly.

LEVR-694 The observatory in its launch configuration shall be attached to a vibration fixture by use of a flight-type launch-vehicle attach fitting (adapter) and attachment (separation system) hardware.

LEVR-1984 Sine sweep vibration shall be applied at the base of the adapter in each of three orthogonal axes, one of which is parallel to the thrust axis.

LEVR-1985 The test sweep rate shall be 4 octaves per minute to simulate the flight sine transient vibration; lower sweep rates shall be used in the appropriate frequency bands as required to match the duration and rate of change of frequency of any flight sustained, pogo-like vibration.

LEVR-1986 The test shall be performed by sweeping the applied vibration once through the 5 to 50 Hz frequency range in each test axis.

LEVR-1987 Mission-specific sine sweep test levels shall be developed for each ELV payload. Guidelines for developing the test levels are given in 3.4.3.1.b.

LEVR-695 Prior to the observatory test, a survey of the test fixture/exciter combination shall be performed to evaluate the fixture dynamics, the proposed choice of control accelerometer locations, and the control strategy.

LEVR-1988 The evaluation shall include consideration of cross-axis responses.

LEVR-1989 If a mechanical test model of the observatory is available it shall be included in the survey to evaluate the need for limiting (or notching).

LEVR-696 During the protoflight hardware sine sweep vibration test to the specified test levels, loads induced in the observatory and/or adapter structure while sweeping through resonance shall not exceed 1.25 times flight limit loads.

LEVR-1990 If required, test levels shall be reduced ("notched") at critical frequencies. Acceleration responses of specific critical items may also be limited to 1.25 times flight limit levels if required to preclude unrealistic levels, provided that the observatory model used for the coupled loads analysis has sufficient detail and that the specific responses are recovered (using the acceleration transformation matrix) from the coupled loads analysis results.

LEVR-1991 The minimum controlled input test level shall be 0.1 g to facilitate shaker control.

LEVR-697 A low-level sine sweep shall be performed prior to the protoflight--level sine sweep test in each test axis.

LEVR-1992 Data from the low-level sweeps measured at locations identified by a notching analysis shall be examined to determine if there are any significant test response deviations from analytical predictions.

LEVR-1993 The data utilized shall include cross-axis response levels.

LEVR-1994 Based on the results of the low-level tests, the predetermined notch levels shall be verified prior to the protoflight-level test.

LEVR-1995 The flight limit loads used for notching analysis shall be based on the final verification cycle coupled loads analysis (including a test-verified observatory model).

b. Mission-Specific Test Level Development - Sinusoidal vibration test levels required to simulate the flight environment for ELV observatory vary with the observatory attach fitting (adapter) and observatory configuration, including overall weight and length, mass and stiffness distributions, and axial-to-lateral coupling.

LEVR-1996 It therefore is impracticable to specify generalized sine sweep vibration test levels applicable to all observatory, and mission-specific test levels shall be developed for each ELV observatory based on the coupled loads analysis.

Alternatively, observatory interface dynamic response data from flight measurements or coupled loads analysis for similar observatory may be used for the base drive input in conjunction with a suitable uncertainty factor approved by the GSFC LDCM project office.

LEVR-699 Prior to the availability of coupled loads analysis results, preliminary sine test levels shall be estimated by using the ELV "user manual" sine vibration levels for observatory base drive analysis, with notching levels based on net loads equivalent to the user manual c.g. load factor loads.

LEVR-700 c. Performance - Before and after each vibration test, the observatory shall be examined and functionally tested.

LEVR-1997 During the tests, performance shall be monitored in accordance with the verification specification.

3.4.3.2 ELV Observatory Subsystem (including Instruments) and Component Sine Sweep Vibration Tests

LEVR-702 As a screen for design and workmanship defects, these items (per Table 3-4) shall be subjected to a sine sweep vibration test along each of three mutually perpendicular axes.

LEVR-1998 For the sinusoidal vibration environment, limit levels shall be defined to be consistent with the minimum probability level of Table 3-5. The protoflight qualification level is then defined as the limit level times 1.25.

The test input frequency range will be limited to the band from 5 to 50 Hz. The fatigue life considerations of Section 3.4.2.1 apply where hardware reliability goals demand the demonstration of a specific hardware lifetime.

LEVR-2000 a. Vibration Test Requirements - The test item in its launch configuration shall be attached to the test equipment by a rigid fixture.

LEVR-2001 The mounting shall simulate, insofar as practicable, the actual mounting of the item in the observatory, with particular attention given to duplicating the mounting interface.

LEVR-2002 All connections to the item (connectors and harnesses, plumbing, etc.) shall be simulated with lengths at least to the first tie-down point.

LEVR-2003 In mating the test item to the fixture, a flight-type mounting (including vibration isolators or kinematic mounts, if part of the design) and fasteners, including torque levels and locking features, shall be used.

LEVR-2004 Normally-sealed items shall be pressurized during test to their prelaunch pressure.

LEVR-704 In cases where significant changes in strength, stiffness, or applied load result from variations in internal and external pressure during the launch phase, a special test shall be considered to cover those effects.

LEVR-705 Sine sweep vibration shall be applied at the base of the test item in each of three mutually perpendicular axes.

LEVR-2005 The test sweep rate shall be consistent with the observatory-level sweep rate, i.e., 4 octaves per minute to simulate the flight sine transient vibration, and (if required) lower sweep rates in the appropriate frequency bands to match the duration and rate of change of frequency of any flight sustained, pogo-like vibration.

LEVR-2006 The test shall be performed by sweeping the applied vibration once through the 5 to 50 Hz frequency range in each test axis. This frequency range takes precedence over that presented in the Atlas V Payload Planners Guide.

Observatory subsystems, including instrument, and component levels depend on the type of structure to which the item is attached, the local attachment stiffness, the distance from the observatory separation plane, and the item's mass, size, and stiffness.

LEVR-2007 It therefore is impracticable to specify generalized sine sweep vibration test levels applicable to all subsystems/instruments, and components, and mission-specific test levels shall be developed for each observatory. Guidelines for developing the specific test levels are given in Section 3.4.3.2.b.

LEVR-707 Prior to the test, a survey of the test fixture/exciter combination shall be performed to evaluate the fixture dynamics, the proposed choice of control accelerometer locations, and the control strategy.

LEVR-2008 The evaluation shall include consideration of cross-axis responses.

LEVR-2009 If a mechanical test or engineering model of the test article is available it shall be included in the survey.

LEVR-708 A low-level sine sweep shall be performed prior to the protoflight level sine sweep test in each test axis (with particular emphasis on cross-axis responses) to verify the control strategy and check test fixture dynamics.

LEVR-709 b. Mission Specific Test Level Development - The mission-specific sine sweep test levels for observatory subsystems/components shall be based on test data from structural model observatory sine sweep tests if available.

LEVR-2011 If not available, the test levels shall be based on an envelope of two sets of responses:

LEVR-710 (1)Coupled loads analysis dynamic responses shall be utilized if acceleration-response time histories are available at the test article location for all significant flight event loading conditions.

LEVR-2012 Equivalent sine sweep vibration test input levels shall be developed using shock response spectra (SRS) techniques for transient flight events. It should be noted that, in developing equivalent test input levels by dividing the SRS by Q (where Q=Cc/2c), assumption of a lower Q is more conservative. In the absence of test data, typical assumed values of Q for subsystems/components are from 10 to 20. For pogo-like flight events, the use of SRS techniques is not generally required.

LEVR-711 (2)Subsystem/component responses from a base drive analysis of the observatory and adapter, using the observatory sine sweep test levels as input (in three axes), shall be included in the test level envelope.

LEVR-2013 The base drive responses of the test article shall be corrected for effects of the observatory test sweep rates if the sweep rates are not included in the base drive analysis input.

LEVR-2014 Subsystem/component test sweep rates shall match observatory test sweep rates.

LEVR-712 If the facility's shaker can only apply translational (but not rotational) accelerations, then for test articles with predicted large rotational responses, the test levels shall be increased based on analysis to assure adequate response levels.

Also, for certain cases such as large items mounted on kinematic mount flexures, which experience both significant rotations and translations, it may be necessary to use the test article c.g. rotational and translational acceleration response levels as not-to-exceed test levels in conjunction with appropriate notching or limiting.

LEVR-714 c. Performance - Before and after test exposure, the test item shall be examined and functionally tested.

LEVR-2016 During the test, performance shall be monitored in accordance with the verification specification.

3.4.3.3 Acceptance Requirements

LEVR-716 Sine sweep vibration testing for the acceptance of previously qualified hardware shall be conducted at the flight limit levels using the same sweep rates as used for protoflight hardware.

3.4.4 Mechanical Shock Qualification

LEVR-718 Both self-induced and externally induced shocks shall be considered in defining the mechanical shock environment.

3.4.4.1 Subsystem Mechanical Shock Tests

LEVR-720 All subsystems, including instruments, shall be qualified for the mechanical shock environment.

LEVR-721 a. Self-Induced Shock - The subsystem shall be exposed to self-induced shocks by actuation of all shock-producing devices.

Self-induced shocks occur principally when pyrotechnic and pneumatic devices are actuated to release booms, solar arrays, protective covers, etc. Also the impact on deployable devices as they reach their operational position at the "end of travel" is a likely source of significant shock.

LEVR-2018 When hardware contains such devices, it shall be exposed to each shock source twice to account for the scatter associated with the actuation of the same device.

LEVR-2019 The internal observatory flight firing circuits shall be used to trigger the event rather than external test firing circuits. With the GSFC

LDCM project's approval, this testing may be deferred to the observatory level of assembly.

LEVR-722 b. Externally Induced Shock - Mechanical shocks originating from other subsystems, observatories, or launch vehicle operations shall be assessed.

LEVR-2021 When the most severe shock is externally induced, a suitable simulation of that shock shall be applied at the subsystem interface.

LEVR-2022 When it is feasible to apply this shock with a controllable shock-generating device, the qualification level shall be 1.4 times the maximum expected value at the subsystem interface, applied once in each of the three axes.

LEVR-2023 A pulse or complex transient (whose positive and negative shock spectrum matches the desired spectrum within +25% and -10%) with a duration of 10ms or less shall be applied to the test item interface once along each of the three axes.

LEVR-2266 Equalization of the shock spectrum shall be performed at a maximum resolution of one-third octave.

LEVR-2024 The fraction of critical damping (c/cc) used in the shock spectral analysis of the test pulse shall equal the fraction of critical damping used in the analysis of the data from which the test specification was derived.

LEVR-2025 In the absence of a strong rationale for some other value, a fraction of critical damping equivalent to a Q of 10 shall be used for shock spectrum analysis.

If the GSFC LDCM project approves that it is not feasible to apply the shock with a controllable shock-generating device (e.g. the subsystem is too large for the device), the test may be conducted at the observatory level by actuating the devices in the observatory that produce the shocks external to the subsystem to be tested.

LEVR-2026 The shock-producing device(s) shall be actuated a minimum of two times for this test.

c. Component Shock Testing - The decision to perform component shock testing to is typically based on an assessment of the shock susceptibility of the component and the expected shock levels. If there is low potential for damage due to the shock environment, then shock testing may be deferred with GSFC LDCM project approval to the observatory level of assembly. For standard electronics, the potential for damage due to shock can be quantified based on Figure 3-1 If the flight shock environment as shown on an SRS plot (Q=10) is enveloped by the curve shown in Figure 3-1, then the shock environment can be considered benign and there is low risk in deferring the shock test.

LEVR-2027 For the case in which the shock levels are above the curve, then component level shock testing shall be considered. The curve provided in Figure 3-1 is intended as a guideline for determining whether component level shock testing should be performed. Each component should be evaluated individually to determine its susceptibility for damage due to the predicted shock environment.

It will not be necessary to conduct a test for externally induced shocks if it can be demonstrated that the shock spectrum of the self-induced environment is greater at all frequencies than the envelope of the spectra created by the external events at all locations within the subsystem.

LEVR-727 d. Test Setup - During test, the test item shall be in the electrical and mechanical operational modes appropriate to the phase of mission operations when the shock will occur.

LEVR-728 e. Performance - Before and after the mechanical shock test, the test item shall be examined and functionally tested.

LEVR-2030 During the tests, performance shall be monitored in accordance with the verification specification.

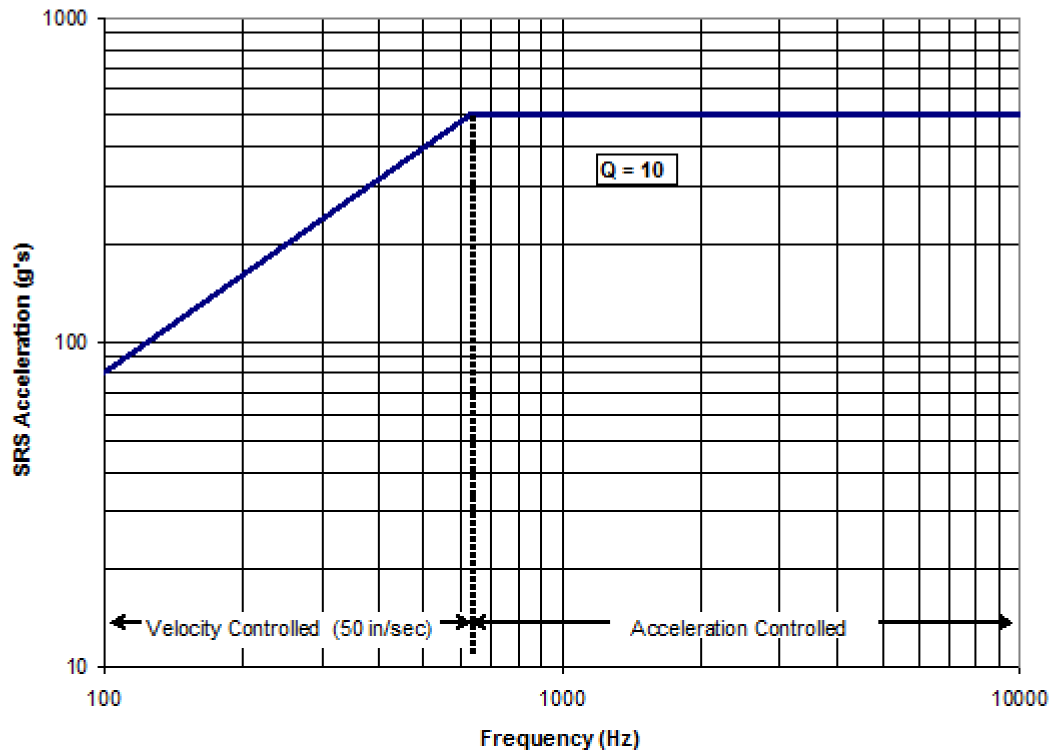


Figure 3 - 1 Shock Response Spectrum (SRS) for assessing Component Test Requirements

3.4.4.2 Observatory Mechanical Shock Tests

LEVR-732 The observatory shall be qualified for the shock induced during payload separation (when applicable) and for any other externally induced shocks whose levels are not enveloped at the payload interface by the separation shock level.

The payload separation shock is usually higher than other launch vehicle-induced shocks; however that is not always the case. For instance, the shocks induced at the payload interface during inertial upper stage (IUS) actuation can be greater. In addition, mechanical shock testing may be performed at the observatory level of assembly to satisfy the subsystem mechanical shock requirements of Section 3.4.4.1.

LEVR-733 a. Other Observatory Shocks - If launch vehicle induced shocks or shocks from other sources are not enveloped by the separation test, the observatory shall be subjected to a test designed to simulate the greater environment.

LEVR-2032 If a controllable source is used, the qualification level shall be 1.4 x the maximum expected level at the payload interface applied once in each of the three axes. The tolerance band on the simulated level of response is +25% and -10%.

LEVR-734 The analysis shall be performed with a fraction of critical damping corresponding to a Q of 10 or, if other than 10, with the Q for which the shock being simulated was analyzed.

The subsystem mechanical shock requirements may be satisfied by testing at the observatory level of assembly as described above.

LEVR-736 b. Performance - Before and after the mechanical shock test, the test item shall be examined and functionally tested.

LEVR-2035 During the tests, performance shall be monitored in accordance with the verification test plan and specification.

3.4.4.3 Acceptance Requirements

Elimination of mechanical shock tests for acceptance of previously qualified hardware will be considered for approval by the GSFC LDCM project office.

Testing will be given careful consideration evaluating mission reliability goals, shock severity, hardware susceptibility, design changes from the previous qualification configuration including proximity to the shock source, and previous history.

3.4.5 Mechanical Function Verification

LEVR-740 A kinematic analysis of all observatory mechanical operations shall be performed (a) to ensure that each mechanism can perform satisfactorily and has adequate margins under worst-case conditions, (b) to ensure that satisfactory clearances exist for both the stowed and operational configurations as well as during any mechanical operation, and (c) to ensure that all mechanical elements are capable of withstanding the worst-case loads that may be encountered.

LEVR-2037 Observatory qualification tests shall be performed to demonstrate that the installation of each mechanical device is correct and that no problems exist that will prevent proper operation of the mechanism during mission life.

LEVR-741 Subsystem qualification tests shall be performed for each mechanical operation at nominal-, low-, and high-energy levels.

LEVR-2038 To establish that functioning is proper for normal operations, the nominal test shall be conducted under the most probable conditions expected during normal flight.

LEVR-2039 A high-energy test and a low-energy test shall also be conducted to prove positive margins of strength and function.

LEVR-2040 The levels of these tests shall demonstrate margins beyond the nominal conditions by considering adverse interaction of potential extremes of parameters such as temperature, friction, spring forces, stiffness of electrical cabling or thermal insulation, and, when applicable, spin rate.

LEVR-2041 Parameters to be varied during the high- and low-energy tests shall include, to the maximum extent practicable, all those that could substantively affect the operation of the mechanism as determined by the results of analytic predictions or development tests.

LEVR-2042 As a minimum, successful operation at temperature extremes 10 deg C beyond the range of expected flight temperatures shall be demonstrated.

LEVR-742 Lubricants susceptible to adverse affects from humidity, such as MoS2 shall be given protection where storage or non-operating environments can be expected to cause adverse effects.

Testing will be performed in a humidity controlled environment.

3.4.5.1 Life Testing

LEVR-744 A life test program shall be implemented for mechanical elements that move repetitively as part of their normal function and whose useful life shall be determined in order to verify their adequacy for the mission.

The verification plan and the verification specification will address the life test program, identifying the mechanical elements that require such testing, describing the test hardware that will be used, and the test methods that will be employed.

Life test planning will be initiated as early as possible in the development phase, and presented at each program system/peer review to allow enough time to complete the life test and thoroughly disassemble and inspect the mechanism, while retaining enough time to react to any anomalous findings.

Once the plan is finalized, an independent peer review of the procedure and criteria will be held.

LEVR-746 The life test mechanism shall be fabricated and assembled such that it is as nearly identical as possible to the actual flight mechanism, with special attention to the development and implementation of detailed assembly procedures and certification logs. It is preferable that the life test mechanism actually be a flight spare or Qualification Unit.

LEVR-2046 The life test mechanism shall replicate the flight interfaces, especially the perhaps less obvious details, such as the method of mounting of the mechanism, the preloading and/or clamping of bearings or other tribological interfaces, the routing of harnesses, the attachment of thermal blankets, and any other items that could have an influence on the performance of the mechanism.

LEVR-747 Prior to the start of life testing, mechanisms shall be subjected to the same ground testing environments, both structural and thermal, that are anticipated for the flight units (protoflight or acceptance levels, as appropriate). These environments may have a significant influence on the life test performance of the mechanism.

LEVR-748 The life test mechanism test setup shall simulate flight conditions including the effects on lubrication and external loads. For example, gravity may cause lubrication to puddle at the bottom of a bearing race or run out of the bearing. In some cases, the effects of gravity may cause abnormally high loads on the mechanism.

LEVR-749 The thermal environment of the mechanism during the life test shall be representative of the on-orbit environment.

LEVR-2047 If expected bulk temperature changes are significant, then the life test shall include a number of transitions from the hot on-orbit predictions to the cold on-orbit predictions, and vice versa.

LEVR-2048 Depending on the thermal design, significant temperature gradients may be developed which could have a profound influence on the life of the mechanism and, therefore, shall be factored into the thermal profile for the life test.

LEVR-750 Consideration shall be given to including in the life test the effects of vacuum on the performance of the mechanism with particular attention to its effects on the thermal environment (i.e., no convective heat transfer) and potentially adverse effects on lubrication and materials.

Life testing in a gaseous nitrogen environment as an inexpensive alternative to a long duration vacuum test, for example, may have a completely unexpected or unanticipated affect on lubricant tribology.

LEVR-751 Life testing of electrically powered devices shall be conducted with nominal supply voltage.

The selection of the proper instrumentation for the life test is very important.

LEVR-2049 Physical parameters that are an indication of the health of the mechanism shall be closely monitored and trended during the life test. These parameters may include in-rush and steady-state currents, electrical opens or shorts, threshold voltages, temperatures (both steady-state and rate of change), torques, angular or linear positions, vibration, times of actuation and open/closed loop system responses.

LEVR-753 The life test shall be designed to "fail safe" in the event of any failure of the test setup, ground support equipment, or test article. There may be a severe impact to the life test results if it is necessary to stop a life test to replace or repair ground support equipment.

LEVR-2050 Uninterruptible power supplies shall be used when required for autonomous shutdown without damage to the test article or loss of test data.

LEVR-2051 Redundant sensors shall be provided for all critical test data.

LEVR-2052 If used, the vacuum pumping station shall be designed to maintain the integrity of the vacuum in the event of a sudden loss of power.

LEVR-2053 Any autonomous data capture shall include a time stamp to help diagnose the conditions present prior to a test shutdown.

LEVR-754 The test spectrum for the life test shall represent the required mission life for the flight mechanism, including both ground and on-orbit mechanism operations.

In order to reduce test time and cost, the test spectrum will be simplified as much as possible while retaining an appropriate balance between realism and conservatism.

