JPL D-26405

Mars Telecom Orbiter
Preliminary
Environmental Requirements Document

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Preliminary

October 8, 2003

Jet Propulsion Laboratory
California Institute of Technology

EXPORT CONTROLLED INFORMATION

Mars Telecom Orbiter
Preliminary
Environmental Requirements Document

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CHANGE LOG

DATE	SECTIONS CHANGED	REASON FOR CHANGE
July 12, 2003	All	Initial Draft Release
Sept 23, 2003	All	Initial Preliminary Release

FOREWORD

The Environmental Requirements Document is subject to periodic updates throughout the project life cycle. Many of the design and verification requirements may be updated as the Project matures.

Paper copies of this document may not be current and should not be relied on for official purposes. The current version is in the Product Data Management System (PDMS) at http://pdms.

This document is subject to the International Traffic in Arms Regulations (ITAR) limitations and restrictions for the export of technical information to foreign entities.

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1 INTRODUCTION

1.1 Purpose

This document defines the formal environmental program for the JPL Mars Telecom Orbiter (MTO). The purpose of a formal environmental design and verification program is to ensure the MTO flight hardware design is compatible with the mission environments, plus a robust margin.

The launch vehicle environments envelope Delta IV – 4450-14, Atlas V – 401, 511, 531, 541, and 551.

The MTO mission life is projected for 10 years plus an Earth to Mars cruise time of approximately 10 months (launch October 2009 and orbit insertion in August 2010). The Orbiter will be placed into a 5.8 hour, 4450 km orbit.

The following definitions are used throughout this document:

"Shall" = required

"Should" = recommended

"Will" = planned; to be carried out.

1.2 Scope

This document specifies the natural, self-induced, and mission-activity-induced design environments occurring over the mission life cycle which consists of the following phases: Ground Operations (including storage and transportation), Launch, and Space Operations. Included within this document are the Environmental Program Approach (Section 2); Environmental Test Policies (Section 3); the Environmental Design and Verification Requirements (Section 4); and the Environmental Test Implementations (Section 5).

1.3 Applicability

The requirements specified herein apply to MTO hardware supplied by JPL and by JPL contractors to MTO project. The requirements presented herein apply to EM/QUAL model (when used for qualification purposes or a potential flight spare), protoflight, flight, and flight spare hardware supplied by JPL and by JPL contractors and/or partners.

1.4 Applicable Documents

The documents listed in this section form a part of this ERD to the extent those documents are specified herein. In case of conflict between this document and any referenced document, this ERD shall take precedence. These documents may be used to provide further guidance to the ERD users.

Launch Vehicle Documents

CLSB-0105-0546	**Atlas Launch System Mission Planner's Guide** Revision 9, September 2001, by International Launch Services
MDC00H0043	**Delta IV Payload Planners Guide** October 2000

JPL Documents

JPL D-14040	Environmental Assurance Requirements http://rules.jpl.nasa.gov/cgi/doc-gw.pl?DocID=35491
DocID-60133	Assembly and Subsystem Level Environmental Verification http://rules.jpl.nasa.gov/cgi/doc-gw.pl?DocID=60133
JPL D-8208	Spacecraft Design and Fabrication Requirements http://rules.jpl.nasa.gov/cgi/doc-gw.pl?DocID=35120
JPL 900-434	Standard Environmental Testing Facilities and Practices http://rules.jpl.nasa.gov/cgi/doc-gw.pl?DocID=35492
JPL D-560	JPL Standard for Systems Safety http://rules.jpl.nasa.gov/cgi/doc-gw.pl?DocID=34880
JPL D-1348	Electrostatic Discharge (ESD) Control http://rules.jpl.nasa.gov/cgi/doc-gw.pl?DocID=34906
JPL D-8091	Anomaly Resolution http://rules.jpl.nasa.gov/cgi/doc-gw.pl?DocID=35506
JPL D-10401	Project Reviews http://rules.jpl.nasa.gov/cgi/doc-gw.pl?DocID=35163

Standards

MIL-E-6051D	System Electromagnetic Compatibility Requirements
MIL-STD-461C	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
MIL-STD-462	Measurement of Electromagnetic Interference Characteristics
MIL-STD-463	Definitions and System of Units, Electromagnetic Interference and Electromagnetic Compatibility

MIL-STD-1541	Electromagnetic Compatibility Requirements for Space Systems
NASA-HDBK-7004	Force Limited Vibration Testing Handbook
NASA-STD-7001	Payload Vibroacoustic Test Criteria
NASA-STD-7003	Pyroshock Test Criteria
NASA-STD-4003	Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment, September 8, 2003

JPL Forms

JPL Form 2683	Environmental Test Authorization and Summary (ETAS)
JPL Form 2573-S	Environmental Analysis Completion Statement (EACS)
JPL Form 1994-S	Category B Waiver Request

MTO Project Documents

JPL D-	MTO Project Configuration Management Plan
JPL D-	MTO Project Mission Assurance Plan
JPL D-	MTO Project Safety Plan
JPL D-	MTO Project Contamination Control Plan
JPL D-	MTO Project Quality Assurance Plan

2 ENVIRONMENTAL PROGRAM APPROACH

2.1 General

The environmental program is intended to demonstrate, through design, test, and/or analysis methods, the ability of the design to successfully withstand and/or operate in the required MTO ground, transportation, launch, and mission environments.

2.1.1 Environmental Verification Approach

Table 2.1-1 and Figure 2.1-1 show the general MTO assembly and system (spacecraft) environmental verification approach.

Table 2.1-1 General Environmental Assurance Approach for MTO

Environmental Program: Perform environmental tests for MTO assemblies by using a Protoflight (PF) program or a Qualification (Qual)/ Flight Acceptance (FA) program. See section 2.2.1 for definitions.
Environmental Test: Dynamics (a) Random vibration (w/ force limiting), assembly and system level. (b) Pyroshock, external (for selected assemblies containing components potentially susceptible to the pyroshock requirements, such as crystals, ceramics, epoxies, glass envelopes, solder joints and wire leads, seals, particle generation, relays and switches, and very light weight structural elements). If there is no EM available for Qualification, perform Protoflight test on a single PF unit. Pyroshock tests for the remaining flight units, such as structures, are not required unless specifically indicated. (c) Acoustic (for selected assemblies with large area to mass ratio, i.e., antennas and solar panels, or assemblies with thin diaphragms, and for system level). (d) Quasi-Static Loads (for assemblies with fundamental resonances below 80 Hz, and for the structure subsystem). (e) Firing of spacecraft and assembly pyrotechnic devices.
Environmental Test: EMC For all systems and subsystems tied to the power bus, perform comprehensive EMC tests including Conducted and Radiated Emissions, Conducted and Radiated Susceptibility, Isolation/Grounding. Perform on EM/Qual hardware provided this hardware is identical in form, fit and function (flight parts not necessary) to the flight hardware. Perform on the flight hardware if no EM/Qual units available. Perform delta testing on flight hardware if there are any design changes subsequent to EM/Qual testing. Perform isolation and grounding test on all flight hardware even if no changes since test on EM/Qual hardware.
Environmental Test: Thermal/Vacuum (T/V) Perform T/V test for all Qual and flight hardware. In certain cases temperature atmosphere testing may be substituted for T/V testing if approved by the JPL Environmental Requirements Engineer (ERE).
Thermal cycling: One to three thermal cycles required for assemblies where mission thermal environment is not expected to exhibit large thermal cycle range (e.g., ≥ 20°C). Up to 8 thermal cycles required for assemblies where mission thermal environment is expected to exhibit large thermal cycle range. *Note: This thermal cycling requirement does not include qualification for new packaging technologies*