LEVR-1956 It shall include, if applicable, a representative range of velocities, number of direction reversals, and number of dead times or stop/start sequences between movements.

LEVR-1957 Direction reversals and stop/start operations could have a significant effect on lubrication life, internal stresses, and, ultimately, the long term performance of the mechanism and therefore shall be given priority in the development of the life test plan.

LEVR-1958 Similarly, system dynamics effects due to inertial loads shall be considered in development of the plan and implemented where appropriate, such as in applications where normal operation includes multiple start / stop or acceleration / deceleration maneuvers.

LEVR-755 The minimum requirement for demonstrated life test operation without failure shall be 2.0 times the mission life. However, due to the uncertainties and simplifications inherent in the test, a marginally successful test requires post-test inspections and characterizations to extrapolate the remaining useful life.

Because this can be difficult and uncertain, even higher margins will be considered if time permits in order to establish greater confidence due to the limited number of life test units that are typically available.

LEVR-1960 Pre- and post-life test baseline performance tests shall be conducted with clear requirements established for determining minimum acceptable performance at end-of-life.

When it is necessary to accelerate the life test in order to achieve the required life demonstration in the time available, caution will be exercised in increasing the speed or duty cycle of the mechanism.

Mechanisms may survive a life test at a certain speed or duty cycle, but fail if the speed is increased or decreased, or if the duty cycle is increased significantly. There are three lubrication regimes to consider when considering whether to accelerate a life test, "boundary lubrication", "mixed lubrication", and "full elastohydrodynamic (EHD) lubrication".

For boundary and mixed lubrication regimes, the most likely failure mechanisms will be wear and lubricant breakdown, not fatigue.

Unfortunately failure by wear is not an exact science; therefore, life test acceleration by increasing speed will be considered with caution.

LEVR-1962 A mechanism that normally operates in these two regimes shall never be accelerated in a life test to a level where the lubrication system moves into the EHD regime for the test. Acceleration of a life test for systems in boundary or mixed lubrication regimes may be considered if it can be shown by analysis or test that the mechanism rotor oscillations for the accelerated operation are similar to that during normal operation.

LEVR-1963 For example, in a step motor, it shall be shown that the rotor oscillations damp out to less than 10% of the peak overshoot amplitude prior to initiating the next accelerated step.

LEVR-1964 Rationale for acceleration shall be presented in the initial test plan.

LEVR-758 In the EHD regime, no appreciable wear shall occur and the failure mechanism shall be material fatigue rather than wear.

LEVR-1965 Therefore, while life test acceleration by increasing speed may be considered, other speed limiting factors shall also be considered.

LEVR-1966 For example, at the speed at which EHD lubrication is attained, one shall be concerned with bearing retainer imbalances which may produce excessive wear of the retainer, which would in turn produce contaminants which could degrade the performance of the bearings.

LEVR-1967 Additionally, thermal issues may arise related to increased power dissipation for higher speed operation, like increased bearing gradients, which shall be thoroughly evaluated.

If there are significant downtimes associated with the operation of an intermittent mechanism, the life test can be accelerated by reducing this downtime, as long as this does not adversely affect temperatures and leaves enough "settle time" for the lubricant film to "squish out" of the contact area to simulate a full stop condition.

LEVR-760 For all these reasons, the life test shall be run as nearly as possible using the on-orbit speeds and duty cycles. In some cases it may not be possible to accelerate the test at all.

Upon completion of the life test, it is imperative that careful disassembly procedures are followed and that the proper level of inspections are conducted. Successful tests will not have any anomalous conditions such as abnormal wear, significant lubrication breakdown, or excessive debris generation. These or other anomalous conditions may be cause for declaring the life test a failure despite completion of the required test spectrum.

LEVR-1968 A thorough investigation of all moving components and wear surfaces shall be conducted. This may include physical dimensional inspection of components, high magnification photography, lubricant analysis, Scanning Electron Microscope (SEM) analysis, etc.

LEVR-1969 Photographic documentation of the life test article shall be made from incoming component inspection/acceptance through full assembly to act as a baseline for comparison.

LEVR-762 For those mechanical elements that move repetitively as part of their normal function determined not to require life testing, the rationale for eliminating the test along with the analyses to verify the validity of the rationale shall be provided for approval by the GSFC LDCM project office. Reference Section 3.2.3.

3.4.5.2 Demonstration

Compliance with the mechanical function qualification requirements will be demonstrated by a combination of analysis and test. The functional qualification aspects of the demonstration are discussed below.

The life test demonstrations will be described in detail in an approved verification plan and verification specification.

LEVR-765 a. Analysis - An analysis of the observatory shall be conducted to ensure that satisfactory clearances exist for both the stowed and operational configurations.

LEVR-1972 Therefore, in conjunction with the flight-loads analysis, an assessment of the relative displacements of the various observatory elements with respect to other observatories and various elements of the ELV payload fairing shall be made for potentially critical events.

LEVR-1973 During analysis, the following effects shall be considered: an adverse build-up of tolerances, thermal distortions, and mechanical misalignments, as well as the effects of static and dynamic displacements induced by particular mission events.

LEVR-766 In addition, a kinematic analysis of all deployment and retraction sequences shall be conducted to ensure that each mechanism has adequate torque margin under worst-case friction conditions and is capable of withstanding the worst-case loads that may be encountered during unlatching, deployment, retraction, relatching, or ejection sequences.

LEVR-1974 In addition, the analysis shall verify that sufficient clearance exists during the motion of the mechanisms to avoid any interference.

LEVR-768 The selection of lubricant for use in critical moving mechanical assemblies shall be based upon development tests of the lubricant that demonstrate its ability to provide adequate lubrication under all specified operating conditions over the design lifetime.

LEVR-1975 Since life testing cannot typically provide proof of lubricant availability based on evaporation over the required life of the mechanism, an analysis shall be performed to show that there is an adequate amount of lubricant in the system (not including degradation) for the duration of the mechanism life with a margin greater than 10.

Lubricant availability analyses based on degradation rates will be proven through life testing (see Section 3.4.5.1).

The design of each ball bearing installation will be substantiated by analysis and either development tests or previous usage.

The materials, stresses, stiffness, fatigue life, preload, and possible binding under normal, as well as the most severe combined loading conditions, and other expected environmental conditions will be included in the analysis.

Alignments, fits, tolerances, thermal and load induced distortions, and other conditions will be considered in determining preload variations.

LEVR-2219 Bearing fatigue life calculations shall be based on a survival probability of 99.95 percent when subjected to maximum time varying loads.

LEVR-2220 For noncritical applications or deployables, if nonquiet running is acceptable, and the bearing material is 52100 Carbon Steel or 440C Stainless Steel, the mean Hertzian contact stress shall not exceed 2760 megapascals (400,000 psi) when subjected to the yield load.

LEVR-2221 During operation, the mean Hertzian contact stress shall not exceed 2310 megapascals (335,000 psi).

LEVR-2222 For materials other than these, a hertzian contact stress allowable shall be determined based on manufacturer recommendations with appropriate reduction factors for aerospace applications and approved by the GSFC LDCM project office.

LEVR-2223 In addition to the requirements stated above, bearing applications requiring quiet operation or low torque ripple shall be designed so that the bearing race and ball stress levels are below the levels that would cause unacceptable permanent deformation during application of ascent loads.

LEVR-2224 Where bearing deformation is required to carry a portion or all of the vehicle ascent loads, and where smoothness of operation is required on orbit, the mean Hertzian stress levels of the bearing steel (52100 and 440C) shall not exceed 2310 megapascals (335,000 psi) when subjected to the yield load.

LEVR-2225 The upper and lower extremes of the contact ellipses shall be contained by the raceways.

LEVR-2226 The stress and shoulder height requirements of the races shall be analyzed for both nominal and off-nominal bearing tolerances.

LEVR-2227 During operation, the mean Hertzian contact stress shall not exceed 830 megapascals (120,000 psi) over the worst case environment.

LEVR-2228 For materials other than 52100 carbon steel and 440C stainless steel, a hertzian contact stress allowable shall be determined based on manufacturer recommendations with appropriate reduction factors for aerospace applications and approved by the GSFC LDCM project office.

LEVR-770 b. Observatory Testing - A series of mechanical function tests shall be performed on the observatory to demonstrate "freedom-of-motion" of all appendages and other mechanical devices whose operation may be affected by the process of integrating them with the observatory.

LEVR-2229 The tests shall demonstrate proper release, motion, and lock-in of each device, as appropriate, in order to ensure that no tolerance buildup, assembly error, or other problem will prevent proper operation of the mechanism during mission life.

Unless the design of the device dictates otherwise, mechanical testing may be conducted in ambient laboratory conditions. The testing will be performed at an appropriate time in the observatory environmental test sequence.

LEVR-2231 If any device is subsequently removed from the observatory, the testing shall be repeated after final reinstallation of the device.

LEVR-771 c. Subsystem Testing - Each subsystem, and instrument, that performs a mechanical operation shall undergo functional qualification testing. With the GSFC LDCM project office approval, such testing may be performed at the observatory level of assembly. The test is conducted after any other testing that may affect mechanical operation. The purpose is to confirm proper performance and to ensure that no degradation has occurred during the previous tests.

During the test, the electrical and mechanical components of the subsystem will be in the appropriate operational mode.

The subsystem will also be exposed to pertinent environmental effects that may occur before and during mechanical operation.

The verification specification will stipulate the tests to be conducted, the necessary environmental conditioning, and the range of required operations.

(1) Information Requirements

The following information will be provided to define the series of functional qualification tests:

- o A description of mission requirements, how the mechanism is intended to operate, and when operation occurs during the mission;
- o The required range of acceptable operation and criteria for acceptable performance;
- o The anticipated variation of all pertinent flight conditions or other parameters that may affect performance.

(2) Test Levels and Margins

For each mechanical operation, such as appendage deployment, tests at nominal-, low-, and high-energy levels will be performed.

One test will be conducted at the most probable level that will occur during a normal mission (the nominal level). The test establishes that functioning is proper for nominal operating conditions and baseline measurements will be obtained for subsequent tests.

Other tests will be conducted to prove positive margins of strength and function, including torque or force ratio, a high-energy test and a low-energy test.

The levels of these tests will demonstrate margins beyond the nominal operational limits over the full range of motion at the worst case environments and the operating parameters of the system (rate, acceleration, etc.).

The margins will take into account all the uncertainties of operation, strength, and test.

If a margin test cannot be conducted at the subsystem level due to its size and complexity these verification tests will be performed at the highest level of assembly possible and the results combined to provide subsystem performance.

LEVR-781 While in an appropriate functional configuration the hardware shall be subjected to events such as separation, appendage deployment, retromotor ejection, or other mechanical operations, such as spin-up or despin that are associated with the particular mission.

LEVR-782 Gravity compensation shall be provided to the extent necessary to achieve the test objectives.

LEVR-2239 The uncompensated gravity effects shall be less than 10 percent of the operational loads.

Uncompensated gravity of 0.1 g is usually achievable and acceptable for separation tests and for comparative measurements of appendage positioning if the direction is correct, i.e., the net shear and moment imposed during measurements acts in the same direction as it would in flight, thereby causing any mechanism with backlash to assume the correct extreme positions. For testing of certain mechanical functions, however, more stringent uncompensated gravity constraints may be required.

LEVR-2234 When appropriate, the subsystem shall be preconditioned before test or conditioned during test to pertinent environmental levels. This can include vibration, high- and low-temperature cycling, pressure-time profiles, transportation and handling.

(3) Performance

LEVR-784 Before and after test, the subsystem shall be examined and electrically tested. During the test, the subsystem performance shall be monitored in accordance with the verification specification.

(4) Component Characterization and Testing

LEVR-786 For applications where motor performance is critical to mission success, the design shall be based on a complete motor characterization at the minimum and maximum voltages from the spacecraft bus and motor driver and shall include as a minimum: rotor inertia, friction and damping parameters, back-EMF constant or torque constant, time constant, torque characteristics, speed versus torque curves, thermal dissipation, temperature effects, and where applicable, analysis to demonstrate adequate margin against back driving.

LEVR-787 For applications where the motor is integrated into a higher assembly, the motor characterization shall be performed at the motor level prior to integration.

LEVR-788 After initial functional testing, a run-in test shall be performed on each moving mechanical assembly before it is subjected to further acceptance testing, unless it can be shown that this procedure would be detrimental to performance and would result in reduced reliability. The primary purpose of the run-in test is to detect material and workmanship defects that occur early in the component life. Another purpose is to wear-in parts of the moving mechanical assembly so that they perform in a consistent and controlled manner. Satisfactory wear-in may be manifested by a reduction in running friction to a consistent low level.

LEVR-1864 The run-in test shall be conducted for a minimum of 50 hours except for items where the number of cycles of operation, rather than hours of operation, is a more appropriate measure of the capability to perform in a consistent and controlled manner.

LEVR-1865 For these units, the run-in test shall be for at least 15 cycles or 5% of the total expected life cycles, whichever is greater.

LEVR-1866 The run-in test conditions shall be representative of the operational loads, speed, and environment; however, operation of the assembly at ambient conditions may be conducted if the test objectives can be met and the ambient environment will not degrade reliability or cause unacceptable changes to occur within the equipment such as generation of excessive debris.

LEVR-1867 During the run-in test, sufficient periodic measurements shall be made to indicate what conditions may be changing with time and what wear rate characteristics exist.

Test procedures, test time, and criteria for performance adequacy will be in accordance with an approved test plan.

LEVR-1869 All gear trains using solid or liquid lubricants shall be inspected and cleaned following the run-in test.

3.4.5.3 Torque/Force Margin

LEVR-790 The torque or force margin shall be demonstrated by test to be sufficiently large to guarantee system-performance under worst-case conditions throughout its life by fully accommodating the uncertainty in the resisting forces or torques and in the source of energy.

The Torque Margin (TM) is a measure of the degree to which the torque available to accomplish a mechanical function exceeds the torque required. The torque margin is generally the ratio of the driving or available torques times an appropriate Factor of Safety (FS) minus one.

LEVR-2408 The torque margin requirement defined in Table below applies to all mechanical functions, those driven by motors as well as springs, etc. at beginning of life (BOL) only; end of life (EOL) mechanism performance is determined by life testing as discussed in Section 3.4.5.1, and/or by analysis; however, all torque increases due to life test results shall be included in the final TM calculation and verification.

LEVR-1871 Positive margin (>0) using the TM equation and FS stated herein shall be shown for worst case EOL predicted conditions and at the extreme operating parameters of the system (rate, acceleration, etc.).

For linear devices, the term "force" should replace "torque" throughout this section.

LEVR-792 For final design verification, the torque margin shall be verified by testing the qualification (or protoflight) unit both before and after exposure to qualification level environmental testing.

Table 3 - 8 Torque/Force Margins By Project Phase

Project Phase	Known Torque Factor of Safety (FS_k)	Variable Torque Factor of Safety (FS_v)
Preliminary Design Review	2.00	4.0
Critical Design Review	1.50	3.0
Acceptance / Qualification Test	1.50	2.0

LEVR-798 Along with system level test, available torque (T_{avail}) and resistive torque (T_r) under worst case conditions shall be determined, whenever possible, through component, system and subsystem level tests.

LEVR-2245 Torque ratios for gear driven systems shall be verified, using subsystem level results, on both sides of the geartrain.

LEVR-2246 The minimum available torque for these types of systems shall never be less than 1 in-oz at the motor.

LEVR-2247 Kick-off springs that do not operate over the entire range of the mechanical function shall be neglected when computing available torque over the full range. However, the use of kick-off spring forces in the Torque Margin calculation at the beginning of travel or initial separation is acceptable.

LEVR-2248 A Factor of Safety of at least 1.5 over inertial driven or known quantifiable resistive torques (that do not change over the operating life of the unit) shall be used in the final computing of torque margin as indicated in the table below.

LEVR-2249 FS requirements for parasitic forces dominated by a combination of variable items shall be determined based on the program phase as indicated in the table below. See Section 3.2.3 for criteria on Qualification of Hardware by Similarity.

LEVR-2250 The final test verified Torque Margin shall be greater than zero (>0) based on the FS listed for the Acceptance / Qualification Test phase.

LEVR-812 For those cases where high confidence does not exist in determination of worst case load or driving capability, a Safety Factor higher than that stated above may be appropriate. Factors of Safety shall be based on a confidence level determined from the quantity and fidelity of heritage and program test data.

At the program PDR, a detailed plan to determine torque margin will be presented.

By CDR, it will be demonstrated (see LEVR section 3.4.5.2) that the detail design complies with the program requirements as outlined in this section.

LEVR-813 The required Factors of Safety shall be appropriately higher than given above if:

a The designs involve an unusually large degree of uncertainty in the characterization of resistive torques.

b The torque margin testing is not performed in the required environmental conditions or is not repeatable and has a large tolerance band.

c The torque margin testing is performed only at the component level.

It is important to note that this torque margin requirement relates to the verification phase of the hardware in question.

Conservative decisions will be made during the design phase to ensure adequate margins are realized.

It is recognized that under some unique circumstances these specified Factors of Safety might be detrimental (excessive) to the design of a system. Any exceptions to these requirements will be approved by the GSFC LDCM project office.

LEVR-818 The minimum available driving torque for the mechanism shall be determined based on the FS listed above.

The Torque Margin (TM) will be greater than zero.

LEVR-2327 The TM shall be calculated using the following formula:

$$TM = \{T_{avail} / (FS_k \, \Sigma T_{known} + FS_v \, \Sigma T_{variable})\} - 1$$

Where:

Driving Torques:

T_{avail} = Minimum Available Torque or Force generated by the mechanism at worst case environmental conditions at any time in its life. If motors are used in the system, T_{avail} is determined at the output of the motor, not including gear heads or gear trains at its output based on minimum supplied motor voltage. T_{avail} similarly applies to other actuators such as springs, pyrotechnics, solenoids, heat actuated devices, etc.

Resistive Torques:

ΣT_{known} = Sum of the fixed torques or forces that are known and quantifiable such as accelerated inertias ($T=I\alpha$) and not influenced by friction, temperature, life, etc. A constant Safety Factor is applied to the calculated torque.

$\Sigma T_{variable}$ = Sum of the torques or forces that may vary over environmental conditions and life such as static or dynamic friction, alignment effects, latching forces, wire harness loads, damper drag, variations in lubricant effectiveness, including degradation or depletion of lubricant over life, etc.

LEVR-1873 The torque margin on all flight units shall also be verified by testing when possible (without breaking the flight hardware configuration), both before and after exposure to acceptance level environmental testing.

LEVR-1874 All torque margin testing shall be performed at the highest possible level of assembly, throughout the mechanism's range of travel, under worst-case predicted EOL environmental conditions, representing the worst-case combination of maximum and/or minimum predicted (not qualification) temperatures, gradients, positions, acceleration/ deceleration of load, rate, voltage, vacuum, etc.

As the deviation from these worst case conditions increases, a higher Factor of Safety than that stated below will be used.

3.4.5.4 Acceptance Requirements

LEVR-827 For the acceptance testing of previously qualified hardware, the observatory and subsystem tests described in Sections 3.4.5.2.b and 3.4.5.2.c shall be performed, except that the subsystem tests need be performed only at the nominal energy level.

LEVR-1876 Adequate torque ratio (margin) shall be demonstrated for all flight mechanisms.

3.4.6 Pressure Profile Qualification

The need for a pressure profile test will be assessed for all subsystems.

LEVR-1877 A qualification test shall be required if analysis does not indicate a positive margin at loads equal to twice those induced by the maximum expected pressure differential during launch. If a test is required, the limit pressure profile is determined by the predicted pressure-time profile for the nominal trajectory of the particular mission.

LEVR-830 Because pressure-induced loads vary with the square of the rate of change, the qualification pressure profile shall be determined by multiplying the predicted pressure rate of change by a factor of 1.12 (the square root of 1.25, the required qualification factor on load).

3.4.6.1 Demonstration

LEVR-832 The hardware shall be qualified for the pressure profile environment by analysis and/or test.

LEVR-1878 An analysis shall be performed to estimate the pressure differential induced by the nominal launch and reentry trajectories, as appropriate, across elements susceptible to such loading (e.g. thermal blankets, contamination enclosures, and housings of components). If analysis does not indicate a positive margin at loads equal to twice those induced by the maximum expected pressure differential, testing is required. Although testing at the subsystem level is usually appropriate, testing at the observatory level of assembly may be performed based on approval of the GSFC LDCM project office.

LEVR-833 a. Test Profile - The flight pressure profile shall be determined by the analytically predicted pressure-time history inside the payload fairing for the nominal launch trajectory for the mission (including reentry if appropriate).

LEVR-1880 Because pressure-induced loads vary as the square of the pressure rate, the pressure profile for qualification shall be determined by increasing the predicted flight rate by a factor of 1.12 (square root of 1.25, the required test factor for loads).

LEVR-1881 The pressure profile shall be applied once.

b. Facility Considerations - Loads induced by the changing pressure environment are affected both by the pressure change rate and the venting area.

LEVR-1882 Because the exact times of occurrence of the maximum pressure differential is not always coincident with the maximum rate of change, the pumping capacity of the facility shall be capable of matching the desired pressure profile within ± 5% at all times.

LEVR-835 c. Test Setup - During the test, the subsystem shall be in the electrical and mechanical operational modes that are appropriate for the event being simulated.

LEVR-836 d. Performance - Before and after the pressure profile test, the subsystem shall be examined and functionally tested.

LEVR-1885 During the tests, performance shall be monitored in accordance with the verification specification.

3.4.6.2 Acceptance Requirements

Pressure profile test requirements do not apply for the acceptance testing of previously qualified hardware.

3.4.7 Mass Properties Verification

Hardware mass property requirements are mission-dependent and, therefore, are determined on a case-by-case basis.

LEVR-1886 The mass properties program shall include an analytic assessment of the observatory's ability to comply with the mission requirements, supplemented as necessary by measurement.

3.4.7.1 Demonstration

LEVR-842 The mass properties of the observatory shall be verified by analysis and/or measurement.

When mass properties are to be derived by analysis, it may be necessary to make some direct measurements of subsystems and components in order to attain the accuracy required for the mission and to ensure that analytical determination of observatory mass properties is feasible.

Determination of the various subsystem properties will be sufficiently accurate that, when combined analytically to derive the mass properties of the observatory, the uncertainties will be small enough to ensure compliance with observatory mass property requirements.

LEVR-1888 If analytic determination of observatory mass properties is not feasible, then direct measurement shall be performed.

LEVR-1889 The following mass properties shall be determined:

a. Weight, Center of Gravity, and Moment of Inertia:

Weight, center of gravity, and moment of inertia are used in predicting observatory performance during launch, insertion into orbit, and orbital operations.

LEVR-2270 The parameters shall be determined for all configurations to evaluate flight performance in accordance with mission requirements.

b. Balance

(1) Procedure for Direct Measurement - Balance may be achieved analytically, if necessary, with the aid of direct measurements. Direct measurements shall include performing an initial balance before beginning the environmental verification program and a final balance after completing the program.

One purpose of the initial balance is to ensure the feasibility of attaining the stipulated final balance. A residual unbalance of not more than four times the final balance requirement is the recommended objective of initial balance. Another reason for doing the initial balance prior to environmental exposures is to evaluate the method of attaching the balance weights and the effect of the weights on the operation of the hardware during the environmental exposures.

LEVR-1890 Final balance shall be performed after completion of all environmental testing in order to properly adjust for all changes to weight distribution made during the verification program such as hardware replacement or redesign.

LEVR-847 (2)Maintaining Balance - Changes to the hardware that may affect weight distribution shall be minimized and fully documented after completion of final balance.

LEVR-1891 The effects of such changes (including any disassembly, hardware substitution, etc.) on the residual unbalance of the hardware shall be assessed. The assessment involves sufficient dimensional measurement and mass properties determination to permit a judgment as to whether the configuration changes have caused the residual unbalance to exceed requirements.

LEVR-1892 Additional balance operations shall be performed as necessary to achieve the required static and dynamic balance.

(3) Correcting Unbalance - To correct unbalance, weights may be attached, removed, or relocated.

LEVR-1893 The amount of residual unbalance for all appropriate configurations shall be performed and recorded for comparison with the balance requirements of the verification specification. Balance operations include interface, fit, and alignment checks as necessary to ensure that alignment of geometric axes is comparable with requirements.

Balancing operations include measurement and tabulation of weights and mass center locations (referenced to hardware coordinates) of appendages, motors, and other elements that may not be assembled for balancing.

LEVR-850 The data shall be analyzed to determine unbalance contributed by such elements to each appropriate configuration.

LEVR-851 The facilities and procedures for balancing will be fully defined at the time of initial balance, and sufficient exploratory balancing operations shall be performed to provide confidence that the final balance can be accomplished satisfactorily and expeditiously.

3.4.7.2 Acceptance Requirements

The mass property requirements cited above apply to all flight hardware.

3.5 ELECTROMAGNETIC COMPATIBILITY (EMC) REQUIREMENTS

Requirements for electromagnetic compatibility are as follows:

a. The observatory (spacecraft) and its elements will not generate electromagnetic interference that could adversely affect its own subsystems and components or the safety and operation of the launch vehicle and launch site.

b. The observatory and its subsystems and components will not be susceptible to emissions that could adversely affect their safety and performance.

This applies whether the emissions are self-generated or emanate from other sources, or whether they are intentional or unintentional.

3.5.1 Requirements Summary

The EMC test requirements herein when performed as a set are intended to provide an adequate measure of hardware quality and workmanship.

The tests will be performed to fixed levels which are intended to envelope those that may be expected during a typical mission and allow for some degradation of the hardware during the mission.

The levels will be tailored to meet mission specific requirements, such as, the enveloping of launch vehicle and launch site environments, or the inclusion of very sensitive detectors or instruments on the observatory.

Thus tailored, the requirements envelope the environments usually encountered during integration and ground testing. However, because some sensors and devices are particularly sensitive to the low-level EMI ground environment, special work-around procedures may have to be developed to meet individual component needs.

3.5.1.1 The Range of Requirements

Table 3-9 is a matrix of EMC tests that apply to hardware intended for the LDCM that is launched by an Atlas V, Model 401.

LEVR-1898 Tests shall be performed at the component, instrument, and observatory levels of assembly per Table 3-9 EMC Requirements per Level of Assembly.

LEVR-1899 The Contractor shall select the requirements that fit the characteristics of the mission and hardware, e.g. a transmitter would require a different group of EMC tests than a receiver. Symbols in the hardware levels of assembly columns will assist in the selection of an appropriate EMC test program.

LEVR-863 Once the EMC test program is selected, all flight hardware shall be tested. The EMC test program is meant to uncover workmanship defects and unit-to-unit variations in electromagnetic characteristics, as well as design flaws. The qualification and flight acceptance EMC programs are the same. Performance of both will provide a margin of hardware reliability.

Table 3 - 9 EMC Requirements per Level of Assembly

Type	Observatory Test	Paragraph Number	Component	Instrument/ Subsystem	Observatory
CE01	DC power leads	3.5.2.1.a	R	R	-
CE03	Power Leads	3.5.2.1.a	R	R	-
CMN	Power Leads	3.5.2.1.b	R	R	-
CE06	Obs. Transmitter/receivers	3.5.2.1.c	R	-	R

RE02	E-fields	3.5.2.2.a, b & c	R	R	R*
RE02	Observatory transmitters	3.5.2.2.c	R	-	-
RE03	Spurious (transmitter antenna)	3.5.2.2.d	-	-	-
CS01	Power line	3.5.3.1.a	R	R	-
CS02	Power line	3.5.3.1.a	R	R	-
CS03	Intermodulation products	3.5.3.1.b	R	-	-
CS04	Signal rejection	3.5.3.1.c	R	-	-
CS05	Cross modulation	3.5.3.1.d	R	-	-
CS06	Power line transients	3.5.3.1.e	R	R	-
RS03	E-field (general compatibility)	3.5.3.2	R	R	R

CE: Conducted Emission

CS: Conducted Susceptibility

R: Required test to ensure reliable operation of observatory, and to help ensure compatibility with the launch vehicle and launch site

RE: Radiated Emission

RS: Radiated Susceptibility

* : Shall meet any unique requirements of launch vehicle and launch site for transmitters that are on during launch

The EMC tests are intended to verify that:

(1) The hardware will operate properly if subjected to conducted or radiated emissions from other sources that could occur during launch or in orbit (susceptibility tests).

(2) The hardware does not generate either conducted or radiated signals that could hinder the operation of other systems (emissions tests).

3.5.1.2 Testing at Lower Levels of Assembly

Testing will be performed at the component, instrument/subsystem, and observatory levels of assembly. Testing at lower levels of assembly has many advantages: it uncovers problems early in the program when they are less costly to correct and less disruptive to the program schedule; it uncovers problems that cannot be detected or traced at higher levels of assembly;

it characterizes box-to-box EMI performance, providing a baseline that can be used to alert the project to potential problems at higher levels of assembly; and it aids in troubleshooting.

3.5.1.3 Basis of the Tests

A description of the individual EMC tests listed in Table 3-9, including their requirement limits and test procedures, are provided in paragraphs 3.5.2 through 3.5.3.3. Most of the tests are based on the requirements of MIL-STD-461C and MIL-STD-462 as amended by Notice 1.

For ELV launch, the EMI/EMC test levels are modified based on the Atlas V, Model 401 launch vehicle and the VAFB, CA launch site environments.

The ELV launch site requirements will be established during coordination between the Contractor, GSFC LDCM project office, and the NASA/KSC Launch Vehicle Program Office All modifications shall be approved by the GSFC LDCM Project Office.

3.5.1.4 Safety and Controls

During prelaunch and prerelease checkout, sensitive detectors and hardware may require special procedures to protect them from the damage of high-level radiated emissions.

LEVR-1901 If special procedures are needed to protect sensitive hardware from damage, they shall be applied during EMC testing.

LEVR-885 Live electro-explosive devices (EEDs) used to initiate such observatory functions as boom and antenna deployment shall be replaced by inert EEDs.

LEVR-1902 When replacement of EEDs is not possible, special safety precautions shall be taken to ensure the safety of the observatory and its operating personnel.

LEVR-886 Spurious signals that lie above specified testing limits shall be evaluated to determine if they pose a threat to the observatory.

LEVR-2251 Spurious signals shall be eliminated if possible to protect observatory and instruments from the possibility of interference.

LEVR-2252 Retest shall be performed to verify that intended solutions are effective at the component or assembly level of the initial deficiency.

3.5.2 Emission Requirements

The following paragraphs on emission tests will be used to implement the emission requirements of Table 3-9.

3.5.2.1 Conducted Emission Limits

Conducted emission limits and requirements on power leads, as well as on antenna terminals, will be applied to component level hardware as defined below. The requirements do not apply to secondary power leads to subunits within the level of assembly under test unless they are specifically included in a hardware specification.

LEVR-890 a. Conducted emissions on power, and power-return leads shall be limited to the levels specified in Figure 3-2.

LEVR-891 Testing shall be in accordance with MIL-STD-461C and MIL-STD-462, test numbers CE01 (30 Hz to 20 kHz) and CE03 (20 kHz to 50 MHz, as applicable, with limits as shown in Figure 3-2.

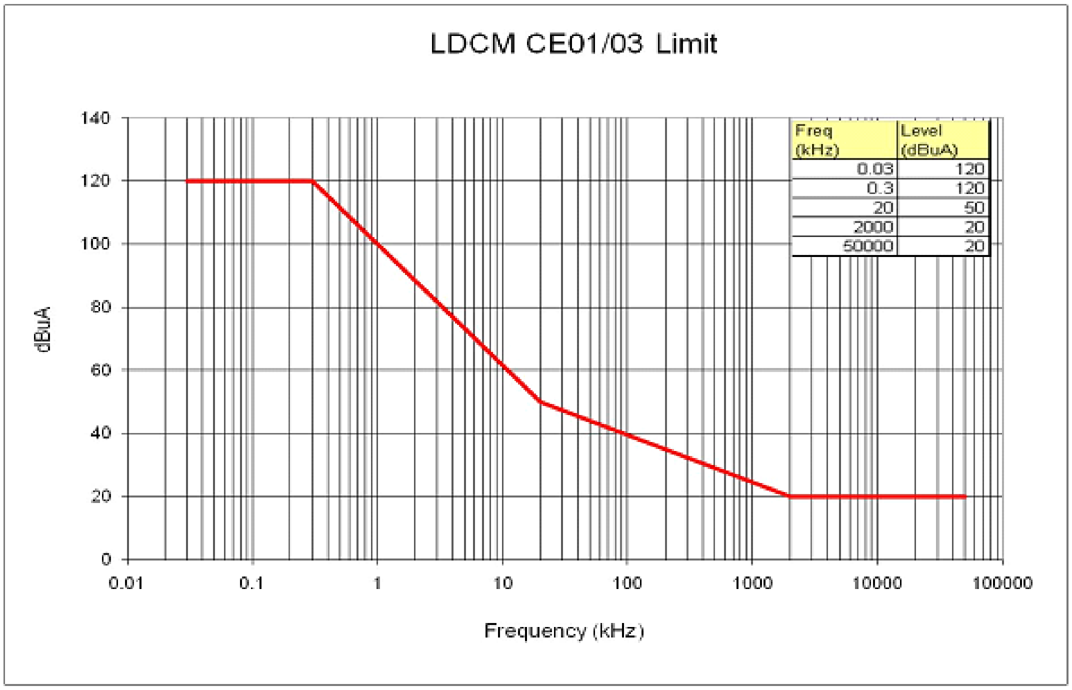


Figure 3 - 2 Conducted Emission Limits on Power Lines

LEVR-892 b. A Conducted Emissions (CE) test to control Common Mode Noise (CMN) shall be required at the subsystem/component level as shown in Figure 3-3.

LEVR-1917 The CMN frequency domain current test shall be performed on all non-passive components which receive or generate observatory primary power. The CMN test procedure is the same as narrowband CE01 and CE03 except that the current probe is placed around both the supply and return primary wires together.

The purpose of the test is to limit CMN emissions that flow through the observatory structure and flight harness which result in the generation of undesirable electrical currents, and electro-magnetic fields at the integrated system level.

LEVR-894 Specific CMN requirements shall be determined carefully from observatory hardware designs or mission scenario. An observatory that has analog or low level signal interfaces, low level detectors, and instruments that measure electromagnetic fields may be particularly sensitive to CMN. If mission requirements do not place stricter control on CMN, the limits of Figure 3-3 are required.

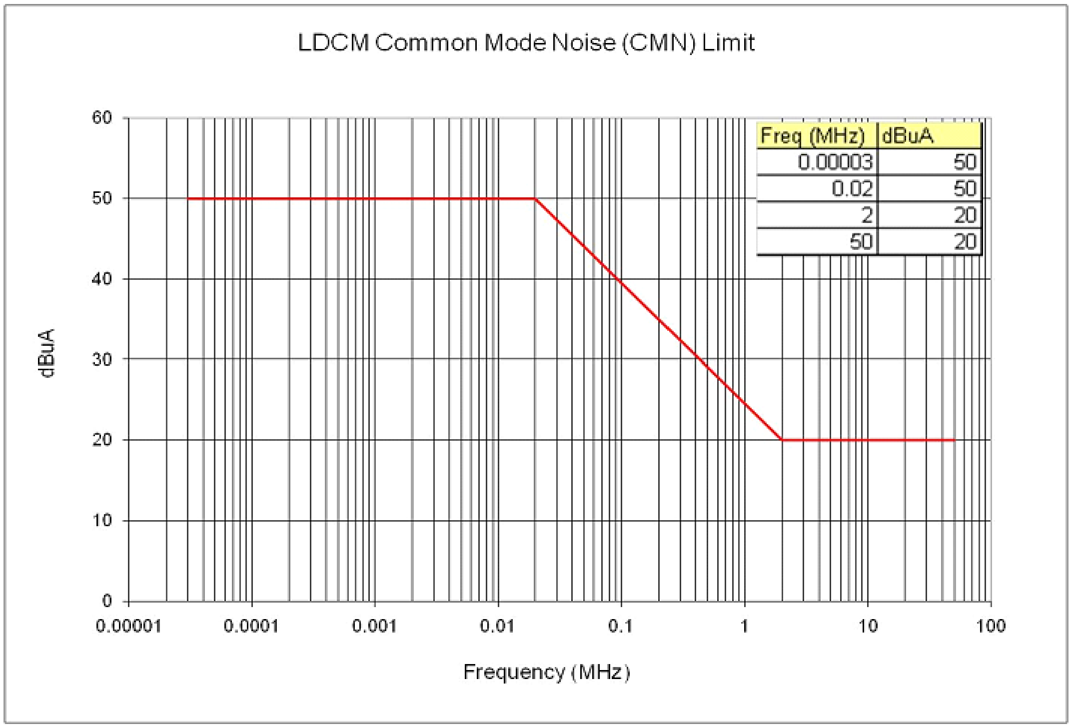


Figure 3 - 3 Common Mode Conducted Emission Limits on Primary Power Lines

The CMN test procedure is the same as narrowband CE01/03 except that the current probe is placed around both the plus and return primary wires together.

LEVR-899 c. Conducted emissions on the antenna terminals of observatory receivers, and transmitters in key-up modes shall not exceed 34 dB uV for narrowband emissions.

LEVR-900 Harmonics (greater than the third) and all other spurious emissions from transmitters in the key-down mode shall have peak powers 80 dB down from the power at the fundamental.

LEVR-1921 Power at the second and third harmonics shall be suppressed by {50 +

10*Log P (Where P = Peak Power in watts at the fundamental) dB}, or 80 dB, whichever requires less suppression.

LEVR-901 Testing shall be in accordance with MIL-STD-462, test number CE06. The test is conducted on receivers and transmitters before they are integrated with their antenna systems. Refer to MIL-STD-461C and MIL-STD-462 for additional details concerning this requirement.

3.5.2.2 Radiated Emission Limits

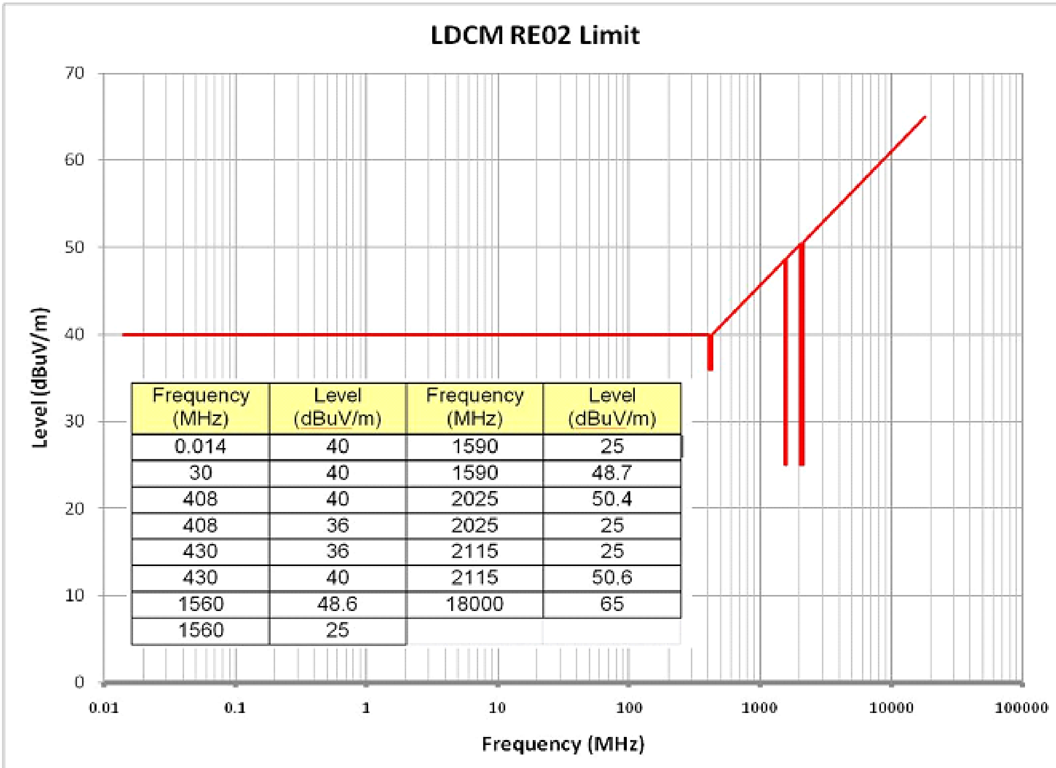
Radiated emission limits and requirements will be applied to observatory hardware as defined in Sections 3.5.2.2.a through 3.5.2.2.c below.

LEVR-2279 Additional tests or test conditions shall be performed as necessary, for example, if the observatory receives at frequencies other than S-band (1.77 - 2.3 GHz) and GPS at L1 at 1.57542 GHz.

LEVR-2280 If the free flyer observatories or their instruments contain sensitive magnetic field detectors or devices with high sensitivities to magnetic fields, more stringent limits on magnetic field emission may be required. Testing shall be in accordance with MIL-STD-462, test number RE04, with limits as defined above.

LEVR-2281 a. Unintentional radiated narrowband electric field levels produced by observatories shall not exceed the levels specified in Figure 3-4.

LEVR-2282 Testing shall be in accordance with MIL-STD-461C and MIL-STD-462, test number RE02, with the test frequency range and limits revised as defined in Figure 3-4.



Frequency (MHz)	Level (dBuV/m)	Frequency (MHz)	Level (dBuV/m)
0.014	40	1590	25
30	40	1590	48.7
408	40	2025	50.4
408	36	2025	25
430	36	2115	25
430	40	2115	50.6
1560	48.6	18000	65
1560	25		

Figure 3 - 4 Unintentional Payload/Subsystem Radiated Narrowband Electric Field Limits

LEVR-2285 b. Since allowable levels of radiation from observatory transmitter antenna systems depend on the launch vehicle and launch site, the unique requirements of the launch vehicle and launch site for transmitters that will be on during launch shall be met as defined in the LS-IRD.

LEVR-2286 c. Radiated spurious and harmonic emissions from observatory transmitter antennas shall have peak powers 80 dB down from the power at the fundamental (for harmonics greater than the third).

LEVR-2287 Power at the second and third harmonics shall be suppressed by {50 + 10*Log P (Where P = Peak Power in watts at the fundamental) dB}, or 80 dB whichever requires less suppression. These are the same limits as those for conducted spurious and harmonic emissions on antenna terminals in Section 3.5.2.1.

LEVR-2288 When the MIL-STD-462 test CE06 for conducted emissions on antenna terminals cannot be applied, test RE03 for radiated spurious and harmonic emissions shall be used as an alternative test. Refer to MIL-STD-461C and MIL-STD-462 for details.

3.5.2.3 Acceptance Requirements

LEVR-1824 The emission requirements of Section 3.5.2 shall apply to all previously qualified hardware.

3.5.3 Susceptibility Requirements

The following paragraphs on susceptibility tests provide requirements to implement the susceptibility requirements of Table 3-9.

3.5.3.1 Conducted Susceptibility Requirements

LEVR-917 The following conducted susceptibility design and test requirements shall be applied to power leads and to antenna terminals of observatory hardware:

LEVR-918 a. Conducted Susceptibility CS01 and CS02 (Power lines) - The tests shall be conducted using nominal spacecraft bus voltage over the frequency range of 30 Hz to 200 MHz in accordance with the limit requirements and test procedures of MIL-STD-461C and MIL-STD-462. See Figure 3-5 for CS01 test limits.

LEVR-2788 If degraded performance is observed, the signal level shall be decreased to determine the threshold of interference.