Environments verified by analysis, sample/development test, etc: (a) Radiation: TID: verify all materials and parts meet RDF=2 TID requirement; Perform radiation transport analysis for non-compliant materials and parts. Displacement Damage: evaluate all parts for displacement damage sensitivity and application acceptability. SEE: perform circuit functional analysis. Evaluate the need for additional shielding or part replacement for parts not meeting SEE requirements. (b) Launch Pressure Decay: verify the design guidelines are followed or perform venting analysis. (c) Micrometeoroids: verify the good design practices are followed for susceptible hardware (e.g. external cables, tanks, fuel lines, etc). Evaluate the need for additional shielding based on probability of damage to spacecraft
Environmental Test/Analysis Reporting The following forms are used for formal reporting of environmental requirements verification: (1) Environmental Test Authorization and Summary (ETAS) (2) Environmental Analysis Completion Statement (EACS) (3) Radiation Analysis Completion Statement (RACS)

Environmental Program Flow

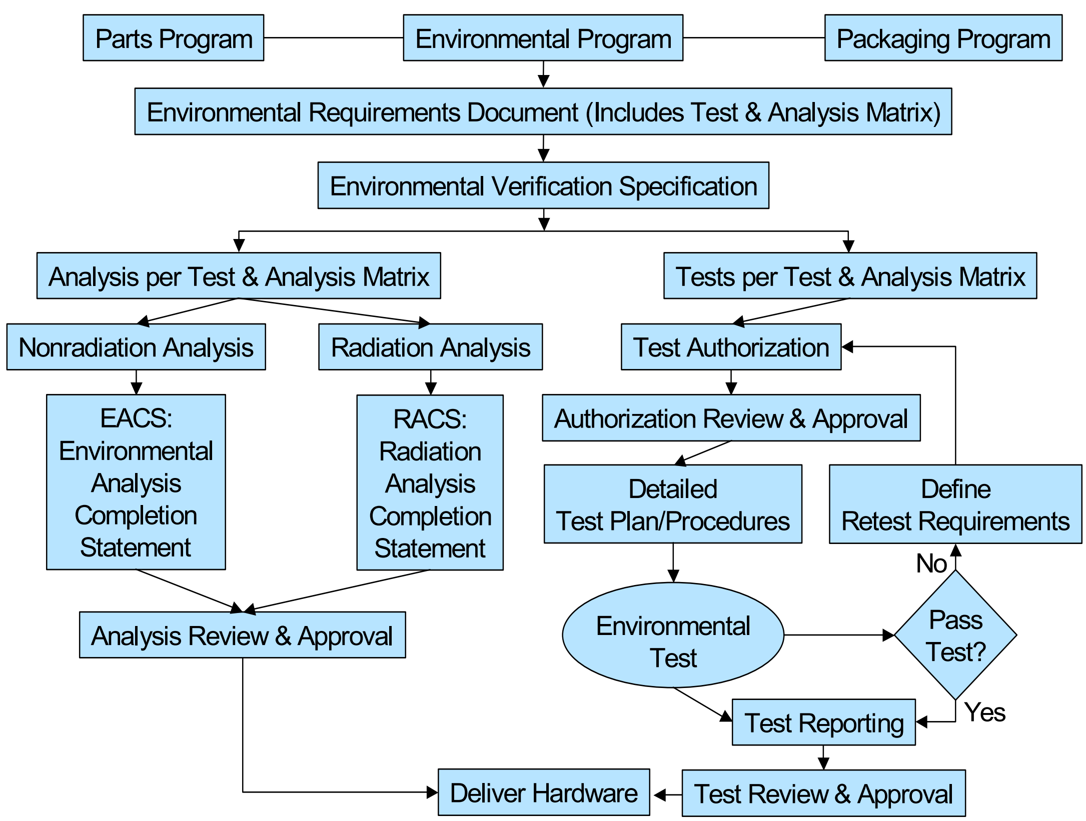

Figure 2.1-1 Environmental Program Flow

2.2 Environmental Verification

The Environmental Design and Verification Requirements are presented in Section 4 of this document.

MTO hardware shall be designed and verified consistent with the MTO Project margin requirements shown in Table 2.2-1, Mars Telecom Orbital Environmental Design and Test Margin Requirements. Deviation from the environmental margin or verification requirements shall require JPL MTO Project approval using the waiver process defined in JPL D-TBD MTO Project Configuration Management Plan.

2.2.1. Verification By Environmental Test

Environmental testing is the preferred method for verification of the environmental design requirements. Environmental testing is conducted at the system level and assembly and subsystem (or instrument) levels. The assembly level is the lowest environmental hardware test level normally addressed by the MTO environmental program. It pertains to a testable portion of a subsystem. Some subsystems have no lower level testable assemblies. In such a case, the subsystem is the lowest testable level and the term assembly (used for testing) pertains to the subsystem in this document.

Assembly/subsystem/instrument (henceforth, assembly) level testing is performed prior to delivery for higher level integration into the MTO system. Assembly level testing is the responsibility of the hardware supplying organization subject to certain requirements, approvals, and reports. Post delivery environmental testing at the system level of integration is the responsibility of the System Integration and Test (I&T) Manager. Section 3 of this document provides the project policies for environmental testing.

Environmental tests are categorized for the purpose of hardware quality verification as <u>Qualification (Qual)</u>, <u>Protoflight (PF)</u>, and <u>Flight Acceptance (FA)</u>.

Other environmental-related tests may also be performed as outlined below.

2.2.1.1 Qualification Test

Qualification (QUAL) testing is performed on a dedicated Qualification Model of flight hardware (or an Engineering Qualification Model (EQM) if approved for qualification purposes), <u>which is not intended to fly</u>, in order to qualify the hardware design for the maximum expected flight environment plus margin, including margin on environment duration or cycles.

See Table 2.2-1 for required Qualification test margins. Design and verification requirements are given in section 4.

2.2.1.2 Protoflight Test

Protoflight (PF) testing is performed on flight hardware, which is intended to be flown, and for which there is no or inadequate previous qualification heritage. Protoflight testing accomplishes the combined purposes of design qualification and flight acceptance.

See Table 2.2-1for required Protoflight test margins. Design and verification requirements are given in section 4.

2.2.1.3 Flight Acceptance Test

Flight Acceptance (FA) testing is performed on flight hardware and spares only when a protoflight or qualification test is performed on an identical item. If, as determined by a Heritage Review, previous qualification or protoflight test levels of a heritage assembly are adequate for the mission and the heritage design and operation is not modified in a way that negates the previous qualification, then the assembly may be flight acceptance tested.

See Table 2.2-1 for required Flight Acceptance test levels and durations. Design and verification requirements are given in section 4.

2.2.1.4 MTO Environmental Test Practices

Qual / FA: Perform environmental Qualification testing on a dedicated Qual unit and FA test all flight units.
This will be performed on new designs and identical builds or group buys and where the number of flight units, including flight spares, is 4 or more or where a dedicated Qual unit is justified. (ref 2.2.1.1 above).

PF / PF: Perform Protoflight testing on all flight units where a dedicated Qual unit is not justified.
This will be performed on new designs and identical builds or build-to-print units where the number of flight units is one, two, or three. (ref 2.2.1.2 above). The number of vibration test cycles in excess of the initial PF requirement will be closely monitored to minimize possible cumulative over testing.

FA: Perform Flight Acceptance testing.
This will be performed where a formal Heritage Review determines this to be the appropriate environmental test or where a dedicated Qual unit has justified FA testing the flight unit(s) (ref 2.2.1.3 above).

2.2.1.5 Other Environmental Tests

In addition to the above, other types of tests may be performed as outlined below.