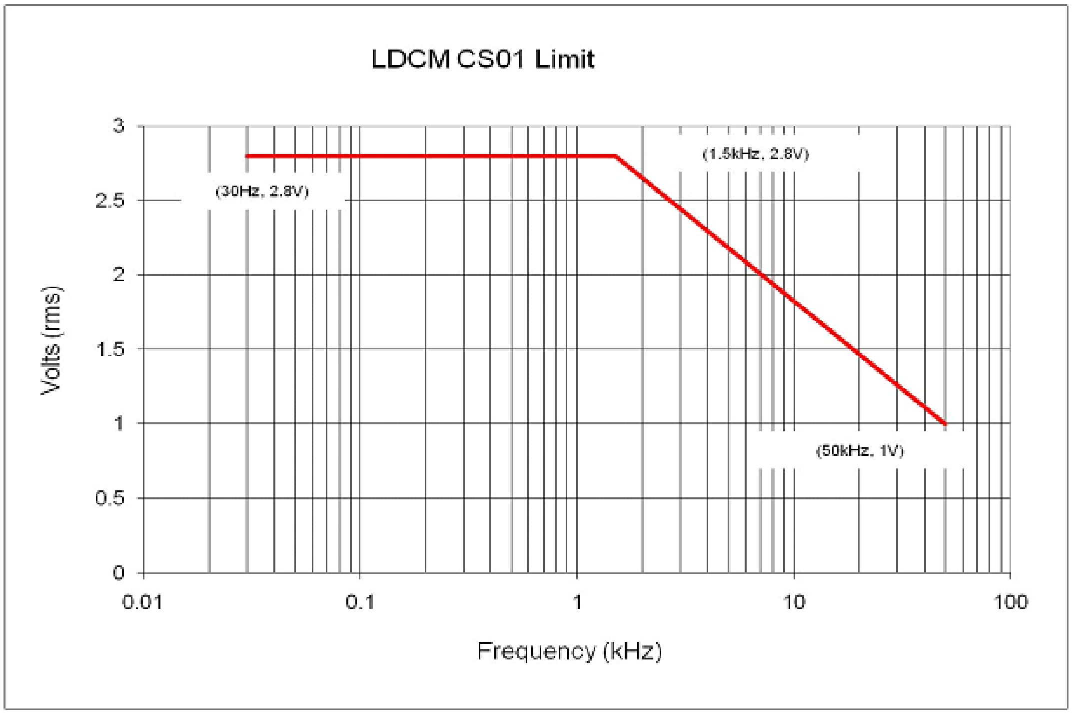


Figure 3 - 5 Power Line Conducted Susceptibility Limits

LEVR-2307 Conducted Susceptibility CS02 shall use a continuous wave signal over the specified frequency range, as defined in Figure 3-6, that is applied directly to the test hardware input terminal.

LEVR-2328 If the LDCM Project Office has not identified the appropriate modulation by time component design is complete or selection is complete, then the following guidelines for selecting an appropriate modulation shall apply:

Conducted Susceptibility CS02 is performed using 50% modulation with 1000-Hz tone.

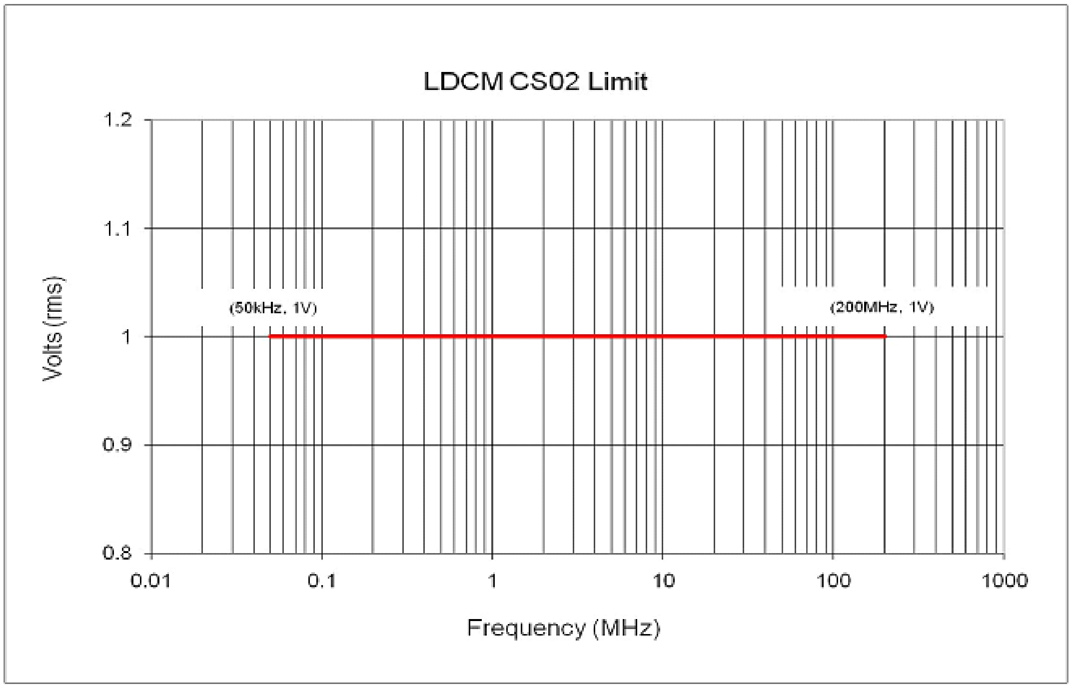


Figure 3 - 6 Power Line Conducted Susceptibility

LEVR-925 b. Conducted Susceptibility CS03 (Two-Signal Intermodulation) - This test, which determines the presence of intermodulation products from two signals, is conducted on receivers operating in the frequency range of 30 Hz to 18 GHz where this test is appropriate for that type of receiver. The item under test shall perform in accordance with the limit requirements and the test procedures of MIL-STD-461C and 462 except that the operational frequency range of equipment subject to this test is increased to 18 GHz and the highest frequency used in the test procedure is increased to 40 GHz.

LEVR-2409 The receiver under test shall perform in accordance with the limit requirements and the test procedures of MIL-STD-461C and MIL-STD-462 except that the operational frequency range of equipment subject to this test is increased to 18 GHz and the highest frequency used in the test procedure is increased to 40 GHz.

LEVR-926 c. Conducted Susceptibility CS04 (Rejection of Undesired Signals) - Receivers operating in the frequency range from 30

Hz to 18 GHz is tested for rejection of spurious signals where this test is appropriate for that type of receiver. The receiver under test shall perform in accordance with the limit requirements and the test procedures of MIL-STD-461C and MIL-STD-462 except that the frequency range is increased to 40 GHz.

LEVR-927 d. Conducted Susceptibility CS05 (Cross Modulation) - Receivers of amplitude-modulated RF signals operating in the frequency range of 30 Hz to 18 GHz is tested to determine the presence of products of cross modulation where this test is appropriate for that type of receiver. The item under test shall perform in accordance with the limit requirements and test procedures of MIL-STD-461C and MIL-STD-462 except that the operational frequency range of equipment subject to this test is increased to 18 GHz and the highest frequency used in the test procedure is increased to 40 GHz.

LEVR-928 e. Conducted Susceptibility CS06 (Powerline Transient) - A transient signal shall be applied to powerlines in accordance with the procedures of MIL-STD-461C and MIL-STD-462. Because the applied transient signal equals the powerline voltage, the resulting total voltage is twice the powerline level. The transient is applied for a duration of 5 minutes at a repetition rate of 60 pps. The test signal is applied to the input power leads of the observatory. See Figure 3-7 for a graphical representation of the applied voltage.

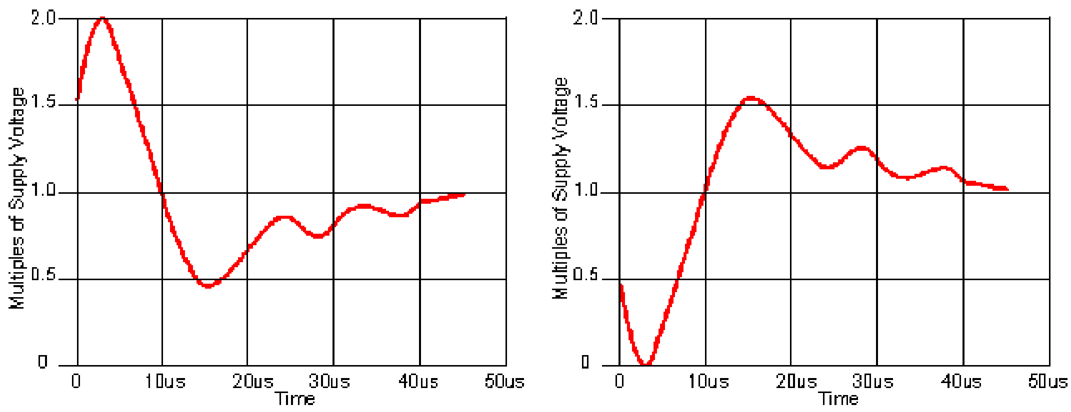


Figure 3 - 7 Transient Conducted Susceptibility on Observatory Power Lines

3.5.3.2 Radiated Susceptibility Requirements

The following tests will be applied to the observatory and instrument(s)/observatory subsystems. The tests are based on procedures and processes defined by MIL-STD-461C and MIL-STD-462, as supplemented. The launch and survival radiated susceptibility test levels over the frequency range of 14 kHz to 18 GHz are defined for the Atlas V, Model 401 using the C22 Launch Vehicle Adapter and the spacecraft transmitters at the VAFB, CA launch site.

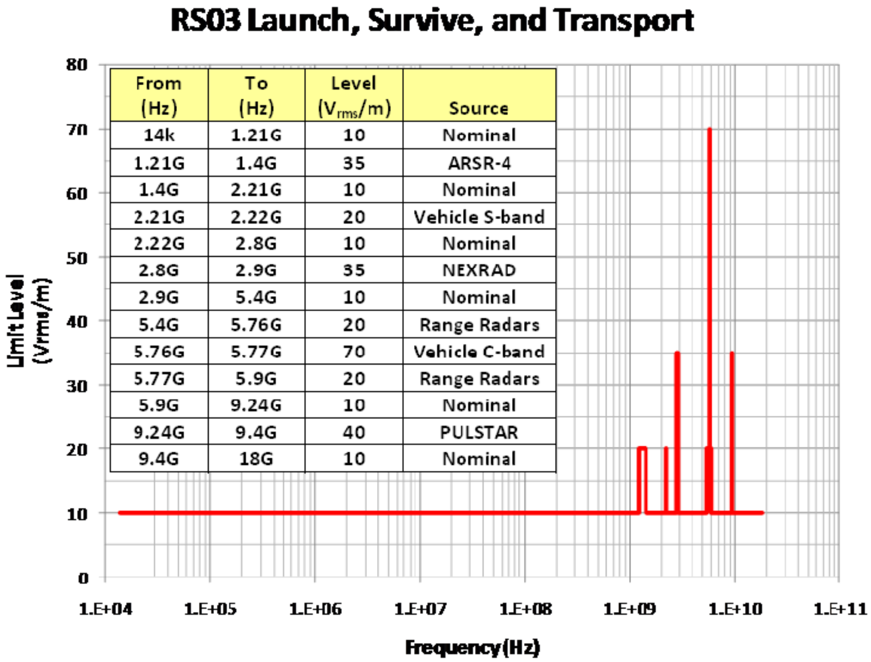
LEVR-931 Radiated Susceptibility Test RS03 (E-field) - The observatory, components, and instruments shall survive in a powered off state when exposed to external electromagnetic signals in accordance with the requirements and test methods of test RS03, using the appropriate modulation of the applied susceptibility signal and the test levels as defined in the Launch and Survival Environmental Limits, Figure 3-8.

LEVR-2274 Radiated Susceptibility Test RS03 (E-field) - The observatory, components, and instruments that are powered on at launch shall survive in a powered on state when exposed to external electromagnetic signals in accordance with the requirements and test methods of test RS03, using the appropriate modulation of the applied susceptibility signal and the test levels as defined in the RS03 Launch, Survive and Transport, Figure 3-8.

LEVR-2276 If the appropriate modulation has not been established by hardware design or mission scenario, then 50% amplitude modulation by a 1000 Hz square wave shall be used.

LEVR-2783 When performing additional testing at discrete frequencies of known emitters, the modulation characteristics of the emitter shall be simulated as closely as possible.

The test will demonstrate that the observatory survive the RF exposed to the specified levels.

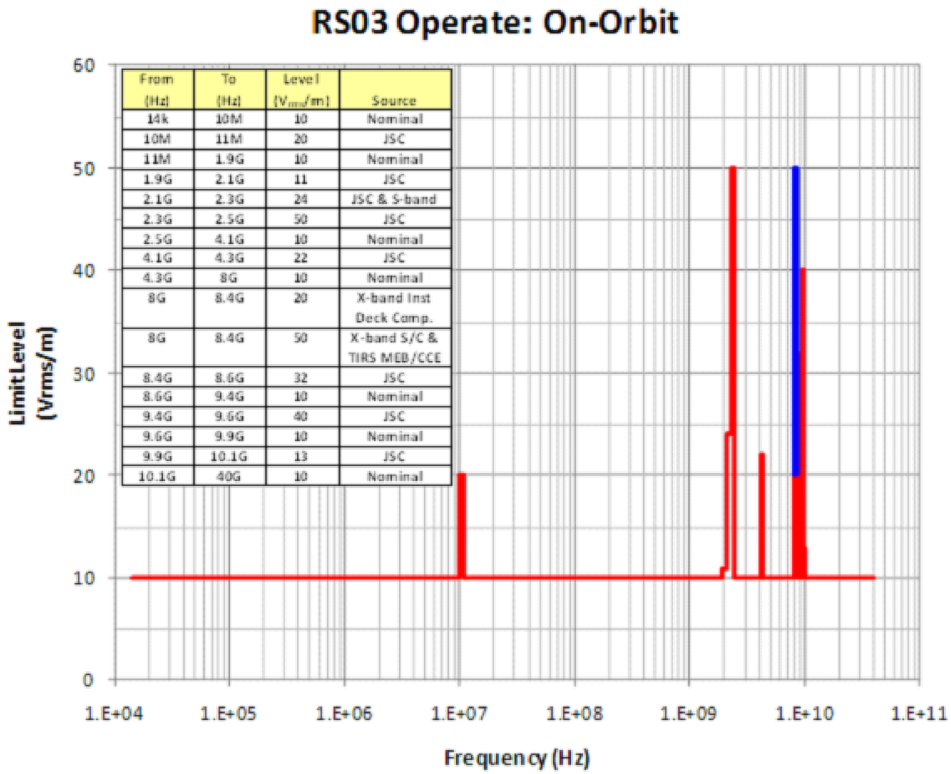


From (Hz)	To (Hz)	Level (V_{rms}/m)	Source
14k	1.21G	10	Nominal
1.21G	1.4G	35	ARSR-4
1.4G	2.21G	10	Nominal
2.21G	2.22G	20	Vehicle S-band
2.22G	2.8G	10	Nominal
2.8G	2.9G	35	NEXRAD
2.9G	5.4G	10	Nominal
5.4G	5.76G	20	Range Radars
5.76G	5.77G	70	Vehicle C-band
5.77G	5.9G	20	Range Radars
5.9G	9.24G	10	Nominal
9.24G	9.4G	40	PULSTAR
9.4G	18G	10	Nominal

Figure 3 - 8 RS03 Launch Site Survival Susceptibility Environment

LEVR-2277 The LDCM Observatory shall meet all mission requirements during continuous exposure to the radiated emissions defined in the RS03 Operate: On-Orbit contained in Figure 3-9. Use LEVR-2783 and LEVR-2276 for discrete frequency emitter testing.

The test will demonstrate that the observatory can meet their performance requirements while exposed to the specified levels.



From (Hz)	To (Hz)	Level (V_{rms}/m)	Source
14k	10M	10	Nominal
10M	11M	20	JSC
11M	1.9G	10	Nominal
1.9G	2.1G	11	JSC
2.1G	2.3G	24	JSC & S-band
2.3G	2.5G	50	JSC
2.5G	4.1G	10	Nominal
4.1G	4.3G	22	JSC
4.3G	8G	10	Nominal
8G	8.4G	20	X-band Inst Deck Comp.
8G	8.4G	50	X-band S/C & TIRS MEB/CCE
8.4G	8.6G	32	JSC
8.6G	9.4G	10	Nominal
9.4G	9.6G	40	JSC
9.6G	9.9G	10	Nominal
9.9G	10.1G	13	JSC
10.1G	40G	10	Nominal

Figure 3 - 9 On-orbit Operational Radiated Susceptibility Environment

3.5.3.3 Acceptance Requirements

The susceptibility test requirements of Section 3.5.3 shall apply to all previously qualified hardware.

3.6 VACUUM and THERMAL REQUIREMENTS

The vacuum and thermal requirements herein apply to ELV observatories. An appropriate set of tests and analyses will be selected to demonstrate the following observatory or observatory equipment capabilities.

LEVR-968 a. The observatory shall perform satisfactorily within the vacuum and thermal mission limits, including launch.

b. The thermal design and the thermal control system will maintain the affected hardware within the established mission thermal limits during planned mission phases, including survival/safe-hold, if applicable.

c. The quality of workmanship and materials of the hardware will be sufficient to pass thermal cycle test screening in vacuum, or under ambient pressure if the hardware can be shown by analyses to be insensitive to vacuum effects relative to temperature levels and temperature gradients.

3.6.1 Summary of Requirements

Table 3-10 summarizes the tests and analyses that collectively will fulfill the general requirements of Section 3.6. Tests noted in the table may require supporting analyses.

LEVR-974 The thermal cycle fatigue life test requirements of Section 3.4.2.1 shall also apply for hardware (e.g., solar arrays) susceptible to thermally induced mechanical fatigue.

The qualification and acceptance thermal-vacuum verification programs for passively controlled items are the same except that a 10° C temperature margin is added for qualification/protoflight testing and a 5°C margin is added for acceptance testing. For items controlled by active temperature control thermal systems, the margins are the same for qualification/protoflight and acceptance testing, as specified in Section 3.6.2.4.

LEVR-976 Electronic card/piece part thermal analyses shall be performed to ensure that the GSFC Preferred Parts List (PPL) derated temperature limits and the allowable junction temperatures are not exceeded during qualification test conditions.

3.6.2 Thermal-Vacuum Qualification

The thermal-vacuum qualification program ensures that the observatory operates satisfactorily in a simulated space environment at more severe conditions than expected during the mission.

LEVR-2309 Thermal-Vacuum, Thermal Balance, and Leakage testing shall be performed as shown in Table 3-10.

Table 3 - 10 Vacuum and Thermal Requirements

Requirement	Observatory	Instruments	Subsystems	Unit/ Component
Thermal-Vacuum	T	T	T, A	T2
Thermal Balance	T and A	T and A	T, A	T, A
Leakage *	T	T, A	T	T

T = Test required.

T2 = Temperature cycling at ambient pressure may be substituted only if shown by analysis and approved by the LDCM Project.

A = Analysis required; tests may be required to substantiate the analysis.

T, A = Test is not required at this level of assembly if analysis verification is established for non-tested elements.

Temperature cycling at ambient pressure may be substituted for thermal-vacuum temperature cycling if it can be shown by a comprehensive analysis to be acceptable and approved by the LDCM Project.

* = Heat pipes shall require leakage testing at the component level, and verified by performance tests at higher levels of assembly.

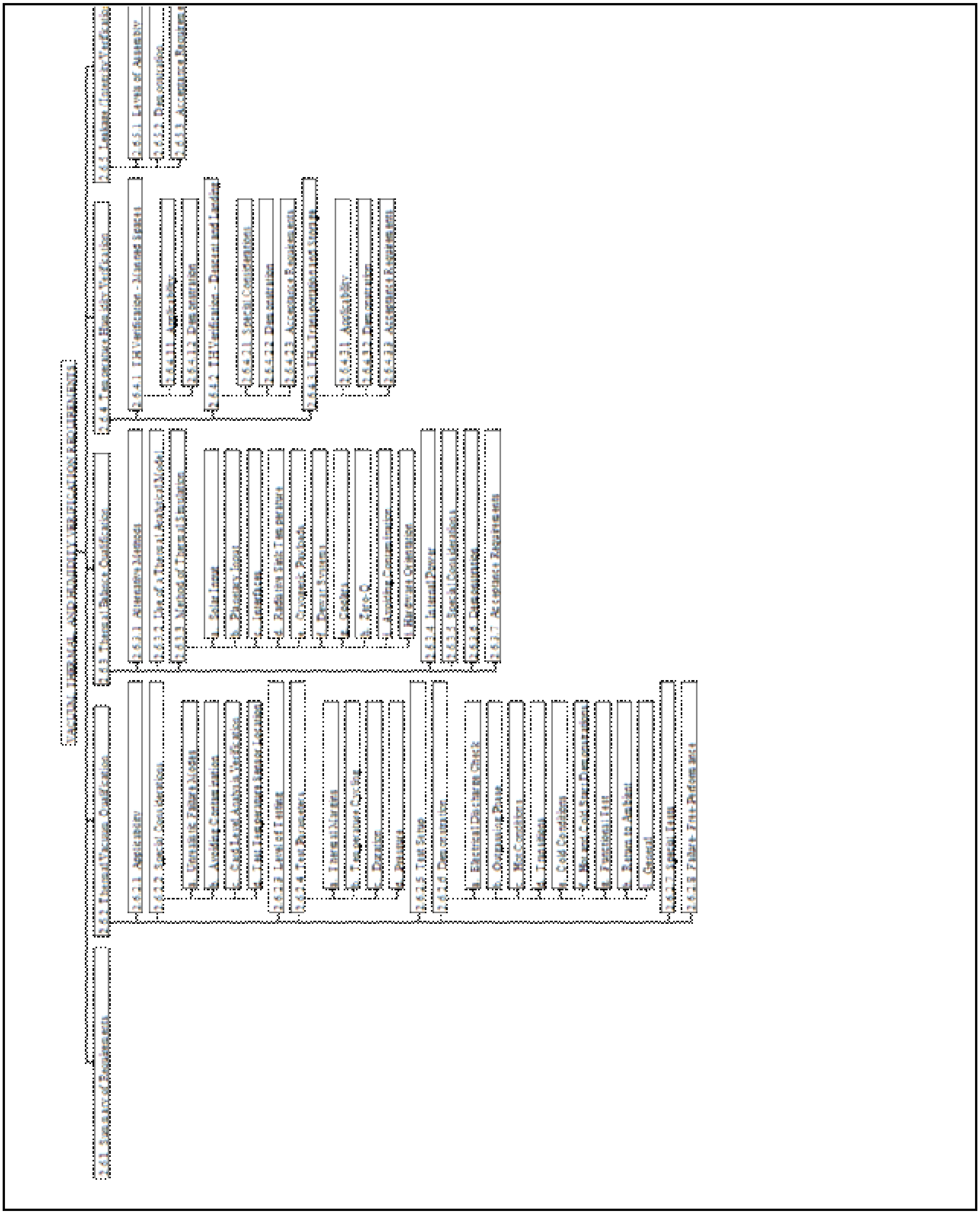
LEVR-2055 This analysis shall show that temperature levels and gradients are as severe in air as in a vacuum.

Consideration will be given to environmental control of the enclosure.

Hardware that passes this test at a lower level of assembly need not be retested at a higher level unless there is reason to suspect its integrity.

Survival/Safehold testing is performed on that equipment which may experience (non-operating) temperature extremes more severe than when operating. The equipment tested is not expected to operate properly within specifications until the temperatures have returned to qualification temperatures.

LEVR-1025 Card level thermal analysis using qualification level boundary conditions shall be performed to insure derated temperature limits, for example, junction temperature limits, are not exceeded.



3.6.2.1 Applicability

All flight hardware will be subjected to thermal-vacuum testing in order to demonstrate satisfactory operation in modes representative of mission functions at the nominal operating temperatures, at temperatures in excess of the extremes predicted for the mission, and during temperature transitions.

LEVR-2056 The tests shall demonstrate satisfactory operation over the range of possible flight voltages.

LEVR-2057 In addition, hot protoflight and cold survival temperature turn-on of the electronics shall be demonstrated where applicable.

The Goddard Space Flight Center generally utilizes a protoflight qualification test program. Protoflight thermal test levels are the same as prototype. Figure 3-10 shows temperature test margins. Contingency margins required by design rules are included in the development of the expected flight temperatures.

Spare components will undergo a test program in which the number of thermal cycles is equivalent to the total number of cycles to which other flight components are subjected at the component, subsystem, and observatory levels of assembly.

LEVR-2058 As a minimum, flight spare components shall be subjected to eight thermal cycles prior to integration onto the observatory.

LEVR-1035 A transition from prime to redundant components shall be exercised during the test program, at every cold and hot start test along with at least a complete cycle from prime to redundant and back at the nominal flight predicted temperature, to verify proper orbital operations.

LEVR-2059 Testing to validate all applicable operational modes shall be performed.

The method of conducting the tests will be described in the environmental verification test specification and procedures.

LEVR-1036 For flight spare and redundant components, the duration and test temperature levels of the tests shall be the same as those for flight components.

LEVR-1037 For repaired equipment, usually a component, flight acceptance testing shall be sufficient to demonstrate flight worthiness, as approved by the LDCM project.

If additional testing is expected at either the Subsystem or the Observatory level, the number of cycles can be reduced so long as the total number of cycles satisfies the 12 cycle requirement.

Consideration should be given to conducting the thermal balance verification test in conjunction with the thermal-vacuum test program. A combined test is often technically and economically advantageous.

Any combined test performed will satisfy the requirements of both tests.

The approach that is chosen will be described in the environmental verification specification and procedures.

3.6.2.2 Special Considerations

a. Unrealistic Failure Modes - Care will be taken during the test to prevent unrealistic environmental conditions that could induce test failure modes.

LEVR-2064 Maximum rates of temperature change shall not exceed acceptable limits. The limits are based on hardware characteristics or orbital predictions.

b. Avoiding Contamination - Elements of a test item can be sensitive to contamination arising from test operations or from the test item itself.

LEVR-2065 If the test item contains sensitive elements, the test chamber and all test support equipment shall be examined and certified prior to placement of the item in the chamber to ensure that it is not a significant source of contamination.

LEVR-2066 Potential contaminants emanating from the test item shall not be masked by contaminants from the chamber or the test equipment.

LEVR-2067 Chamber bakeout and certification shall be required for contamination sensitive hardware.

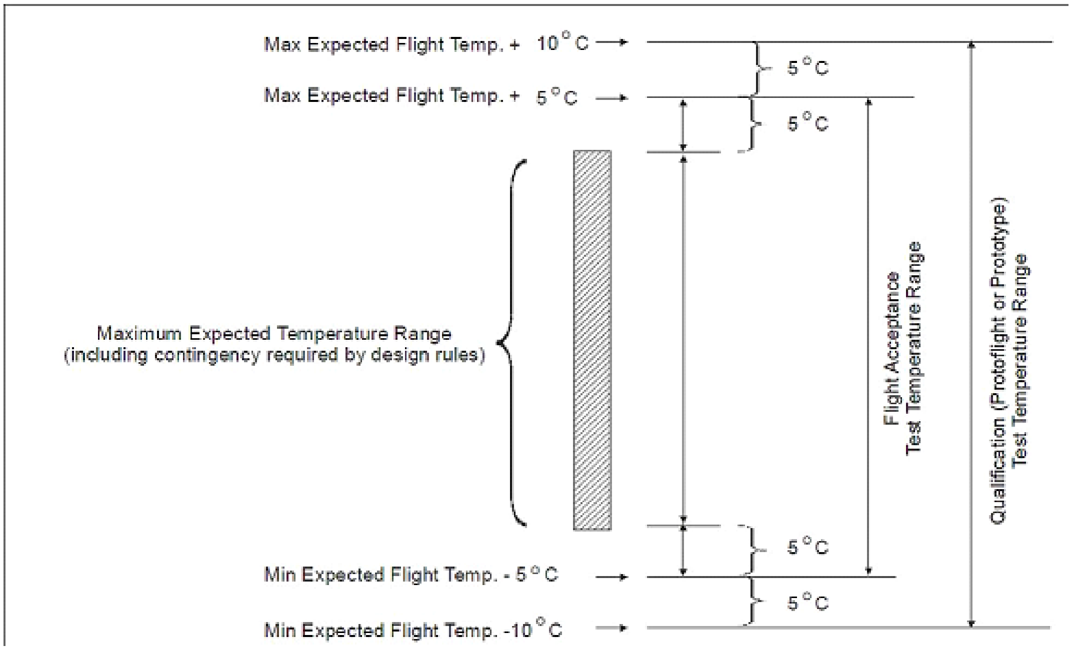


Figure 3 - 10 Qualification Protoflight and Prototype and Acceptance Thermal-Vacuum Temperatures

LEVR-1052 The level of contamination present during thermal vacuum testing shall be monitored using, as a minimum, a Temperature-controlled Quartz Crystal Microbalance (TQCM) to measure the accretion rate and a cold finger to obtain a measure of the content and relative amount of the contamination.

The use of additional contamination monitors such as a Residual Gas Analyzer (RGA), Gas Chromatographs/Mass Spectrometers (GC/MS), Fourier Transform Infrared Spectrometers (FTIS), Cyrogenic QCMs, mirrors, and chamber wipes will also be considered.

When using TQCMs, RGAs, or mirrors, the locations of the sensors will be carefully placed so that they will adequately measure outgassing from the desired source.

Transitions from cold to hot conditions increase contamination hazards because material that has accreted on the chamber walls may evaporate and deposit on the relatively cool test item.

Transitions will be conducted at rates sufficiently slow to prevent that from occurring. It is recommended that testing start with a hot soak and end with a hot soak to minimize this risk.

LEVR-2071 However, if it is necessary that the last exposure be a cold one, the test procedure shall include a phase to warm the test item before the chamber is returned to ambient conditions so that the item will remain the warmest in the test chamber, thus decreasing the likelihood of its contamination during the critical period.

In all cases, every effort will be made to keep the test article warmer than its surroundings during testing

LEVR-1054 c. Card Level Analyses Verification - During hot qualification testing, temperature sensors shall be monitored at strategic points on electronic cards or piece parts to confirm that the detailed thermal analyses performed were conservative. These temperature monitors can either be flight sensors or test sensors.

LEVR-1055 Test Temperature Sensor Location - Test temperatures for a thermal vacuum soak shall be based on the temperatures at selected locations or average temperature of a group of locations.

LEVR-2074 The locations shall be selected in accordance with an assessment to ensure that components or critical parts of the observatory achieve the desired temperature for the required time during the testing cycle.

LEVR-2075 In some cases, the temperature sensors shall be attached to the component base plate or to the heat sink on which the component is mounted, if the temperature requirement is defined at the mounting interface.

LEVR-2076 Temperature soaks and dwells shall begin when the "control" temperature is within ± 2°C of the proposed test temperature.

LEVR-2077 The "control" temperature criterion for cryogenic systems shall be determined by the Contractor thermal engineer subject to approval by the GSFC LDCM project as it may be significantly more stringent than 2°C.

3.6.2.3 Level of Testing

There is a minimum of three levels of testing; the component, subsystem/instrument, and the observatory levels.

LEVR-2078 If it is impracticable to test an entire integrated observatory, and the Project concurs, then the test may be conducted at the highest practicable level of assembly and ancillary testing and analyses shall be conducted to verify the flightworthiness of the integrated observatory.

In cases where testing is compromised, for example the inability to drive temperatures of the all-up assembly to the qualification limits, testing at lower levels of assembly may be warranted.

3.6.2.4 Test Parameters

Thermal margin, temperature cycling, soak duration, test chamber conditions, transition rates, temperature and pressure regimes, are some of the parameters that define key environmental conditions of the test. The following parameters define key environmental conditions of the test:

LEVR-1060 a. Thermal Margins - Thermal margins shall be established to induce stress conditions to detect unsatisfactory performance that would not otherwise be uncovered before flight. The thermal test margin is defined as an increase in a condition beyond the range of conditions the hardware would experience over the expected lifetime. This could include temperature, heat loads, and/or environmental conditions.

The maximum and minimum temperatures to be imposed during the thermal vacuum test will represent, as indicated above, a temperature range large enough, including margins, to induce stress during temperature cycling.

LEVR-2080 The basis for the test temperatures shall be established either by program requirements or by predicted temperatures derived analytically using a test verified model. The latter means that worst case flight predictions will be generated from a thermal analytical model which has been correlated satisfactorily to thermal balance test results.

LEVR-2081 When a thermal balance test precedes the thermal vacuum test, results from that test shall be used to refine the thermal vacuum test criteria, presuming that there is sufficient time to correlate the model and generate updated predictions prior to the thermal vacuum test.

If predictions from a verified model are not available at the time of the thermal vacuum test, the basis will be the on-orbit maximum and minimum allowable operating limits discussed in the following paragraph.

This basis will constitute the “flight” temperature range to which test margins will be applied.

LEVR-1062 For passively controlled systems, a qualification temperature margin of no less than 10° C above the “flight” maximum operating temperature (as established above) and 10° C below the “flight “ minimum operating temperature shall be used in establishing test temperatures. The margins for acceptance testing of previously qualified hardware may be reduced to 5° C, as long as testing to these levels does not preclude protoflight test levels from being achieved at higher levels of assembly.

The test margins for actively controlled hardware, as specified in the following three paragraphs, will apply to both qualification/protoflight and to acceptance testing of those systems and components.

LEVR-1064 For actively controlled systems such as Heaters, ThermoElectric Coolers (TECs), Loop Heat Pipes (LHPs), Capillary Pumped Loops (CPLs), or other devices with selectable/variable set points, a test temperature margin of no less than 5° C or a duty cycle less than 70% for the cold operational temperature shall be imposed on the respective set point band that is under control.

For components/subsystems/observatories with operational heater circuits with fixed temperature setpoints, the margin may be reduced from 10° C to 5° C.

LEVR-1066 If a component/subsystem/observatory has an active control whose range is not selectable/ variable such that the control system will not allow the hardware to be stressed via temperature, then the stressing of the thermal control system shall be induced by the increase or decrease of a heat load either internally or externally of at least 30 %.

LEVR-2084 The active temperature control hardware shall maintain control under these stressed conditions. The goal of this testing is to create an environmental condition in excess of what the system will see on-orbit in order to stress the system and demonstrate its overall flightworthiness.

The 10°C thermal vacuum margin requirement may not apply to cryogenic systems.

Obtaining "cold" margins may not be possible for some cryogenic systems, for example, an instrument inside a dewar. Also, operating the test article at temperatures 10ºC above normal may be detrimental to performance testing.

LEVR-2085 Margins shall be established by the Contractor thermal engineer subject to approval by the GSFC LDCM project based on the unique characteristics of the test article.

LEVR-1069 The survival/safehold thermal-vacuum test shall consist of driving the element, without any test margin, to the desired temperature, and then returning that element to the qualification temperature to functionally check the operation.

LEVR-2086 No component shall be allowed to exceed the non-operating temperature limit with allowable tolerances.

Temperatures will not exceed allowable qualification temperatures for extended periods of time. This may constrain the test to be driven by those components with the smallest allowable temperature range.

Also, for testing at higher levels of assembly, the "red limits" (not-to-exceed temperatures) will be established based on temperatures actually achieved during testing at lower levels of assembly.

b. Temperature Cycling - Cycling between temperature extremes will be performed for the purpose of checking performance during both stabilized conditions and transitions. The minimum number of thermal-vacuum temperature cycles for the observatory, subsystem/instrument, and component levels of assembly are as follows:

LEVR-1072 1. Observatory - Four (4) thermal-vacuum temperature cycles shall be performed at the observatory level of assembly.

LEVR-2089 If the expected mission temperature excursions are small (less than 10° C) or the transition times are long (greater than 72 hours), the minimum number of thermal-vacuum test cycles may be reduced to two (2) with GSFC LDCM project approval; however, in these cases, the durations for the hot and cold temperature dwells shall be doubled.

LEVR-2090 During the cycling, the hardware shall be operating and its performance shall be monitored.

LEVR-1073 2. Instrument/subsystem - A minimum of four (4) thermal-vacuum temperature cycles shall be performed at the instrument level of assembly. Other subsystems are only required to test at the subsystem level if analysis indicates a test is required.

LEVR-2092 During the cycling, the hardware shall be operating and its performance will be monitored.

LEVR-1074 3. Component/Unit - All space hardware shall be subjected to a minimum of eight (8) thermal-vacuum temperature cycles before being installed into the observatory; these may include test cycles performed at the subsystem/instrument level of assembly.

During the cycling, the hardware will be operating and its performance shall be monitored.

For components that have been demonstrated by analysis to be insensitive to vacuum effects relative to temperature levels and temperature gradients, the requirements may be satisfied by temperature cycling at normal room pressure in an air or gaseous-nitrogen environment. Thermal cycling in place of thermal vacuum cycling must be approved by the LDCM Project.

If this approach is used, the number of cycles at ambient pressure will be increased to account for possible analytical uncertainties and to heighten the probability of detecting workmanship defects.

LEVR-2096 The number of thermal cycles shall be increased by fifty (50) percent if testing at ambient pressure (i.e., if 8 cycles would be performed in vacuum, then 12 cycles shall be performed at ambient pressure). Further, it is recommended that the qualification margin of 10º C (in vacuum) be increased to no less than 25 º C if testing at ambient pressure is performed.

The recommended approach is to test in the expected environment (vacuum). If testing at ambient pressure is implemented, LDCM Project approval is required based on the results of a rigorous thermal analysis.

4. Cryogenic systems. The cycling requirement may not apply to cryogenic systems. For example, instruments inside a dewar may never see cycling in flight. Cycling them during ground testing may also be preclusive due to time constraints and may cause undue stress on flight systems.

Operational conditions will be considered when determining cryogenic system cycling.

LEVR-2098 The number of cycles shall be specified by the Contractor and approved by the GSFC LDCM project.

LEVR-1078 Subsystem and unit testing may be combined, in which case the number of cycles shall be a minimum of 8 thermal-vacuum temperature cycles.

c. Duration - The total test duration will be sufficient to demonstrate performance and uncover early failures.

The duration varies with the time spent in flight at the temperature levels and with such factors as the number of mission-critical operating modes, the test item thermal inertia, and test facility characteristics. Dwell times are calculated as cumulative values of all temperature cycles. Dwell times start after each critical location, established with GSFC LDCM Project approval, reaches the agreed upon appropriate temperature level necessary to perform the functional test at or beyond the minimum or maximum test temperature, and within safety limits. Internal power dissipations or external cooling provisions, or both, may require adjustment to establish and maintain the required test temperature levels during the entire functional testing, to the fullest extent practicable. Minimum temperature dwell times are as follows:

LEVR-1080 1. Observatory - Observatories shall be exposed for a minimum of twenty-four (24) hours at each extreme of each temperature cycle.

LEVR-2101 The thermal soaks shall be of sufficient duration to allow time for functional tests for all modes of operations including safehold/survival.

LEVR-1081 Instrument/subsystems - Instruments shall be exposed for a minimum of twelve (12) hours at each extreme of each temperature cycle. If a subsystem is required to test, the same requirement applies.

The thermal soaks will be of sufficient duration to allow time for functional tests for all modes of operation including safehold/survival.

LEVR-1082 Unit/Component - Components shall be exposed for a minimum of four (4) hours at each extreme of each temperature cycle.

The thermal soaks will be of sufficient duration to allow time for functional tests for all modes of operation.

Hot and cold start demonstrations will be performed for each unit/component per Section 3.6.2.6 f.

LEVR-2105 If component testing is done at ambient pressure, the dwell time shall be increased to six (6) hours.

Subsystem and unit testing may be combined, in which case the test time will be the sum of the two values stated above.

The dwell time for cryogenic elements may be significantly longer than noted above.

LEVR-2106 Times shall be approved by the GSFC LDCM project based on the operational characteristics when the minimum time requirements for dwells are not met.

The survival/safehold TV test will consist of soaking the non-operating element for at least four (4) hours at proper temperature conditions.

LEVR-1086 Pressure- The chamber pressure after the electrical discharge checks are conducted shall be less than 1.33 X 10-3 Pa. (1 X 10-5 torr).

LEVR-2107 The ability to function through the voltage breakdown region shall be demonstrated if applicable to mission requirements (those elements that are operational during launch).

3.6.2.5 Test Setup

The setup for the test, including any instrument and/or component stimulators, will be reviewed by the Contractor to ensure that the test objectives will be achieved, and that no test induced problems are introduced.

LEVR-2108 The observatory test configurations shall be as described in the test plan and test procedure.

LEVR-2109 The test item shall be, as nearly as practicable, in flight configuration. Test heaters on the observatory may be required to achieve proper and safe temperatures.

LEVR-1091 Critical temperatures shall be monitored throughout the test and alarmed if possible.

LEVR-2110 The operational modes of the observatory shall be monitored in accordance with Section 3.3. The provisions of Section 3.3 apply except when modified by the time considerations of Section 3.6.2.4 d.

3.6.2.6 Demonstration

LEVR-1093 a. Electrical Discharge Check - Items that are electrically operational during pressure transitions shall undergo an electrical discharge check to ensure that they will not be permanently damaged from electrical discharge during the ascent and early orbital phases of the mission, or during descent and landing (if applicable).

LEVR-2112 The test shall include checks for electrical discharge during the corresponding phases of the vacuum chamber operations.

LEVR-1094 b. Outgassing Phase - If the test article is contamination sensitive (or if required by the contamination control plan) an outgassing phase shall be included to permit a large portion of the volatile contaminants to be removed.

The outgassing phase will be incorporated into a hot exposure that will occur during thermal-vacuum testing. The test item will be cycled hot and remain at this temperature until the contamination control monitors indicate that the outgassing has decreased to an acceptable level.

LEVR-1095 Hot Conditions - The temperature controls shall be adjusted to cause the test item to stabilize at the upper test temperature. Hot turn-on capability is demonstrated as required. The duration of this phase will be at least sufficient to permit the performance of the functional tests with a minimum soak time as specified in Section 3.6.2.4.c.

LEVR-1096 Transitions - The test item shall remain in an operational mode during the transitions between temperatures so that its functioning can be monitored under a changing environment. It is permissible to turn off a test item to achieve cold temperature limits for the later part of the transition to cold.

The requirement may be suspended when turn-on of the test item is to be demonstrated after a particular transition. In certain cases, it may be possible to remove thermal insulation to expedite cool-down rates.

Caution will be taken not to violate temperature limits, or to induce test failures caused by excessive and/or unrealistic gradients.

Violation of functional specifications is acceptable during transitions with the approval of the GSFC LDCM Project Office.

LEVR-1097 The rate of transition shall be specified to insure that stresses caused by thermal gradients will not damage the test article. Contamination effects may also be a factor.

Care will be exercised with cryogenic systems where the thermal stresses can be severe.

LEVR-2117 The cool-down and warm-up for cryogenic systems shall be as flight like as possible.

LEVR-1098 STOP (Structural/Thermal/Optical) analyses with temperature variant properties shall be performed to insure stresses and alignments are acceptable for the given transition rate.

LEVR-1099 Cold Conditions - The temperature controls shall be adjusted to cause the test item to stabilize at the lowest test temperature.

Cold turn-on capability will be demonstrated at the start of the cold condition.

The duration of the cold phase will be sufficient to permit the performance of the functional tests with a minimum soak time as specified in Section 3.6.2.4.c.

f. Hot and Cold Start Demonstrations - Start-up capability will be demonstrated to verify that the test item will turn on after exposure to the extreme temperatures that may occur in orbit.

LEVR-2121 Turn-on capability shall be demonstrated under vacuum at least twice at both the low and high temperatures, as applicable.

Test turn-on temperatures are defined by the expected mission operations without any margin; that is, temperatures will be at either survival/safe-hold or qualification temperature conditions, whichever are more extreme, as appropriate.

At the Unit/Component level, this demonstration will consist of power-off, power-on cycles for each unit/component.