2.2.1.5.1 Development Environmental Test

To gain insight into design compatibility or functionality in expected environments, development testing may be performed (e.g., a dynamics test model may be assembled for purposes of structural verification). Such testing is the responsibility of the hardware supplying organization. While development testing is not a part of the formal environmental test program, it may have a significant impact on the program (e.g., may result in revision of test margins), therefore, development environmental testing should be coordinated with the JPL Project Environmental Requirements Engineer (ERE). Development environmental tests involving flight or flight spare hardware as part of the test article shall be formally controlled and shall meet the formal requirements associated with the environmental test program.

2.2.1.5.2 Life Test

Life test requirements for life-limited items are described in JPL D-TBD, MTO Mission Assurance Plan. The environmental conditions under which life tests are conducted shall be coordinated with the Project Environmental Requirements Engineer.

2.2.1.5.3 Test of Flight Spare Hardware

Flight spare assemblies shall be environmentally tested prior to use on the flight system. Spare hardware which has been used as a qualification unit shall be evaluated upon completion of testing to determine the need for refurbishment prior to commitment of the hardware for use as flight spare hardware. Refurbished hardware shall be subjected to environmental retesting to screen for workmanship defects or to requalify the hardware, as determined by JPL MTO project review.

2.2.1.5.4 Retest of Hardware

Environmental retesting of hardware is performed on qualification, flight, and flight spare hardware that has failed during or after environmental testing or has been redesigned or reworked following the completion of environmental testing. Retest requirements and guidelines are given in paragraph 3.3.8 and Appendix A respectively. Retest levels shall be approved by the ERE.

2.2.2 Verification By Analysis

Environmental compatibility analyses are performed in order to verify hardware design compatibility with ground, transportation, launch, and/or mission environments which may be impractical to verify by test or that are significantly more cost effective than testing (e.g. micrometeoroid compatibility; radiation dosage compatibility). Environmental analyses shall be performed against environmental design criteria in Section 4 of this document.

For each required analysis, an Environmental Analysis Completion Statement (EACS) or a Radiation Analysis Completion Statement (RACS), as applicable, shall be prepared by the hardware supplying organization. The Contract Technical Manager (CTM) may elect to complete these forms for the hardware provider. Approvals by the cognizant Technical Manager or Program Element Manager (PEM) and the JPL ERE are required on the EACS or RACS. All EACS and RACS for a given configuration item shall be submitted prior to commencing with formal environmental testing. These documents shall be included in the HRCR (Hardware Review/Certification Requirements) package. Appendix C includes sample EACS and RACS. Formal analysis reports may be submitted in lieu of EACS and RACS.

2.2.3 Other Forms of Verification

Other methods of verification include Inspection and Process Control. If these methods are utilized, formal documentation shall be submitted to the JPL Project ERE for approval (i.e., inspection report, memorandum documenting method, etc.).

Table 2.2-1 Environmental Design and Test Margin Requirements for MTO (TBC)

Environmental Design and Test Margin Requirements			
Environment	**Design/ Qualification**	**Protoflight (PF)**	**Flight Acceptance (FA)**
Acoustics Level Duration	MEFL[1] + 3 dB 2 min	MEFL + 3 dB 1 min	MEFL 1 min
Random Vibration Level Duration	MEFL + 3 dB 2 min/axis	MEFL + 3 dB 1 min/axis	MEFL 1 min/axis
Pyro Shock Firings or Levels	2 firings or MEFL + 3 dB 2 shocks/axis	2 firings or MEFL + 3 dB 1 shock/axis [5]	N/A (no test required)
Static Loads Level	Design: 1.4 x FLL* Verification: 1.4 x FLL * FLL=Flight Limit Load	1.2 x FLL	1.05 x FLL (composites only)
Thermal Vacuum[2] Temperature Levels	Cold: AFT[4] - 15°C or -35°C (whichever is colder) Hot (non-electronics): AFT + 20°C Hot (electronics): AFT + 20°C or +75°C (whichever is higher)	Cold: AFT[4] - 15°C or -35°C (whichever is colder) Hot (non-electronics): AFT + 20°C Hot (electronics): AFT + 20°C or +75°C (whichever is higher)	Cold: AFT[4] - 5°C or -25°C (whichever is colder) Hot (non-electronics): AFT + 5°C Hot (electronics): AFT + 5°C or +55°C (whichever is higher)
Test Duration[3]	Cold: 24 hours Hot (non-electronics): 24 hours Hot (electronics): 144 hours [6]	Cold: 24 hours Hot (non-electronics): 24 hours Hot (electronics): 144 hours [6]	Cold: 24 hours Hot (non-electronics): 24 hours Hot: (electronics): 60 hours [6]
# of Cold/Hot Starts Electronics only	5 starts hot 5 starts cold	3 starts hot 3 starts cold	3 starts hot 3 starts cold
EMC (Radiated/Conducted Emissions and Susceptibility)	MEFL - 6 dB (emissions) MEFL + 6 dB (susceptibility) [5]	MEFL - 6 dB (emissions) MEFL + 6 dB (susceptibility) [5]	N/A (grounding/isolation only)
Ionizing Radiation Design Factor (RDF)	RDF = 2 Spot shielding, RDF =3		

Notes for Table 2.2-1

1. MEFL = Maximum Expected Flight Level
2. All assemblies shall be tested in vacuum ($<10^{-5}$ torr) unless otherwise exempted
3. Duration requirement may be cumulative if more than 1 test performed
4. AFT = Allowable Flight Temperature, typically includes both operational and non-operational limits
5. For pyro-shock and EMC testing, if there is no suitable EQM or Qual unit available for Qualification, then a Protoflight test shall be performed on a single PF unit. Remaining flight units are given isolation and grounding tests.
6. Based on JPL DocId-60133 "Assembly and Subsystem Level Environmental Verification".

Table 2.2-2 Environmental Requirements Verification Matrix

MTO Environmental Verification Matrix *(Preliminary - Details to be Confirmed Prior to Spacecraft PDR)*

MTO Environmental Verification Matrix	Qual/Protoflight																	Flight Acceptance					**Legend:** A = Verify by Analysis T = Verify by Test T/A = Verify by Test or Analysis P = Verify by Protoflight Test Q = Verify by Qualification Test F = Verify by Flight Acceptance Test H = Test or Analysis performed at higher level of assembly
	Acoustics	Random Vibration	Pyrotechnic Shock	Quasi-Static Loads/Sine burst	Thermal Vacuum	Thermal Shock	Thermal Atmosphere	Multipacting/Ionization Breakdown/Corona	Launch Pressure Profile/Venting	Radiated Susceptibility	Conducted Susceptibility	Radiated Emissions	Conducted Emissions	Grounding/Isolation	Micrometeoroid Penetration	Space Particle Radiation	Atomic Oxygen	Acoustics	Random Vibration	Thermal Vacuum	Thermal Atmosphere	Isolation	
Orbiter System Level	P	P	P		P					P		P								T			T=Thermal Balance and Margin Test
Assembly Level																							
Structures																							
Orbiter Structure				T					A														
Solar Array Substrates	H			T					A														
	H			T					A														
Miscellaneous																							
Solar Array Dampers		P		T																			
Solar Array Hinges				T	H											A							
		P					P																
1 DOF Gimbal		P		T	P				A	T	T	T	T	T	A	A						T	
		P		T	P				A	T	T	T	T	T	A	A						T	

Table 2.2-2 (continued) Environmental Requirements Verification Matrix

MTO Environmental Verification Matrix *(Preliminary - Details to be Confirmed Prior to Spacecraft PDR)*