At the Subsystem/Instrument level, and Observatory level, this demonstration will be consistent with the scenario regarding which units/components are actually power cycled (off/on) in orbit, and also for recovery from a survival/safe-hold mode in orbit.

For example, recovery from cold survival/safe-hold temperatures to cold operational temperatures may be accomplished either by using a flight heater, or alternately, by turning the units/components of the test item back on and allowing internal dissipation to warm temperatures. Proper operation is then checked after the component has returned to the qualification limit.

The duration of the soak with the test item off, or in survival/safe-hold mode, will be in accordance with Section 3.6.2.4.c.

LEVR-1101 g. Functional Test - Functional tests shall be performed at each hot and cold soak plateau and during transitions, if applicable.

LEVR-2127 A comprehensive performance test (CPT) shall be performed at least once during hot plateau(s) and once during cold plateau(s) unless it is determined to be impractical.

In that case, with GSFC LDCM project approval, a limited functional test may be substituted if satisfactory performance is demonstrated for the major mission critical modes of operation. Otherwise, the requirements of Section 3.3.2 apply.

Functionality of the thermal control system hardware will be demonstrated during the Thermal-Vacuum Qualification test.

LEVR-1102 h. Return to Ambient - The test article shall be kept warmer than the surroundings when necessary to protect against contamination from the test facility. Before the chamber can be backfilled with air, all sensors should read above the dew point to insure that water does not condense on the observatory.

i. General - The margins, soak criteria, cycling, and duration guidelines listed above apply to primarily test articles around room temperature (except where noted).

LEVR-2130 Test parameters for high temperature and cryogenic systems shall be based on flight operations.

LEVR-2131 Parameters shall be determined early in the program by the engineering and science teams.

3.6.2.7 Special Tests

Special tests may be required to evaluate unique features, such as a radiation cooler, or to demonstrate the performance of external devices such as solar array hinges or experiment booms that are deployed after the observatory has attained orbit.

LEVR-1106 The test configuration shall reflect, as nearly as practicable, the configuration expected in flight.

LEVR-2132 When items undergoing test include unusual equipment, special care shall be exercised to ensure that the equipment does not present a hazard to the test item, the facility, or personnel.

Any special tests will be included in the environmental verification specification.

3.6.2.8 Failure-Free-Performance

LEVR-1109 At least 100 trouble-free hours of functional operations at the hot conditions, and 100 trouble-free hours of functional operations at the cold conditions shall be demonstrated in the thermal verification program.

3.6.3 Thermal Balance Qualification

The adequacy of the thermal design and the capability of the thermal control system will be verified under simulated on-orbit worst case hot and worst case cold environments, and at least one other condition to be selected by the Contractor and approved by the GSFC LDCM Project.

Consideration will be given for testing an "off nominal" case such as a safehold or a survival mode.

LEVR-2134 The test environments shall bound the worst hot and cold flight environments such that the test results directly validate the adequacy of the thermal design.

An additional objective of the test is to verify and correlate the thermal model so it can be used to predict the behavior of the observatory under future non-tested conditions and/or flight conditions. It is preferable that the thermal balance test precede the thermal vacuum test so that the results of the balance test can be used to establish the temperature goals for the thermal vacuum test.

LEVR-2258 Thermal design margins shall be verified under worst case hot and cold, safehold/survival conditions. Margins to be established include, but are not limited to:

- Operational heater duty cycle less than 70% in worst cold case, including minimum voltage as established by the project;
- Survival heater margin, dependent on survival setpoint/temperature limit and available resources;
- Interface heat flows are within requirements;
- Selectability of multiple setpoints for two-phase flow systems, such as LHP and CPL, in worst case environments;
- Heat transport margins of 30% for two-phase flow systems, such as LHP, CPL, Constant Conductance Heat Pipes (CCHP), Variable Conductance Heat Pipes (VCHP), Diode Heat Pipes (DHP), in worst case environments, and
- Radiator heat rejection margin in worst case environments, dependent on available resources.

Note: For two-phase flow systems, it may be necessary to conduct thermal verification tests at all levels of assembly since it is often not possible to verify performance by analysis (see Table 3-10).

3.6.3.1 Alternative Methods

LEVR-1124 If the flight equipment is not used in the tests, additional tests to verify critical thermal properties, such as thermal control coating absorptivity and emissivity, shall be conducted to demonstrate similarity between the item tested and the flight hardware.

3.6.3.2 Use of a Thermal Analytical Model

LEVR-1126 In the course of a observatory program, analytical thermal models shall be developed for the observatory, its elements, and the mission environment for the purpose of predicting the thermal performance during the mission.

The models can also be modified to predict the thermal performance in a test-chamber environment. That is, the models are frequently used, with appropriate changes to represent known test chamber configurations, to develop the proper environments for thermal balance test cases and to develop the proper controls for thermal vacuum test levels. Frequently it is not possible to provide a direct, one-to-one test environment to simulate the space environment (e.g., chamber walls are warmer than space, or heater plates are used in lieu of solar simulation, or a solar simulator does not exactly match the spectrum or collimation angle, etc.), so it is necessary to use the analytical model to establish the conservative hot and cold test environments.

LEVR-1127 Correlation of the results of the chamber thermal balance tests with predictions derived from the modified analytical model shall be performed to validate the thermal design, evaluate the as-built thermal control system, and to allow for improvements of the thermal math model accuracy.

LEVR-2135 The verified analytical model shall then be used to predict response to untested cases as well as generating flight temperature predictions.

3.6.3.3 Method of Thermal Simulation

A decision will be made as to the method used to simulate thermal inputs. The type of simulation to be used is generally determined by the size of the chamber, the methods available to simulate environmental conditions, and the observatory.

In planning the method to be used, the Contractor will achieve the highest practical order of simulation; that is, the one that requires the minimum number of assumptions and calculations to bound the flight worst case thermal environment.

The closer the simulation is to the spectrum, intensity and the worst case environments, the less reliance on the thermal analytical model to verify the adequacy of the thermal design.

LEVR-2137 The test setup shall account for the effects of shadowing, blockage, and/or reflections (both diffuse and specular) in the flight and test configurations that either are needed for an accurate simulation, or are artifacts that could adversely affect the simulation. Methods of simulation and the major assumptions for a successful test are described below:

LEVR-1130 a. Solar input - Solar inputs shall be simulated by mercury-xenon, xenon, or carbon arc source, cryopanels, and/or heaters as described below. The spectrum and uniformity of the source used to simulate the sun and planet albedo will be understood.

LEVR-2139 While the spectral mismatch does not significantly affect the emissivity, the effect on the absorptivity can be large and shall therefore be determined and compensated for in the test and/or analysis.

Cryopanels/heater plates can also be used to simulate solar flux by setting the temperature to achieve the same heat flux as would be seen in flight. Flux controlled heaters can directly input the flight solar load onto a component.

LEVR-1132 b. Planetary Input - Planetary, or earth emissions, shall be simulated with either:

(1) Skin Heaters - This is an acceptable test for simply shaped observatories. The absorbed energy from all exterior sources is simulated at the exterior surface of the observatory using I^2R heaters. The absorptivity and incident radiation are used to calculate the absorbed energy to be simulated.

(2) Cryopanels/Heater Plates - This can be an acceptable test if the observatory outer skins are not to be touched.

The same information is needed for the plates as for the skin heaters, and the exchange factor between the plates/cryopanels and the observatory will be known.

In both cases, a balance equation considering absorptivity, emissivity, incident and rejected energies will be solved to establish accurate test conditions.

(3) Quartz Lamps- This is an acceptable method of inputting earth emissions (and solar) so long as the differences in spectrum are measured and the input is adjusted. One technique used to monitor and control lamps is to place calorimeters at the skin of the observatory to measure, in situ, the incident energy from the lamps.

(4) Calrods- This is also an acceptable method of inputting earth emissions and solar energy to the observatory. Again, a technique used to monitor and

control the energy input is to place calorimeters at the skin of the observatory.

LEVR-1137 c. Interfaces - Conductive and radiative interface temperatures shall be simulated with cold plates that are held at worst-case boundary conditions.

LEVR-2142 Flight like interface temperatures shall be varied for cold flight, hot flight, and safehold conditions or parametrically varied, if required.

Non-flight like interface heat transfer will be minimized as described below.

Since the test article is supported during testing there is generally a non-flight conductive and radiative heat flow path to supporting structure or space itself. In flight, both a conductive and a radiative interface may still exist, or only a radiative interface with the space environment (e.g., the launch vehicle attachment interface).

As much conductive and radiative isolation as possible will be used between the test article and this non-flight conductive interface.

A heater is placed on the test fixture side of such a conductive interface and two temperature sensors spanning the interface are used. The heater is controlled until the temperatures of the two sensors are the same, thereby minimizing the heat flow through this path. Without good isolation here, it is likely that an unrealistic and hard to quantify bias will be introduced at this interface, making the test results difficult to assess. Isolation is typically achieved by using fiberglass standoffs. However, the observatory may need to be suspended with low conductance cables if the system has a high sensitivity to small heat flows.

d. Radiative Sink Temperature - The over all radiative sink temperature is typically achieved by varying the chamber shroud temperature. Three typical temperature regimes of chambers are (1) Flooded with Liquid Nitrogen, (LN2 approximately 80-90 K), (2) Controlled with Gaseous Nitrogen (GN2 approx. 170-375 K), and (3) Liquid Helium (20-30 K).

Sink temperatures for individual radiators and critical surfaces are controlled with cryopanels. Cryopanels for cryogenic systems may require special enhancements, for example, open-face honeycomb radiators to increase emittance values. Three typical temperature regimes of cryopanels are (1) GN2 (approximately 130-375 K), (2) LN2 (approximately 80-90 K), and (3) Helium (approximately 20-30 K). For temperatures in between these values heaters can be added to the cryopanel or a heater plate that is conductively coupled to the cryopanel can be used.

LEVR-1141 A single effective sink temperature shall be calculated using observatory thermal math models that encompass the effects of solar, Earth IR, Albedo and IR effects from other observatory surfaces (i.e. backloading), with the appropriate correction for gray-body radiation.

LEVR-2145 Test and flight predicts of the energy flow from critical surfaces shall be compared.

Predictions of both the energy flow and temperatures from the test model will be at least as severe as calculated in the flight model.

e. Cryogenic Observatories For cryogenic observatories, chamber walls and/or cryopanels may need to be colder than Liquid Nitrogen temperatures to adequately reject heat.

LEVR-2147 Temperature variations of emissivity shall be taken into account in the sink temperature determination analysis.

f. Dewar Systems - A test dewar may be necessary to simulate the conditions that a observatory would see inside a flight dewar. The cooling in a test dewar is available over the temperature range of approximately 0.3 to 80 Kelvin (with gaps). The dewar system may utilize solid cryogens, (i.e Argon, Nitrogen, Neon or Hydrogen) or liquid cryogens (i.e. helium, nitrogen).

During ground testing there is a gravity effect on cryogens that is not seen in flight. Interfaces between the top of the dewar and the observatory may be warmer than what would be seen in flight.

g. Coolers - Thermoelectric Coolers are semiconductor-based electronic components that function as a small heat pump. Heat moves through the module in proportion to the applied voltage. The devices offer active cooling and precise controllability and are used primarily for “spot cooling” (cooling of a single component). Coolers are also used to recycle cryogen in a closed loop system. This reduces the amount of cryogen needed during a test. This is frequently done when helium is used to reduce cost.

h. Zero-Q - Certain test-peculiar conductive paths, such as test cables attached to the thermal balance test article, are controlled so that non-flight-like heat does not flow into or out of the test article. During thermal balance the test cabling is minimized.

If possible, hat couplers, stimuli, and other non-flight GSE should not be present during thermal balance testing. At a minimum, necessary test cables are wrapped with multi-layer insulation (MLI) for a sufficient distance from the test article.

A more positive method of control is to place a guard heater on the test cable a short distance from the test article, place two temperature sensors spanning the interface, one on the observatory at the connector, the other on the test cable at the connector, and wrap the cable and heater with MLI to a sufficient distance from the test article. The heater is controlled until the temperatures of the two sensors are the same, thereby minimizing the heat flow through this path.

i. Avoiding Contamination - Refer to Section 3.6.2.2.b.

j. Hardware Orientation - Heat pipes, CPLs, LHPs and other two-phase heat transfer devices will be affected by component orientation in the 1g environment, thus limiting a 0g simulation in the test environment.

Test planning should strive for orientations of flight hardware that position these devices in a gravity neutral or reflux orientation to assure their operation in the test configuration.

LEVR-2150 Hardware levelness or other orientation requirements shall be verified in the test chamber, prior to pump down.

3.6.3.4 Internal Power

LEVR-1150 Power dissipation of individual components shall be measured to an accuracy of 1% at voltage and temperature extremes during prior (component) testing.

LEVR-2151 Subassembly testing shall verify internal power dissipations and line losses.

Prior to observatory level testing, the Contractor will provide: (1) details on what can be directly measured using current/voltage monitors, (2) how this information, in conjunction with component/subassembly test data, will be used to determine individual component dissipations during the observatory test, and (3) a plan to resolve discrepancies during test.

3.6.3.5 Special Considerations

LEVR-1152 The test article shall be thermally coated and the mounting surface of components within the test article (as applicable) shall have the same treatment as it will have for flight.

Extraneous effects such as gaseous conduction in residual atmosphere will be kept negligible by vacuum conditions in the chamber; pressures below 1.33 X 10-3 Pa (1 X 10-5 torr) are usually sufficiently low.

Care will also be taken to prevent conditions, such as test configuration-induced contamination, that cause an unrealistic degradation of the test item.

3.6.3.6 Demonstration

The number of energy balance conditions simulated during the test will be sufficient to verify the thermal design and analytical model.

To verify and correlate the thermal analytical model, a minimum of three test cases is required.

It is noted, however, that the number of variables associated with a thermal analytical model is large compared to the number of thermal balance cases that can be practically included in a test.

The verification of the thermal design will be accomplished by using test environments that bound the worst hot and cold flight environments such that the test results directly validate the adequacy of the thermal design.

The duration of the thermal balance test depends on the mission, observatory design, observatory operating modes, and times to reach stabilization. Stabilization is considered to have been achieved when the control sensors change less than 0.05°C per hour, for a period of not less than six hours, and exhibit a decreasing temperature slope over that period. Alternatively, another stabilization criterion which may be used is where the amount of energy represented by the time rate of temperature change (and the thermal mass of the test article) is a small fraction (typically 2 to 5%) of the total energy of the test article, calculated based on the design.

The exposures will be long enough for the observatory to reach stabilization so that temperature distributions in the steady-state conditions may be verified.

The conditions defining temperature stabilization will be described in the environmental verification specification and are determined by the Thermal Subsystem Engineer.

Cryogenic observatories typically require tighter stabilization criteria and therefore have longer stabilization times; the criteria will be established by the thermal engineer.

The differences allowed between predicted and measured temperatures are determined by the cognizant Thermal Subsystem Engineer and verification of the thermal analytical model is considered accomplished if the established criteria are met.

LEVR-2157 This criterion shall be established prior to the environmental testing.

3.6.3.7 Acceptance Requirements

The full qualification thermal balance test may be waived with approval of the GSFC LDCM Project Office, but only if sufficient margin is known to exist and other tests are conducted to verify the thermal similarity to the previously qualified hardware. In addition, other metrics such as thermal-optical property measurements of flight coatings, component level tests, and review and verification of manufacturing and installation procedures for thermal hardware are shown to exist which preclude full re-verification testing.

3.7 CONTAMINATION CONTROL PROGRAM

The objective of the contamination control program is to decrease the likelihood that the performance of observatories will be unacceptably degraded by contaminants.

Since contamination control programs are dependent on the specific mission goals, instrument designs, planned operating scenarios, etc. it is necessary for each program to provide an allowable contamination budget and a Contamination Control Plan (CCP) which defines the complete contamination control program to be implemented for the mission.

LEVR-2158 The specific verification plans and requirements shall be defined in the CCP. The procedures that follow provide an organized approach to the attainment of the objective so that the allowable contamination limit is not violated.

3.7.1 Applicability

The contamination control program is applicable to all observatories, subsystems, instruments, and components during all mission phases (fabrication, assembly, integration, testing, transport, storage, launch site, launch, and on-orbit

3.7.2 Summary of Verification Process

The following are performed in order:

a. Determination of contamination sensitivity;

b. Determination of a contamination allowance;

c. Determination of a contamination budget;

d. Development and implementation of a contamination control plan.

LEVR-1171 Each of the above activities shall be documented and submitted to the GSFC LDCM project office for concurrence/approval.

3.7.3 Contamination Sensitivity

LEVR-1173 An assessment shall be made early in the program to determine whether the possibility exists that the item will be unacceptably degraded by molecular or particulate contaminants, or is a source of contaminants.

LEVR-2159 The assessment shall take into account all the various factors during the entire development program and flight including identification of materials (including quantity and location), manufacturing processes, integration, test, packing and packaging, transportation, and mission operations including launch and return to earth, if applicable.

LEVR-2160 In addition, the assessment shall identify the types of substances that may contaminate and cause unacceptable degradation of the test item.

LEVR-1174 If the assessment indicates a likelihood that contamination will degrade performance, a contamination control program shall be instituted.

LEVR-2161 The degree of effort applied shall be in accordance with the importance of the item's function to mission success, its sensitivity to contamination, and the likelihood of its being contaminated.

3.7.4 Contamination Allowance

LEVR-1176 The amount of degradation of science performance that is allowed for critical, contamination-sensitive items shall be established by the GSFC LDCM Project Office.

LEVR-2162 From this limit, the amount of contamination that can be tolerated, the contamination allowance, shall be established.

LEVR-2163 The rationale for such determination and the ways in which contaminants will cause degradation shall be described in the contamination control plan (Section 3.7.7). The allowable degradation shall also be included in a contamination budget.

3.7.5 Contamination Budget

LEVR-1178 A contamination budget shall be developed for each critical item.

LEVR-2164 It shall describe the quantity of contaminant and the degradation that may be expected during the various phases in the lifetime of the item.

LEVR-2165 The phases shall include the mission itself.

LEVR-2166 The budget shall be stated in terms (or units) that can be measured during testing.

LEVR-2167 The measure of contamination shall be monitored as the program progresses to include the contamination and degradation experienced.

LEVR-2168 The budget shall be monitored to ensure that, given the actual contamination, the mission performance will remain acceptable.

LEVR-2169 In the event that contamination build-up predictions are not borne out, corrective action shall be taken.

A contamination-sensitive item may be cleaned periodically to reestablish a budget baseline.

Contamination avoidance methods, such as cleanrooms and instrument covers, will affect the budget and a general description of their usage will be included.

LEVR-2171 The contamination budget shall be negotiated among the the GSFC LDCM Project Office and the Contractor.

3.7.6 Contamination Control Plan

A contamination control plan will be prepared for each subsystem/instrument and the observatory.

LEVR-2172 The OLI contamination plan shall be prepared in accordance with CDRL-SA-17.

3.7.7 Other Considerations

LEVR-1183 Bake-outs of major wiring harnesses and thermal blankets shall be performed unless it can be satisfactorily demonstrated to the GSFC LDCM project that the contamination allowance can be met without bake-outs.

LEVR-2381 Bake-outs of solar arrays shall be performed.

Bake-outs of other components with large amounts of non-metallic material, such as batteries, electronic boxes, and painted surfaces may also be necessary. Refer to MAR for requirements.

For information regarding outgassing testing refer to ASTM E595, Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment. The Materials Engineering Branch (MEB) maintains an outgassing data web site, http://outgassing.nasa.gov which is updated every three months.

LEVR-1185 Because they can be a source of contamination themselves, special consideration shall also be given to materials and equipment used in cleaning, handling, packaging, and purging flight hardware.

LEVR-1187 The contamination program requirements shall be followed closely during the environmental test program.

Non-flight materials near the flight hardware may damage or contaminate it. For example:

- Non-flight GSE wiring and connector materials can contaminate the flight hardware during thermal testing.
- Packaging material (plastic films and flexible foams) can contaminate hardware or cause corrosion during shipping and storage.
- Plastic bags without anti-static properties can allow electrostatic discharges to damage electronic components on circuit boards.
- Tygon tubing (or other non-flight tubing) used in purge systems can contaminate hardware when gasses or liquids extract plasticizers from the tubing.
- Paints, sealants, and cleaning materials used to maintain clean rooms can contaminate or corrode flight hardware.

LEVR-1193 To protect flight hardware, non-flight hardware that will be exposed to thermal vacuum testing with flight hardware (items such as cables, electronics, fixtures, etc.) shall be fabricated from flight quality materials.

LEVR-2173 Packaging materials shall be tested to verify that they are non-corrosive, non-contaminating, and provide electrostatic protection, if required.

LEVR-2174 All materials used in purge systems shall be tested for cleanliness and compatibility with flight materials.

3.8 End-to-End Compatibility Tests, Mission Readiness, Mission Simulations, Ground Tests

End-to-end compatibility tests, mission readiness tests and simulations, and other required tests with the ground system are documented in the LDCM Spacecraft SOW.

4 Additional Mechanical Test Requirements

4.1 Acoustic Fill Effects

The acoustic sound pressure level in the area between the observatory and the payload fairing, or orbiter side walls, increases as the gap decreases. Thus for large observatories, a fill factor is often used to adjust for this effect.

NASA-STD-7001, Observatory Vibroacoustic Test Criteria recommends the use of the following acoustic Fill Factor:

$$\text{Fill Factor (dB)} = 10 \text{ Log} \left\{ \frac{\left(1 + \frac{C_a}{2fH_{gap}}\right)}{1 + \frac{C_a}{2fH_{gap}}\left(1 - Vol_{ratio}\right)} \right\}$$

where: C_a is the speed of sound in air (typically 344.4 meters/second, 1130 ft/sec, or 13,560 in/sec)

f is the one-third octave band center frequency (Hz),

H_{gap} is the average distance between the observatory and the fairing, or cargo bay, wall, and

Vol_{ratio} is the ratio between the observatory volume and the empty fairing, or cargo bay, volume for the observatory zone of interest.

This fill-factor is typically added to the empty fairing/cargo bay expected or test levels.

LEVR-2175 However, engineering judgment (with review by the LDCM GSFC Project Office) shall be used in the application of this fill-factor for irregular shaped observatories.

As an example, assume a cylindrical observatory section of radius R_S in a fairing of radius R_F shown in Figure 4-1.

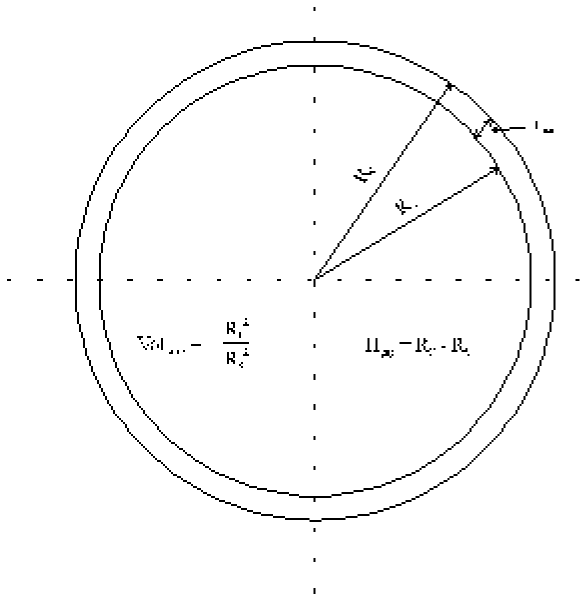


Figure 4 - 1 Cylindrical Observatory in Fairing Acoustic Fill-Factor

The fill-factor to be added to the empty fairing acoustic levels for various size observatories, assuming a fairing diameter of 3.0 meters, is given in Table 4-1, and is shown in Figure 4-2.

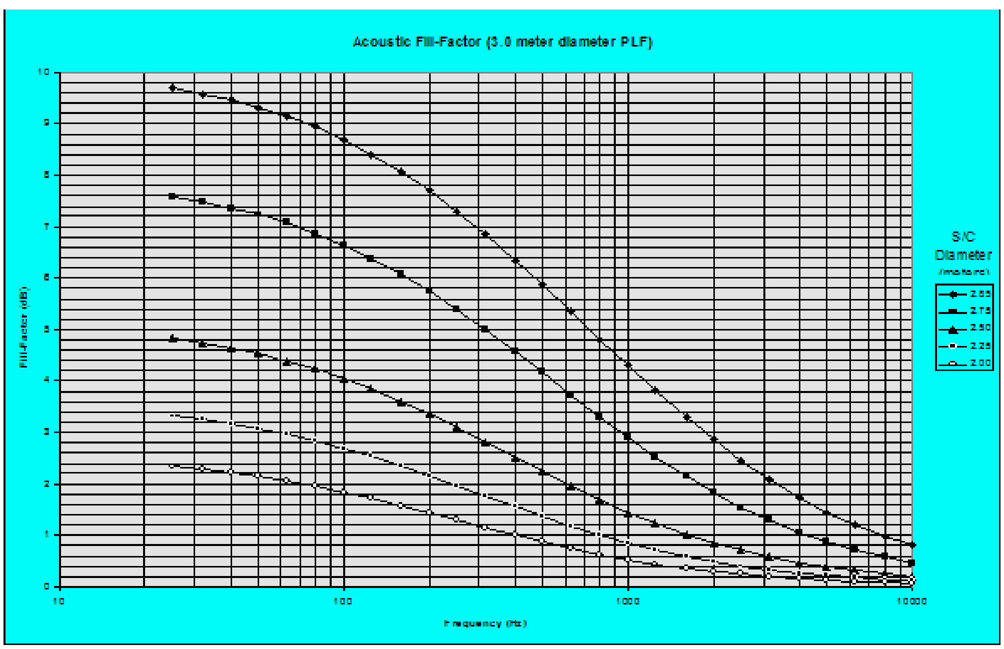


Figure 4 - 2 Acoustic Fill-Factor for Observatories in a 3 meter Diameter Payload Fairing

Additional methods for determining vibroacoustic loads can be found in Dynamic Environmental Criteria NASA Technical Handbook, NASA-HDBK-7005.

4.2 Component Random Vibration

Component random vibration testing is one of the primary workmanship tests to uncover flaws or defects in materials and production.

To the greatest extent possible, test levels will be based on knowledge of the expected environment from previous missions or tests.

However, it is important to test with sufficient amplitude to uncover the defects.

Therefore, the input levels will always be greater than or equal to workmanship test levels for electronic, electrical, or electro-mechanical components. If the hardware contains delicate optics, detectors, sensors, etc., that could be damaged by the levels of the workmanship test in certain frequency bands, the test levels may, with GSFC LDCM project concurrence, be reduced in those frequency regions. A force-limiting control strategy is recommended.

The control method will be described in the Verification Test Procedure and approved by the GSFC LDCM project.

The qualification (prototype or protoflight) test level is generally 3 dB greater than the maximum expected (acceptance) test level. That is not always the case however. If the expected level is less than the workmanship level an envelope of the two is used to determine the acceptance test level. The qualification level is also an envelope of the maximum expected + 3 dB and the workmanship level. Under this condition, the qualification envelope may not exceed the acceptance level by 3 dB. Figure 4-3 demonstrates this.

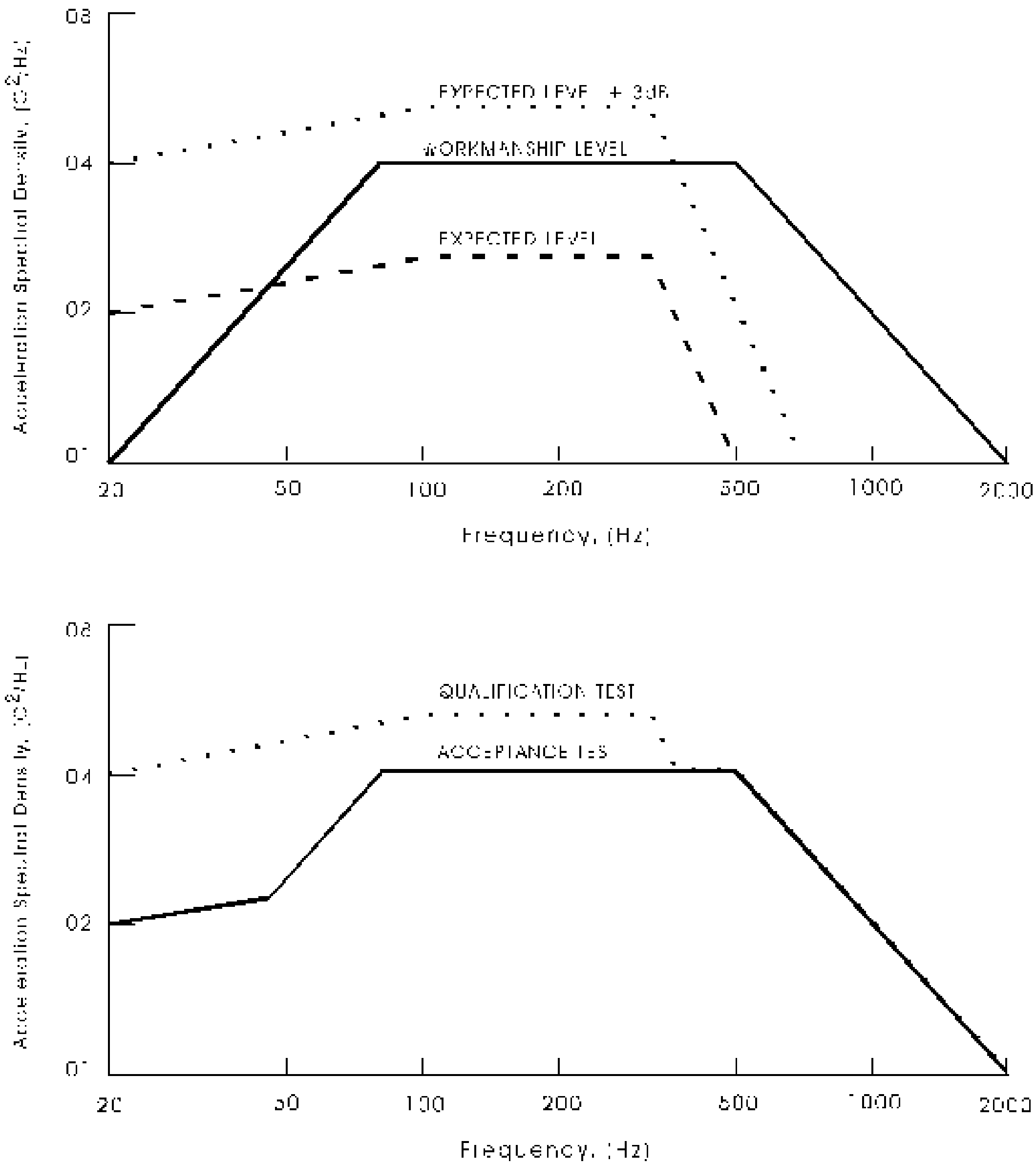


Figure 4 - 3 Determination of Qualification and Acceptance Random Verification Test Levels

4.3 Mechanical Shock

The maximum shock producing event for observatories is generally the actuation of separation devices.

LEVR-2179 The expected shock environment shall be assessed for the device to be used.

LEVR-2259 An observatory separation test shall be performed if pyrotechnic devices are to be used for the separation.

A pyrotechnic shock environment is characterized as a high intensity, high frequency, and very short duration acceleration time history that resembles a summation of decaying sinusoids with very rapid rise times. In addition, it is characterized most realistically as a traveling wave response phenomenon rather than as a classical standing wave response of vibration modes. Typically, at or very near the source, the acceleration time history can have levels in the thousands of g's, have a primary frequency content from 1 kHz to 10 kHz, and decay within 3-15 milliseconds.

LEVR-2180 When assessing the source pyro shock environment descriptor as given in the LEVR, the following three factors shall be considered:

a. Because of the very complex waveform and very short duration of the time history, there is no accepted way for giving a unique, "explicit" description of the environment for test specification purposes. The accepted standard non-unique, "implicit" description is a "damage potential" measure produced by computing the Shock Response Spectrum (SRS) of the actual environment time history. A SRS is defined as the maximum absolute acceleration response, to the environment time history, of a series of damped, single-degree-of-freedom oscillators that have a specified range of resonant frequencies and a constant value of viscous damping (e.g., Q=10). The resulting fundamental objective of the verification test is to create a test environment forcing time history that has nearly the same SRS as the test specification and thereby give some assurance that the test environment has approximately the same "damage potential" as the actual environment.

b. Because of the high frequency, traveling wave response like nature of the subject environment, the acceleration level will be rapidly attenuated as a function of distance from the source and as the response wave traverses discontinuities produced by joints and interfaces.

c. Because of the high frequency, short duration nature of the pyro-shock environment, "potential for damage" is essentially restricted to portions of the observatory, or instrument that, for example, have very high frequency resonances (i.e., electrical/electronic elements such as relays, circuit boards, computer memory, etc.) and have high frequency sensitive electromechanical elements such as gyros, etc.

An Aerospace Systems Pyrotechnic Shock study was performed for GSFC and a report was generated in 1970 entitled Aerospace Systems Pyrotechnic Shock Data, NASA Contractor Report-116437, -116450, -116401, -116402, -116403, -116406, and -116019, Vol. I-VII. (Additional information and references can be found in Pyroshock Test Criteria NASA Technical Standard NASA-STD-7003). The following information, extracted from the 1970 final report of this study, is provided to aid in assessing expected shock levels. The results are empirical and based on a limited amount of data, but provide insight into the characteristics of the shock response spectrum (SRS) produced by various sources, and the attenuation of the shock through various structural elements.

The study evaluated the shock produced by four general types of pyrotechnic devices:

- Linear charges (MDF and FLSC);
- Separation nuts and explosive bolts;
- Pin-puller and pin-pushers;
- Bolt-cutters, pin-cutters and cable-cutters.

Empirically derived expected SRS's for these four categories are given in Tables x-4 through XX-7. It was found that the low-frequency region could be represented, or enveloped, by a constant velocity curve. All shock response curves are for a Q=10.

The attenuation, as a function of frequency and distance was evaluated for the following general types of structure:

- Cylindrical shell;
- Longeron or stringer of skin/ring- frame structure;
- Ring frame of skin/ring- frame structure;
- Primary truss member;
- Complex airframe;
- Complex equipment mounting structure;
- Honeycomb structure.

It was found that the attenuation of the Shock, as a function of distance from the source, could be separated into two parts; the attenuation of the low-frequency constant velocity curve, and the attenuation of the high-frequency peak levels. The attenuation of the constant velocity curve was roughly the same for all types of structure; whereas the attenuation of the higher frequency peak shock response was different for the various categories of structure. Figure 4-8 gives the attenuation of the constant velocity portion of the SRS as a function of distance, and Figure 4-9 gives the attenuation of the peak SRS level as a function of distance for the various general categories of structure.

It is emphasized that this information was derived empirically from a limited set of shock data.

As an example of the use of these attenuation curves, assume that the source spectrum is that for an explosive bolt given in Figure 4-5, and that an estimate of the shock levels 80 inches from the source is being evaluated for complex equipment mounting structure. From Figure 4-8, the constant velocity, low-frequency envelope will be attenuated to approximately 20% of the original level. From Figure 4-9, the peak level will be attenuated to approximately 7.8% of the original level. The assumed source spectrum and new estimate of the SRS envelope is shown in Figure 4-10.

Structural interfaces can attenuate a shock pulse; guideline levels of reduction are as follows:

Table 4 - 1 Shock Pulse Reduction Guidelines

Interface	Percent Reduction
Solid Joint	0
Riveted butt joint	0
Matched angle joint	30-60
Solid joint with layer of different material in joint	0-30

The attenuation due to joints and interfaces is assumed for the first three joints.

A reduction of shock levels can also be expected from intervening structure in a shell type structure. An example is shown in Figure 4-11.