MTO Environmental Verification Matrix	Qual/Protoflight																	Flight Acceptance				
	Acoustics	Random Vibration	Pyrotechnic Shock	Quasi-Static Loads/Sine burst	Thermal Vacuum	Thermal Shock	Thermal Atmosphere	Multipacting/Ionization Breakdown/Corona	Launch Pressure Profile/Venting	Radiated Susceptibility	Conducted Susceptibility	Radiated Emissions	Conducted Emissions	Grounding/Isolation	Micrometeoroid Penetration	Space Particle Radiation	Atomic Oxygen	Acoustics	Random Vibration	Thermal Vacuum	Thermal Atmosphere	Isolation
Electrical Power Subsystem																						
Solar Array Panels Assembly	P				P	P								T	A	A						T
Solar Array Switching Module		P			P				A					T								T
42 Ahr NiH2 Batteries		P	P	A	P									T	A	A						T
Power Distribution Unit		P	P	A	P				A	T	T	T	T	T	A	A						T
DC-DC Converter		P	P	A	P				A	T	T	T	T	T	A	A						T
Pyro Initiation & Prop Valve Drive Module		P	P	A	P				A	T	T	T	T	T	A	A						T
Attitude and Articulation Control Subsystem																						
Star Tracker		P	P	A	P				A	T	T	T	T	T	A	A						T
Sun Sensors		P	P	A	P				A	T	T	T	T	T	A							T
IMU		P	P	A	P				A	T	T	T	T	T	A	A						T
Reaction Wheel Assemblies		P	P	A	P				A	T	T	T	T	T	A	A						T
Gimbal Drive electronics		P	P	A	P				A	T	T	T	T	T	A	A						T

Legend:
A = Verify by Analysis
T = Verify by Test
T/A = Verify by Test or Analysis
P = Verify by Protoflight Test
Q = Verify by Qualification Test
F = Verify by Flight Acceptance Test
H = Test or Analysis performed at higher level of assembly

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Table 2.2-2 (continued) Environmental Requirements Verification Matrix

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MTO Environmental Verification Matrix	Qual/Protoflight																	Flight Acceptance				
	Acoustics	Random Vibration	Pyrotechnic Shock	Quasi-Static Loads/Sine burst	Thermal Vacuum	Thermal Shock	Thermal Atmosphere	Multipacting/Ionization Breakdown/Corona	Launch Pressure Profile/Venting	Radiated Susceptibility	Conducted Susceptibility	Radiated Emissions	Conducted Emissions	Grounding/Isolation	Micrometeoroid Penetration	Space Particle Radiation	Atomic Oxygen	Acoustics	Random Vibration	Thermal Vacuum	Thermal Atmosphere	Isolation
Telecommunications Subsystem																						
Electra Transceiver		P	P	A	P			T/A	A	T	T	T	T	T	A	A						T
Electra UHF Coax Switch		P	P	A	P			T/A	A	T	T	T	T	T	A	A						T
Electra UHF Antenna		P					P								A							
Electra X-band Downconverter																						
Electra USO		P	P	A	P				A	T	T	T	T	T	A	A						T
Electra X-Band Med Gain Antenna		P		A			P		P						A							
High Gain Antenna	P			A		P	P		A													
Low Gain Antennas		P					P								A							
TWTA - Ka Band, 35 watt		P	P	A	P			T/A	A	T	T	T	T	T	A	A						T
TWTA - X-Band, 100 watt		P	P	A	P			T/A	A	T	T	T	T	T	A	A						T
X-Band SSPA, 15 Watt or X-Band TWTA, 30 watt		P	P	A	P				A	T	T	T	T	T	A	A						T
SDST		P	P	A	P			T/A	A	T	T	T	T	T	A	A						T
X-Band Diplexer		P			P																	
Passive RF Components		P					P															
RF Switch, Transfer, Coax		P			P																	
RF Switch, Transfer, Waveguide		P			P																	

Legend:
A = Verify by Analysis
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C&DH		P	P	A	P				A	T	T	T	T	T		A						T
Flight Computer (incl. NVM)		H	H	H	H				H	H	H	H	H	H		H						
CMIC (C&DH Module I/F Card)		H	H	H	H				H	H	H	H	H	H		H						
ULDL (Uplink/DownlinkCard)		H	H	H	H				H	H	H	H	H	H		H						
GIF (G&C I/F Card)		H	H	H	H				H	H	H	H	H	H		H						
AAC (Analog Acquisition Card)		H	H	H	H				H	H	H	H	H	H		H						
DTCI (Data, TLM & CMD I/F Card)		H	H	H	H				H	H	H	H	H	H		H						
Power Card		H	H	H	H				H	H	H	H	H	H		H						
SSR		P	P	A	P				A	T	T	T	T	T		A						T
Propulsion																						
Fuel Propellant Tank				A																		
Fuel Tank PMD		P		A																		
Helium Tank				A																		
Dual Regulator		P		A			P															
Fill & Drain Valves HP		P	P	A			P															
Fill & Drain Valves LP		P	P	A			P															
Fill & Drain Valves Liq		P	P	A			P															
Fill & Drain Valves Liq1/		P	P	A			P															
Filters HP Gas		P		A																		
Filters Fuel 3/8		P		A																		

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Filters Fuel 3/8		P		A																			
Pyro Valves NO Gas		P	P	A			P																
Pyro Valves HP NC Gas		P	P	A			P																
Pyro Valves NC 1/2		P	P	A			P																
Latch Valve 3/4"		P	P	A			P																
Latch Valv 1/4 F		P	P	A			P																
Transducers HP Gas		P	P	A			P							T									
Transducers LP		P	P	A			P							T									
0.9N Thrusters		P	P	A	P	P																	
22N Thrusters		P	P	A	P	P																	
450N Main Engines		P	P	A	P	P																	
Thermal																							
Heaters					P									T									
Thermostats					P																		
ors					P									T									
MLI					P									T	A								P=MLI Bakeout

Table 2.2-2 (continued) Environmental Requirements Verification Matrix

MTO Environmental Verification Matrix *(Preliminary - Details to be Confirmed Prior to Spacecraft PDR)*																							
	Qual/Protoflight																	Flight Acceptance					
MTO Environmental Verification Matrix	Acoustics	Random Vibration	Pyrotechnic Shock	Quasi-Static Loads/Sine burst	Thermal Vacuum	Thermal Shock	Thermal Atmosphere	Multipacting/Ionization Breakdown/Corona	Launch Pressure Profile/Venting	Radiated Susceptibility	Conducted Susceptibility	Radiated Emissions	Conducted Emissions	Grounding/Isolation	Micrometeoroid Penetration	Space Particle Radiation	Atomic Oxygen	Acoustics	Random Vibration	Thermal Vacuum	Thermal Atmosphere	Isolation	**Legend:** A = Verify by Analysis T = Verify by Test T/A = Verify by Test or Analysis P = Verify by Protoflight Test Q = Verify by Qualification Test F = Verify by Flight Acceptance Test H = Test or Analysis performed at higher level of assembly
Harnesses					P										A								P=Harness Bakeout
Payload																							
Optical Comm - optics assembly		P	P	A	P				A	T	T	T	T	T	A	A						T	
Optical Comm - electronics assembly																							
TBD science instrument(s)																							
Orbiting Sample Demonstration Canister (incl. release latches)																							
Narrow Angle Camera		P	P	A	P				A	T	T	T	T	T	A	A						T	

3 ENVIRONMENTAL TEST POLICY

3.1 General

This section provides the implementation, control, and reporting policies for environmental testing of MTO hardware. The requirements of this section apply to all MTO assembly environmental tests taking place at JPL, contractor or subcontractor facilities, or other government agencies.

3.2 Environment Test Controls

To authorize an environmental test, a JPL ERE approved Environmental Test Authorization and Summary (ETAS) form (JPL form 2683) or an equivalent contractor document type is required before the start of an environmental test. Environmental Test Procedures shall be prepared and approved by the ERE or his representative. A representative test program flow of applicable documents is shown in Figure 3-1.

3.2.1 Environmental Test Authorization and Summary (ETAS) – Authorization

The ETAS includes an authorization section to be completed and approved prior to environmental testing, and a summary/reporting section to be completed following environmental testing. (See section 3.4 below for details on the Reporting section of the ETAS). Applicable test requirements from this document are entered on the ETAS form. A separate ETAS shall be prepared for each serial numbered test article listed in the Test and Analysis Configuration Matrix. It is prepared by the hardware Cognizant Engineer and approved by the ERE. The hardware Cognizant Engineer extracts the applicable test requirements from this document and enters them on the ETAS form. If possible, the ETAS should include authorization for the entire environmental test suite for that test article. (For instance, a given test article may be authorized for random vibration, thermal vacuum and EMC all on the same form). Appendix C contains a sample ETAS form.

The ETAS is required for all JPL and contractor-provided hardware. An approved ETAS or a contractor equivalent takes precedence over requirements specified in other environmental documents, including this document. The ETAS, including any revisions, shall be approved by the JPL ERE prior to beginning the test.

Minor changes and exceptions to the environmental test requirements that are noted on the ETAS and approved by the JPL ERE do not require a supporting Engineering Change Request (ECR) or Waiver. However, if the deviation is unacceptable to the JPL ERE (e.g. an environmental test is omitted or severely reduced), appropriate change documentation (ECR or Waiver, or contractor equivalent form) shall be required before the ETAS is approved.

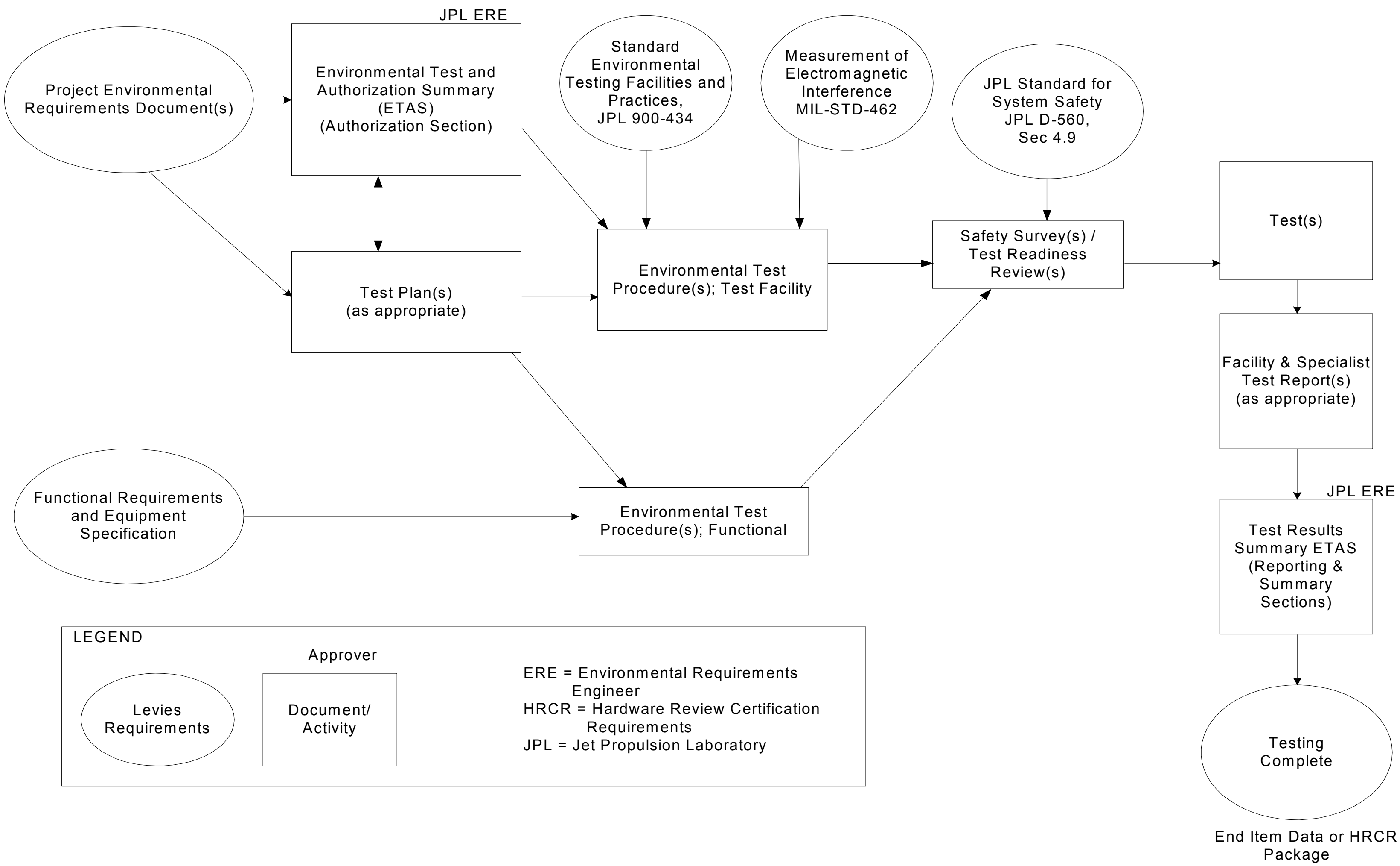

Figure 3.0-1 Environmental Test Authorization and Reporting Flow (for Contractor)

3.2.1.1 Deviation from Requirements

Minor changes and exceptions to the environmental test requirements which are noted on the ETAS and approved by the ERE do not usually require a supporting Engineering Change Request (ECR) or Waiver. However, if the deviation is significant (e.g. an environmental test is omitted or severely reduced) then the ETAS will not be approved and a waiver will be required.

3.2.1.2 Engineering Change Notice (ECN)

A change to environmental test specifications that will affect all serialized units of a particular hardware group shall be implemented through an ECN requiring Project/Flight System Manager and ERE approval.

3.2.2 Environmental Test Procedures

Environmental tests of flight hardware shall be performed in accordance with approved environmental test procedures.

In the event of a test malfunction or failure, or if a revision is made to the applicable ETAS, the environmental test procedure shall be reviewed and, if necessary, re-approved.

3.3 Implementation

Test agencies shall perform environmental testing in accordance with JPL D-35492, Standard Environmental Testing Facilities and Practices (900-434). These minimum standards apply to test facilities at JPL, at a contractor's site, at an independent test laboratory, or other government facilities. EMC/magnetic tests standards shall be in accordance with MIL-STD-462.

3.3.1 Required Tests

MTO assemblies shall be environmentally tested in accordance with the Environmental Requirements Verification Matrix, Table 2.2-2.

3.3.2 Hardware Test Configuration

Each test article shall be tested in equipment groupings as listed in the Environmental Requirements Verification Matrix and shall be configured identical to its flight configuration, including electrical cabling, connectors, and other fittings associated with the flight assembly. Each test article shall be comprised of the serial numbered subassemblies that are intended to remain with the assembly or subsystem through flight. Exceptions to any of the above must be authorized by an approved ETAS.

3.3.3 Operational Requirements During Environmental Test

During environmental testing, each test article shall be operated in functional modes that demonstrate performance within specification when exposed to the extreme range of environmental test conditions, without any adjustments, not possible during flight. Additionally, the test article's functional performance shall be verified before and after environmental testing. Modes that verify functional and electrical interface requirements shall be identified and specified in the functional test procedure. The test article shall be operated in logic and power states that validate the integrity of electrical circuits and interfaces. This includes circuits internal to the assembly and circuits that interface directly with other assemblies of the MTO system or with external interfaces.