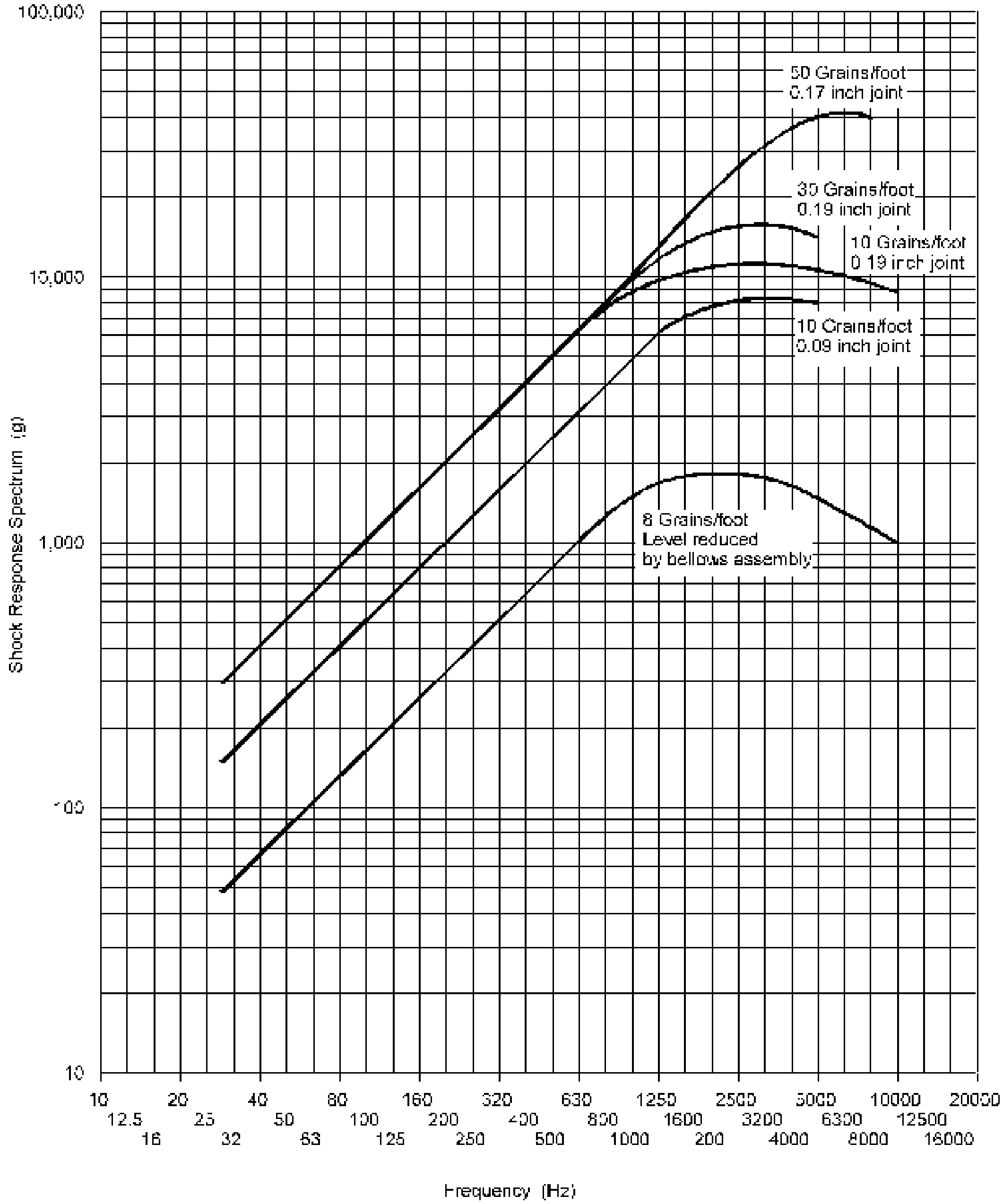


Figure 4 - 4 Shock Environment Produced by Linear Pyrotechnic Devices

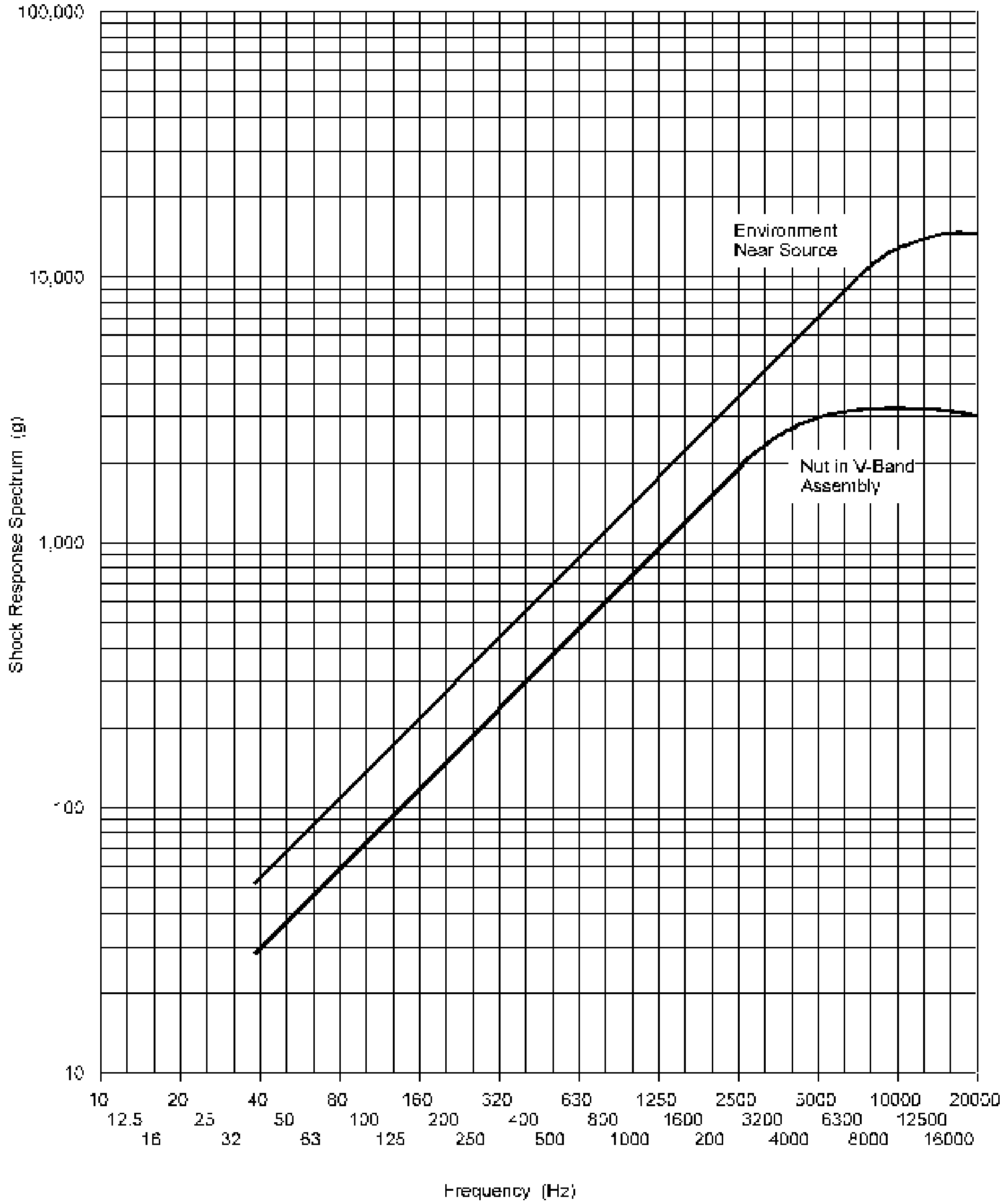


Figure 4 - 5 Shock Environment Produced by Separation Nuts and Explosive Bolts

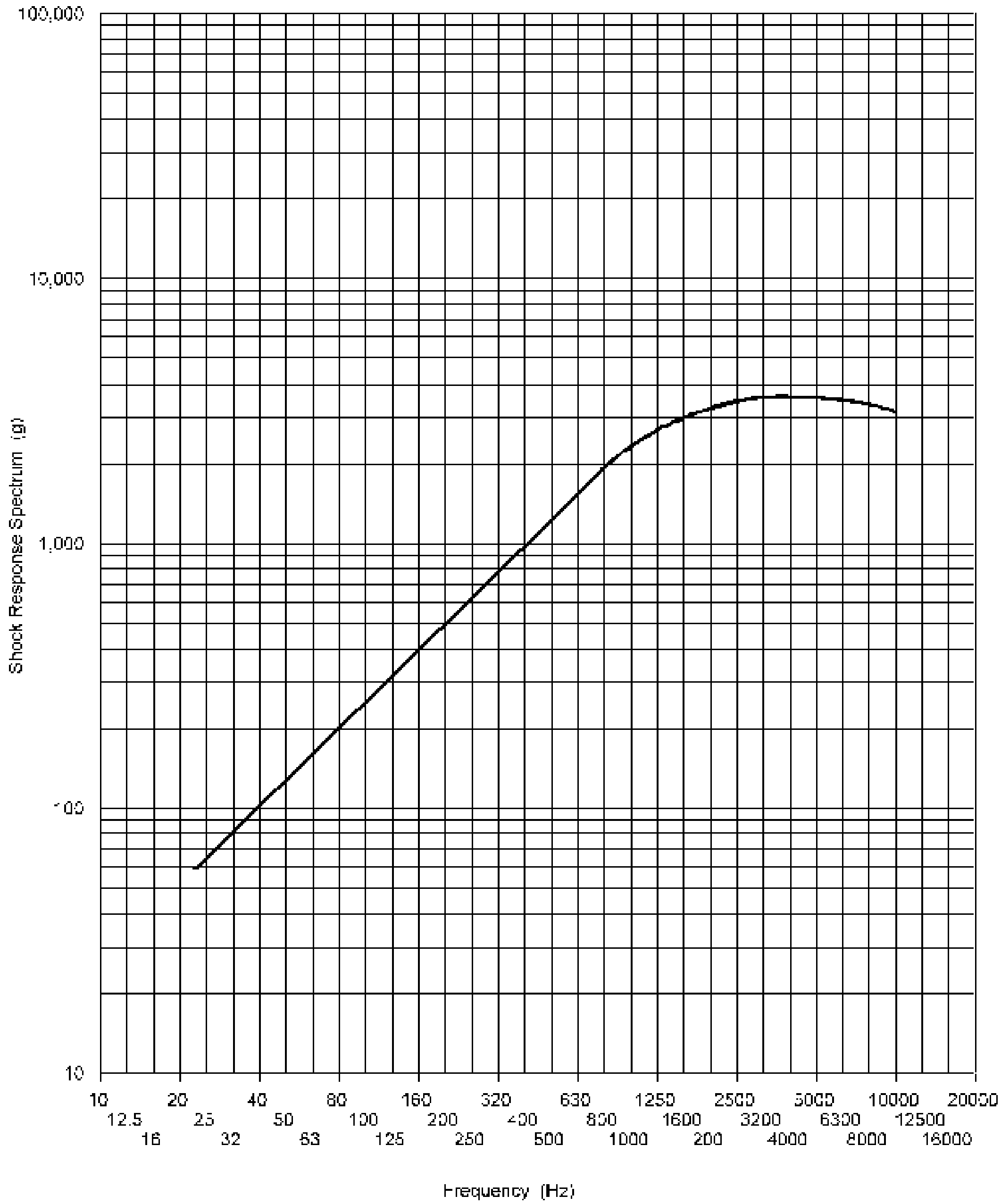


Figure 4 - 6 Shock Environment Produced by Bolt-Cutters, Pin-Cutters, and Cable-Cutters

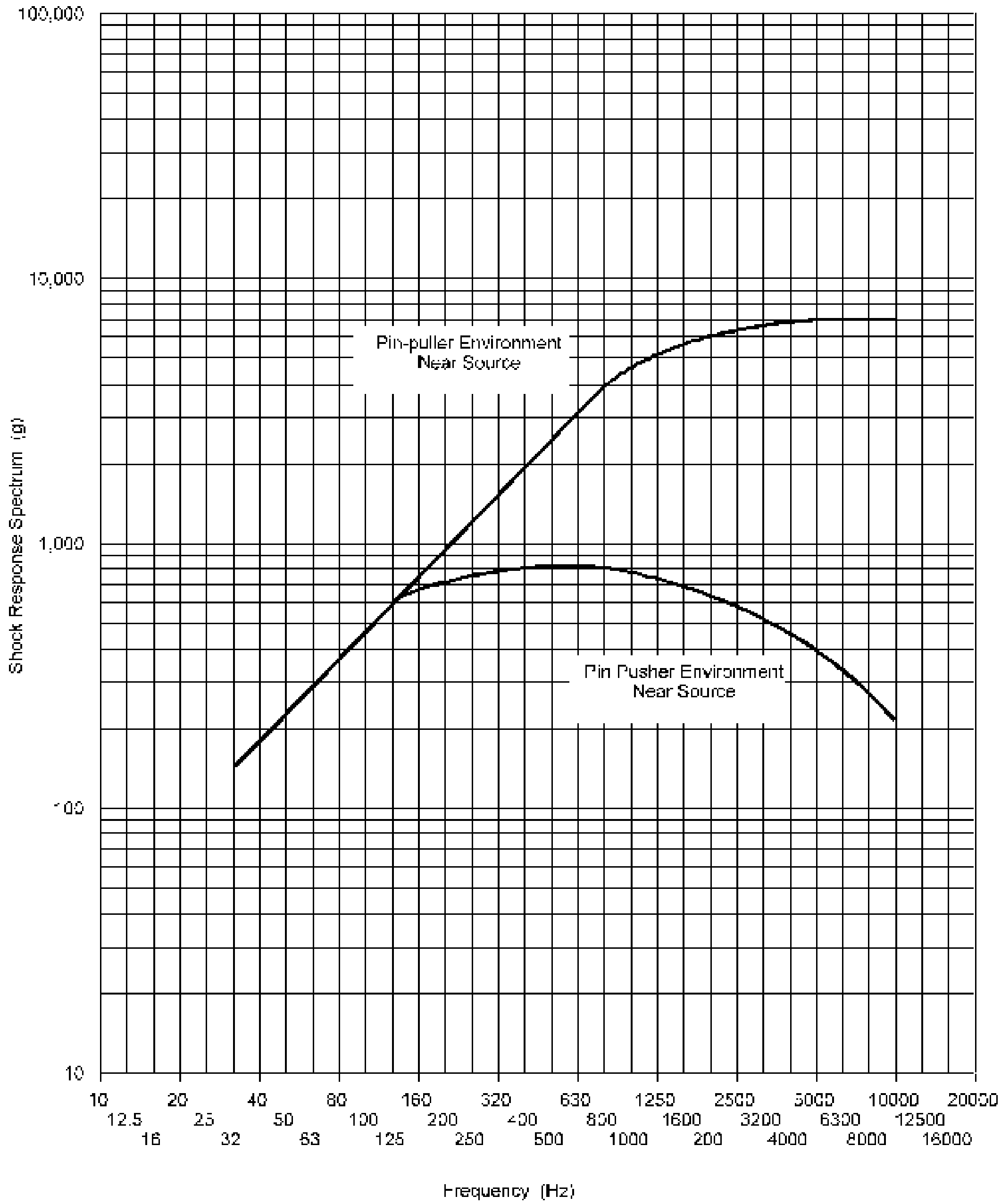


Figure 4 - 7 Shock Environment Produced by Pin-Pullers and Pin-Pushers

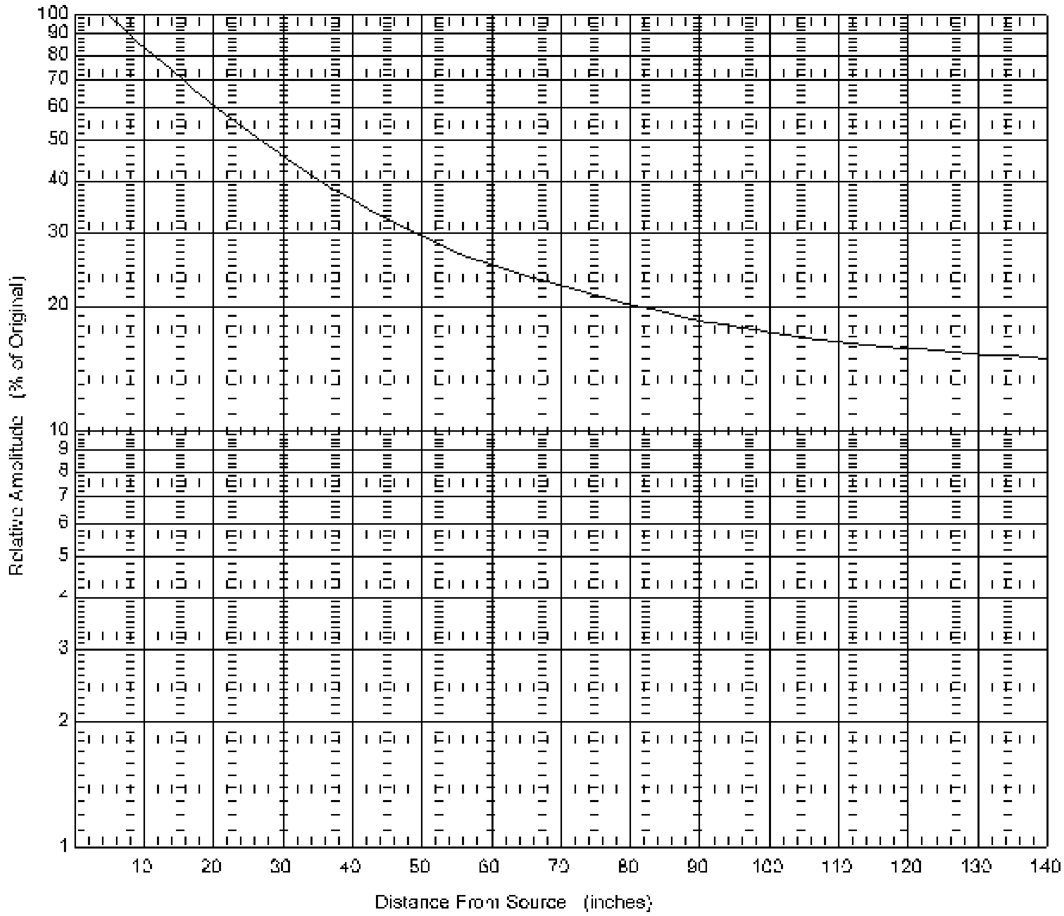


Figure 4 - 8 Attenuation of Constant Velocity Line

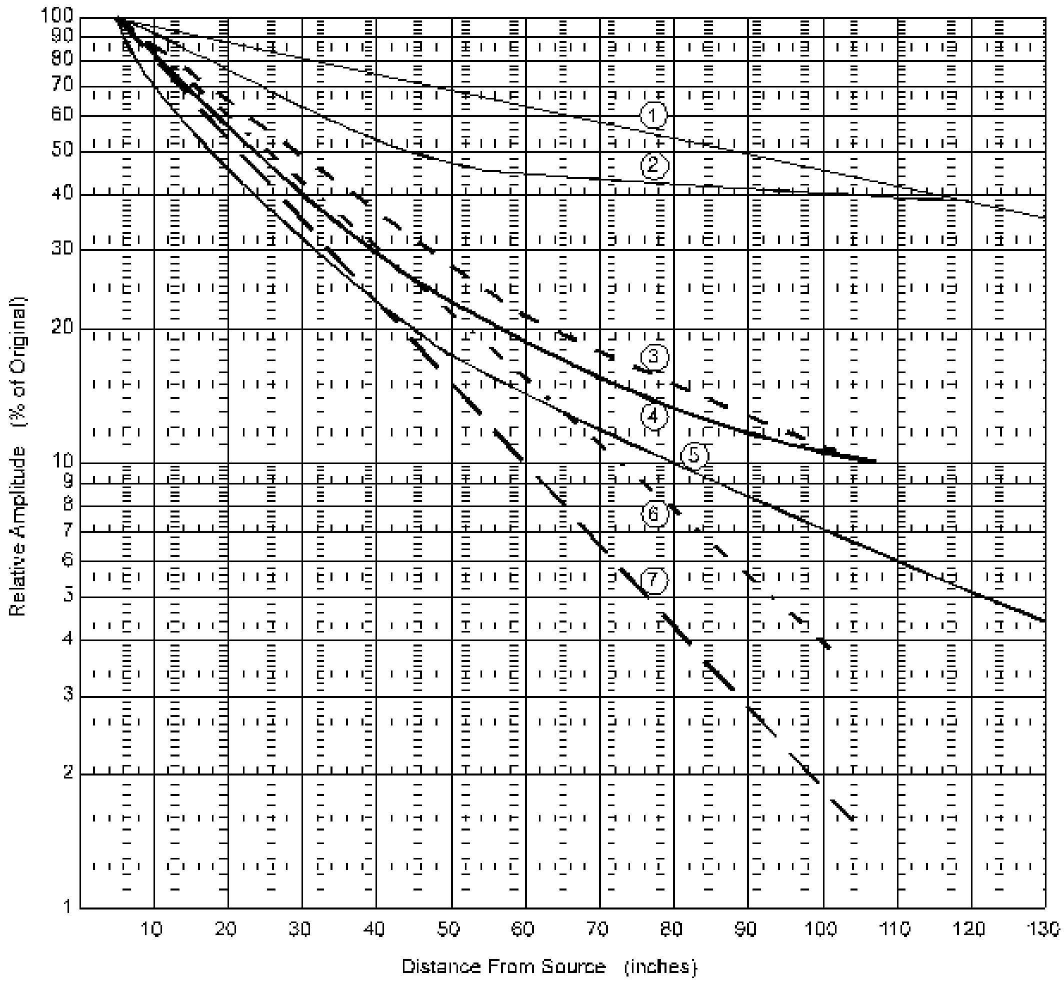


Figure 4 - 9 Peak Pyrotechnic Shock Response vs Distance

1 Honeycomb structure

2 Longeron or stringer of skin/ring-frame structure

3 Primary truss members

4 Cylindrical shell

5 Ring frame of skin/ring-frame structure

6 Complex equipment mounting structure

7 Complex airframe

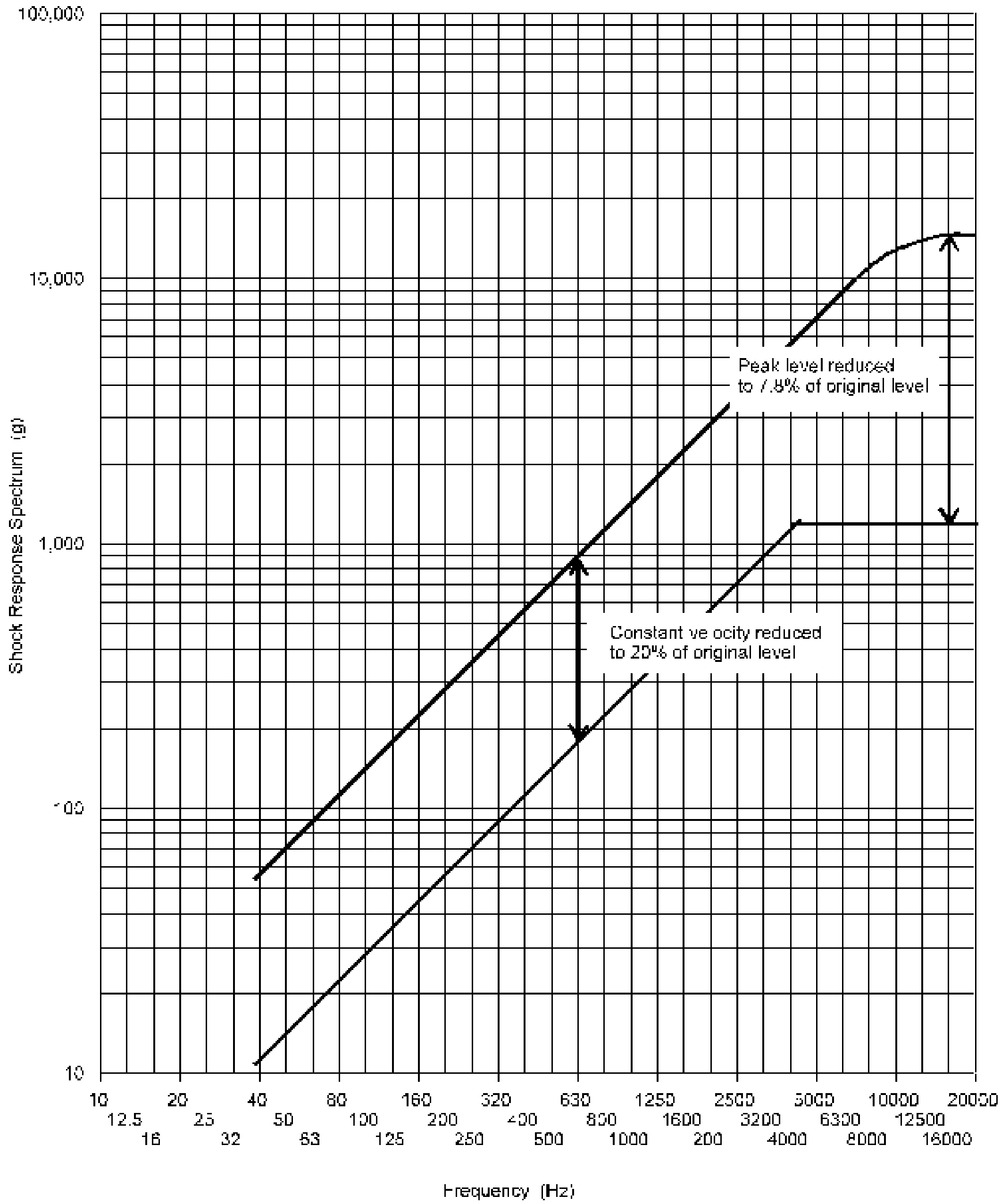


Figure 4 - 10 Shock Attenuation Example

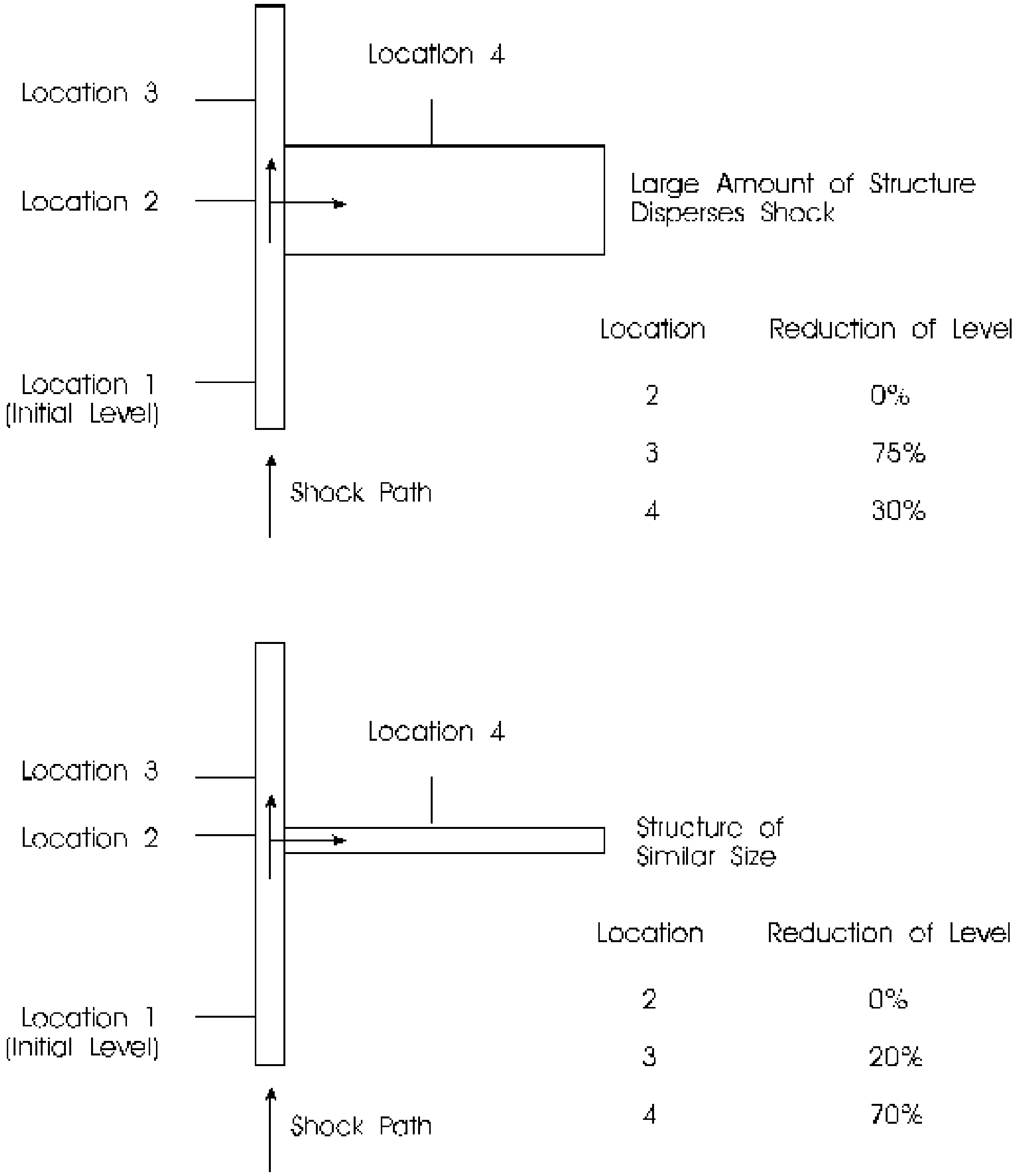


Figure 4 - 11 Reduction of Pyrotechnic Shock Response due to Intervening Structure