Start up capability shall be demonstrated from the non-operational state worst case environmental conditions (e.g., at high and low temperature extremes).

All engineering assemblies shall be powered ON during dynamics tests. This does not apply if the engineering assembly's mechanical operation makes this impractical and it does not operate during the dynamic environment. Science instrument assemblies that are operating during the mission's dynamic events/environments, such as pyro events, propellant burns, and launch shall be powered ON during dynamic tests.

3.3.4 Test Sequence

The Qual test for a Qual assembly shall be completed before the Flight Acceptance (FA) tests for those flight assemblies. Dynamics tests should precede thermal tests (i.e., in order of flight exposure). Dynamic tests should proceed in the reverse order of flight (pyroshock and sine burst prior to random vibration) on a per axis basis (all dynamics tests in 1 axis prior to the next axis). This actual sequence of environmental tests (i.e., dynamics, vacuum, etc.) shall be approved by the JPL ERE based on the flight environment sequence or a review of the hardware design and materials, the sensitivity of the assembly to each environment, and the potential effect each environment has on other environmental characteristics. It is preferable to perform EMC testing prior to dynamics or thermal testing. This allows for hardware changes to correct EMC failures without invalidating the dynamics or thermal tests.

3.3.5 Developmental Testing

Development environmental tests that incorporate flight or flight spare hardware (e.g. flight structure) shall be no more severe than the levels and durations specified herein unless deviations are specifically approved by the JPL ERE using an ETAS form. Furthermore, any such testing that includes flight hardware or flight spares or items intended to be placed into flight or flight spare status shall comply with the formal environmental test program, as well as Problem/Failure Reporting, and Quality Assurance policies and requirements.

3.3.6 Voltage/Temperature/Frequency Margin Testing

If voltage/temperature/frequency margin testing is to be performed or substituted for Worst Case Analysis (WCA), the requirements of the MTO Project Reliability Assurance Requirements (JPL D-TBD) shall apply. Temperatures applied during this test shall not exceed the assembly's protoflight test levels.

3.3.7 Test Failure

Failure or malfunction of the test article during environmental testing shall, in general, be interpreted as a test failure. Testing must be immediately discontinued unless, upon review by JPL MTO ERE and MAM, continuation is of diagnostic value and will not damage the flight hardware. When test failure occurs, PFR shall be prepared in accordance with section 3.4.3.

In case of problems or failures associated with the test equipment, the test must be discontinued unless JPL and Test Agency Engineer agree that the test should continue and flight hardware safety is assured.

3.3.8 Re-Test Requirements

Failure of MTO flight hardware resulting from formal environmental testing shall, in general, invalidate the test. Re-testing to the prescribed environment shall be required, unless other test requirements are approved by the JPL ERE. Furthermore, any design change, modification, or configuration change occurring after completion of testing shall, in general, invalidate the test and shall, depending on the nature of the change, be the cause for assessment of re-test of certain selected environments. The JPL ERE will recommend to JPL MTO project whether or not a re-test is required with inputs from the hardware supplying organization, and if so which environmental test to repeat and what levels the test will use (FA, PF, or Qual). Approval by the JPL ERE of documentation for a re-test is required. The documentation can consist of an attachment to the ETAS for that particular assembly. See Appendix A for Retest Guidelines.

3.3.9 Test Article Handling and Safety

The handling of a test article in an environmental test facility, including attachment of any test fixture, is the responsibility of the hardware supplying organization. <u>Environmental test agencies shall provide adequate protective and diagnostic devices on test facilities to limit over-testing</u>. Such devices shall be functionally checked prior to each test (see JPL D-560). The hardware supplying organization is responsible for controlling all the environments their hardware experiences prior to delivery to instrument I&T. Following delivery to I&T, the I&T Manager is responsible. JPL

Safety shall review all assembly test plans and preparations as detailed in the MTO Safety Plan (JPL D-TBD).

3.3.10 Environmental Test Monitoring

A Quality Assurance (QA) representative, JPL or designated contractor personnel, shall witness all assembly and system level environmental testing involving flight hardware in total or in part. The MTO QA representative and the MTO ERE shall be notified by the hardware supplying organization or by the I&T Manager of pending assembly and system environmental tests. The QA representative shall perform his/her duties in conformance with the MTO Quality Assurance Plan, JPL D-TBD.

3.4 Environmental Test Reporting

3.4.1 Flight Certification

All environmental testing (from the assembly through the system level) shall be reported at the JPL HRCR (Hardware Review/Certification Requirements) Review and at the contractor's Preship Review. (See JPL D-10401, JPL Guideline for Reviews).

3.4.2 Environmental Test Authorization and Summary (ETAS) – Reporting/Summary

Upon completion of each environmental test for a given serial numbered hardware, the Reporting and Summary section of the ETAS shall be updated by the hardware supplying organization. The completed ETAS shall be submitted to the JPL ERE for review and approval. The ETAS shall identify the following: 1) all test-related PFRs for a specific environment (see 3.4.3.1 below); 2) all environmental test reports; 3) all inspection reports occurring prior to and subsequent to environmental testing; 4) any waivers or ECRs relating to the environmental test requirements. The environmental test program for a given serial numbered hardware is completed when the Reporting/Summary portion of the ETAS is approved by the JPL ERE.

For contracted assemblies, the contractor shall complete the ETAS and submit to JPL ERE for approval.

3.4.3 Problem/Failure Report

Failure or malfunction of a test article or test facility during environmental test shall be reported in accordance with MTO Problem/Failure Reporting Plan JPL D-TBD. If MTO flight hardware could have been impacted by an environmental test facility failure, two PFRs shall be written: one for the test article, and one for the environmental test facility.

The QA representative shall be informed of the initiation of PFRs. Environmental test PFRs shall be approved by the JPL ERE.

3.4.3.1 Pass/Fail Criteria

The hardware supplying organization should carefully assess the probable PFR disposition/corrective action. After consideration of any or all redesign, modifications, or reworks open against the hardware, the hardware supplying organization shall present the pass/fail position to the JPL ERE for Project approval. As a part of this review/approval, any re-testing requirements will be identified. The process should be completed prior to hardware delivery for next-level integration.

4 ENVIRONMENTAL DESIGN AND VERIFICATION REQUIREMENTS

4.1 General

The environmental design and verification requirements presented in this section are established to assure design compatibility of the MTO assemblies with the specified ground, launch, and space environments. The MTO flight hardware shall be designed to meet applicable functional, performance, operation and other design requirements without damage or degradation when exposed to the design environments specified herein.

4.2 Contamination

Contamination control shall be in accordance with MTO Project Contamination Control Plan (JPL D-TBD).

4.3 Thermal and Atmospheric Environments

Thermal design and verification requirements for MTO assemblies are specified in this section.

4.3.1 Ground Thermal and Atmospheric Environments

Flight hardware shall be maintained in a controlled environment through the pre-launch development phase (fabrication to launch). Ground operation and handling requirements encompass the environments that MTO assemblies will encounter during fabrication, assembly, integration, alignment, storage, and pre-launch operations and are specified in section 4.3.1.1. The transportation requirement is specified in section 4.3.1.2.

4.3.1.1 Ground Operations, Handling, and Storage Thermal and Atmospheric Environments

MTO assemblies shall be designed to withstand the ground operations, handling, and storage thermal and humidity conditions shown below.

Ambient Air Temperature: 5°C to 45°C (41° F to 113° F)
Relative Humidity: 30% to 70% (Ref.: JPL D-1348)

4.3.1.2 Transportation Thermal and Atmospheric Environments

MTO assemblies shall be transported in protective containers or equivalents. The MTO instrument and assembly container shall be designed in accordance with JPL D-8208, Section 3.18 [or equivalent] such that the thermal environment inside the container to be experienced by the non-powered flight hardware does not exceed the following limits.

Temperature (Internal to Container): 5°C to 50°C (41°F to 122°F)
(5°C above dew point)
(Flight hardware transported in the un-controlled cargo bay of a jet airliner may experience atmospheric temperatures as low as -40°C (-40°F).
Maximum rate of temperature change (Internal to Container): 5°C/hr
Relative Humidity (non-operational): < 70 %

4.3.2 Pre-launch (on-Pad) Thermal and Atmospheric Environments

MTO flight hardware shall be designed to stay within the operational or non-operational allowable flight temperatures (whichever applicable) while in the launch configuration (on-pad), when exposed to the environmental conditions shown in Tables 4.3.2-1.a and b. This environment is based on the two candidate launch vehicle families, Atlas V and Delta IV, as specified in their Mission/Payload Planner's Guides.

Table 4.3.2-1.a Atlas V Temperature Environments

			Temperature Range Inside Payload Fairing**		
			Atlas V 400 Series	Atlas V 500 Series	
Location	Inlet Temperature Capability*	Inlet Flow Rate Capability, kg/min (lb/min)	EPF & LPF, °C(°F)	5-m Short, °C(°F)	5-m Medium, °C(°F)
Post-LV Mate Through Move to Launch Configuration	10-29°C (50-85°F)	Atlas V 400 Series 22.7-72.6 (50-160) Atlas V 500 Series 22.7-136.2 (50-300)	6-20°C (43-68°F)	6-20°C (43-68°F)	6-20°C (43-68°F)
Post-Move to Launch Configuration	10-29°C (50-85°F)	Atlas V 400 Series 22.7-72.6 (50-160) Atlas V 500 Series 22.7-136.2 (50-300)	6-21°C (43-70°F)	6-21°C (43-70°F)	6-21°C (43-70°F)

Notes: * Inlet Temperature Is Adjustable (Within System Capability) According to Spacecraft Requirements
** Temperature Ranges Are Based on Worst-Case Minimum & Maximum External Heating Environments
Ranges Shown Assume a 72.6 kg/min (160 lb/min) for EPF/LPF ECS Flow Rate & 136.2 kg/min (300 lb/min) for 5-m Short/Medium ECS Flow Rate

Table 4.3.2-1.b Delta IV Temperature Environments

Location		Temperature	Relative humidity[1]	Particulate class[2]
Encapsulated payload	Mobile	18.3° to 29.4° ±2.8°C (65° to 85°±5°F)	Max 50% Min not controlled	Class 5000[3]
MST[4]	Environmental enclosure	20° to 25.6°C (68° to 78°F)	Max 75% Min not controlled	Not controlled
	Fairing	Any specified between 10° and 29.4° ±2.8°C (50° and 85° ±5°F)	20 to 50%	Class 5000 inlet
Astrotech	Building 9: airlock, high bays, storage bays	21.0° ± 2.8°C (70° ± 5°F)	40 ± 60%	Class 100,000[3] Functional 10,000

Note: The facilities listed can only limit the maximum humidity level. The facilities do not have the capability to maintain a minimum RH value.
These numbers are provided for planning purposes only. Specific values should be obtained from the controlling agency.

[1]PCES only: A 50% relative humidity maximum can be maintained at a temperature of 18.3°C (65°F). At higher temperatures, the relative humidity can be reduced by drying the conditioned air to a minimum specific humidity of 48 grains of moisture per 0.45 kg (1 lb) of dry air.
[2]Verified/sampled at duct outlet.
[3]FED-STD-209D.
[4]A backup system exists for the mobile service tower (MST) air-conditioning.

4.3.3 Launch Thermal and Atmospheric Environments

4.3.3.1 Launch Thermal Environment

MTO flight hardware shall be designed to stay within the non-operational allowable flight temperature range while exposed to the transient launch thermal conditions.

4.3.3.1.1 Free Molecular Heat Fluxes

MTO temperature control shall be designed to maintain the assembly temperature within the non-operating allowable flight temperature limits when exposed to the free molecular heating fluxes of 1135 W/m^2 after the jettison of the launch vehicle payload fairing.

4.3.3.1.2 Payload Fairing Wall Temperatures

MTO temperature control shall be designed to maintain the assembly within its allowable non-operating flight temperature limits when exposed to the heat fluxes from the payload fairing interior acoustic blankets maximum temperature of 49^oC for 300 seconds during the launch.

4.3.3.2 Explosive Atmosphere

The Orbiter shall be designed to operate in the presence of flammable vapors without initiating an explosion or fire, in accordance with JPL D-560, JPL Standard for Systems Safety, paragraph 2.3.2.

4.3.3.3 Launch Pressure Profile

During launch, the pressure will decrease from 100 kPa (760 torr) on Earth to $1.3x10^{-15}$ kPa (10^{-14} torr) in space. MTO assemblies shall be designed to withstand the pressure decay rate of 5 kPa/s (0.73 psi/s).

4.3.3.4 Venting Adequacy

The purposes for venting the entrapped air inside MTO assemblies are:

(1) Low (Δp)'s: Venting assures that all MTO assemblies and, particularly, assemblies with thin walls such as multiplayer insulations and honeycomb structures, experience only very low (Δp)'s across the containing walls so that high stresses, large deflection, and/or "ballooning" do not occur during launch phase of the mission or during the pump down period of thermal vacuum testing.

(2) Fast Vent Speed: For RF, microwave, and certain high-powered or high-voltage assemblies, the venting provision assures that the entrapped air inside the assembly

escapes to its surroundings with sufficient speed so that multipacting or ionization breakdown (corona) is not a concern during launch or other phases of the mission.

(3) Low Rate of Outgassing or Molecular Flow: The venting provision ascertains that the entrapped gas escape sufficiently fast so that the remaining gas does not contribute to the unwanted small-force disturbances for altitude or attitude control and operation of the spacecraft and instruments in space.

MTO assemblies shall be designed to have one of two venting provisions:

(1) To provide vent hole(s) or path(s) to adequately vent the entrapped air.

(2) To totally enclose or hermetically seal the voids so none of the entrapped air is released.

4.3.3.5 Multipacting and Ionization Breakdown (Corona)

Assemblies shall be designed to not have corona, multipacting, or other forms of high voltage breakdown in all environments, for DC and AC voltages and RF assemblies. RF/high voltage circuitry should also be designed to prevent multipacting/arcing damage at critical lower pressures during the launch and operating phase of the mission. Confirmation of meeting this requirement may be made through test, analysis or inspection.

4.3.4 Flight Thermal Environments

4.3.4.1 Flight Thermal Environment

MTO assemblies and their temperature control subsystems shall be designed to maintain temperatures within the allowable flight limits when exposed to the near-Earth, cruise, and Mars orbit thermal environments shown in Table 4.3.4-1.a and b.

Solar radiation varies inversely with the square of the distance from the sun. The solar flux at 1.0 astronomical unit is 1367 $W/m^2 \pm 1.5\%$.

Table 4.3.4-1.a Near-Earth, Cruise and Mars Orbit Thermal Environments [TBR]

Mission Phase	Direct Solar	Reflected Solar (albedo)	Planetary IR (LW Radiation)
Earth Orbit:	1400 W/m^2 (average at 1 AU)	0.32 (450 W/m^2) (global annual mean) 0.70 (polar regions)	270 W/m^2 (206K to 262K effective blackbody temperature)
Earth Occultation	0	0	-
Earth/Mars Cruise:			
Near Earth	1414 W/m^2 (at earth perihelion) 1323 W/m^2 (at earth aphelion)	Negligible beyond 4 earth radii	Negligible beyond 4 earth radii
Mars Perihelion	710 W/m^2	Negligible beyond 4 Mars radii	Negligible beyond 4 Mars radii
Mars Aphelion	490 W/m^2	Negligible beyond 4 Mars radii	Negligible beyond 4 Mars radii
Mars Orbit:			
Mars Perihelion	710 W/m^2	See Table 4.3.4-1.b	128 W/m^2
Mars Aphelion	490 W/m^2	See Table 4.3.4-1.b	99 W/m^2
Mars Occultation	0	0	-

Note: Due to Orbiter orientation, a surface may not see direct solar, reflected solar or planetary infrared. The percentage of the solar constant associated with wavelengths in the range of 0.085 to 7.0 micrometers is given in Table 4.3.4-1.c. The percentages are expected to remain unchanged for planetary reflected solar radiation. The relative spectral distribution for planetary infrared (IR) is represented by a Planck distribution consistent with the provided planetary IR fluxes.

Table 4.3.4-1.b Mars Albedo Distribution

LATITUDE (deg)	PERIHELION ALBEDO (maximum albedo)	APHELION ALBEDO (minimum albedo)
80 to 90	0.5	0.3
70 to 80	0.5	0.2
60 to 70	0.5	0.2
50 to 60	0.5	0.17
40 to 50	0.28	0.17
30 to 40	0.28	0.18
20 to 30	0.28	0.22
10 to 20	0.28	0.25
0 to 10	0.28	0.25
-10 to 0	0.28	0.20
-20 to -10	0.25	0.18
-30 to -20	0.22	0.18
-40 to -30	0.22	0.18
-50 to -40	0.25	0.3
-60 to -50	0.25	0.4
-70 to -60	0.3	0.4
-80 to -70	0.4	0.4
-90 to -80	0.4	0.4

Solar declination at perihelion = -23.7 deg
Solar declination at aphelion = 23.7 deg

Table 4.3.4-1.c Solar-Spectral-Irradiance Data, 0.0850 to 7.0 Micrometers

λ (μm)	P (%)	λ (μm)	P (%)	λ (μm)	P (%)
0.0850	3.8×10^{-4}	0.36	5.317	0.67	43.745
0.0900	3.9×10^{-4}	0.365	5.723	0.68	44.816
0.0950	4.0×10^{-4}	0.37	6.151	0.69	45.856
0.1000	4.1×10^{-4}	0.375	6.583	0.70	46.880
0.1050	4.2×10^{-4}	0.38	7.003	0.71	47.882
0.1100	4.2×10^{-4}	0.385	7.413	0.72	48.865
0.1150	4.3×10^{-4}	0.39	7.819	0.73	49.827
0.1200	4.4×10^{-4}	0.395	8.242	0.74	50.769
0.1250	4.7×10^{-4}	0.40	8.725	0.75	51.691
0.1320	4.9×10^{-4}	0.405	9.293	0.80	56.019
0.1350	5.2×10^{-4}	0.41	9.920	0.85	59.890
0.1400	5.4×10^{-4}	0.415	10.572	0.90	63.358
0.1450	5.6×10^{-4}	0.42	11.222	0.95	66.544
0.1500	5.8×10^{-4}	0.425	11.858	1.0	69.465
0.1550	6.3×10^{-4}	0.43	12.474	1.1	74.409
0.1600	6.9×10^{-4}	0.435	13.084	1.2	78.386
0.1650	8.2×10^{-4}	0.44	13.726	1.3	81.638
0.1700	1.01×10^{-3}	0.445	14.415	1.4	84.343
0.1750	1.31×10^{-3}	0.45	15.141	1.5	86.645
0.1800	1.70×10^{-3}	0.455	15.892	1.6	88.607
0.1850	2.33×10^{-3}	0.46	16.653	1.7	90.256
0.1900	3.16×10^{-3}	0.465	17.414	1.8	91.590
0.1950	5.2×10^{-3}	0.47	18.168	1.9	92.643
0.2000	8.1×10^{-3}	0.475	18.921	2.0	93.489
0.2050	1.34×10^{-2}	0.48	19.682	2.1	94.202
0.2100	2.05×10^{-2}	0.485	20.430	2.2	94.827
0.2150	3.53×10^{-2}	0.49	21.156	2.3	95.370
0.22	0.0502	0.495	21.878	2.4	95.858
0.225	0.0729	0.50	22.599	2.5	96.294
0.23	0.0972	0.505	23.313	2.6	96.671
0.235	0.1205	0.51	24.015	2.7	97.007
0.24	0.1430	0.515	24.702	2.8	97.310
0.245	0.1681	0.52	25.379	2.9	97.584
0.25	0.1944	0.525	26.060	3.0	97.828
0.255	0.2267	0.53	26.743	3.1	98.038
0.26	0.270	0.535	29.419	3.2	98.218
0.265	0.328	0.54	28.084	3.3	98.372
0.27	0.405	0.545	28.738	3.4	98.505
0.275	0.486	0.55	29.381	3.5	98.620
0.28	0.465	0.555	30.017	3.6	98.725
0.285	0.644	0.56	30.648	3.7	98.819
0.29	0.811	0.565	31.276	3.8	98.906
0.295	1.008	0.57	31.908	3.9	98.985
0.30	1.211	0.575	32.542	4.0	99.058
0.305	1.417	0.58	33.176	4.1	99.125
0.31	1.656	0.585	33.809	4.2	99.186
0.315	1.924	0.59	34.440	4.3	99.241
0.32	2.219	0.595	35.065	4.4	99.291
0.325	2.552	0.60	35.683	4.5	99.337
0.33	2.928	0.61	36.902	4.6	99.379
0.335	3.324	0.62	38.098	4.7	99.416
0.34	3.722	0.63	39.270	4.8	99.450
0.345	4.118	0.64	40.421	4.9	99.482
0.35	4.517	0.65	41.550	5.0	99.511
0.355	4.919	0.66	42.658	6.0	99.718
				7.0	99.819

λ (μm) is wavelength; and P is the percentage of the solar constant associated with wavelengths shorter than λ.

4.3.4.2 Vacuum Condition

MTO assemblies shall be designed for vacuum conditions of $1.33x10^{-15}$ kPa (10^{-14} torr).

4.3.4.3 Aerobraking Environment [TBR]

If MTO utilizes this option for finalizing its mission orbit, this section is applicable. This section describes the aerodynamic heating rates and forces encountered by the Orbiter during the atmospheric passes in an aerobraking mission. Aerobraking uses the drag force on the Orbiter to remove orbital energy and reduce propellant requirements. The aerobraking phase will include three subphases: walk-in, main phase (or steady state), and walk-out. The severity of the aerobraking environment will depend on the amount of orbital energy removed, the duration of the steady state subphase, and the Orbiter ballistic coefficient. The orbital energy removed is determined by the initial orbit period and the final period for aerobraking.

Figure 4.3.4.3-1 represents the transient heating rate profile for a representative aerobraking drag pass. To convert freestream heating to surface heating use the following expression:

$$Q_{heatsurf} = Q_{heatfreestream} * Ch * AC * Cos(Ainc)$$

where: $Q_{heatfreestream} = 0.5 * Rho * V^3$

Rho = instantaneous atmospheric density

V = instantaneous velocity with respect to the atmosphere

Ch = is the transition flowfield heat coefficient (value = 0.9),

AC = is the surface thermal accommodation coefficient (value = 0.95),

Ainc = Incidence Angle (measured from surface normal)

A typical aerobraking drag pass will have a duration that ranges from 300 seconds (in long period orbits) to 1200 seconds (in short period orbits). The drag duration is defined as the length of time the dynamic pressure is greater than 0.0015 N/m^2. The dynamic pressure (q) is defined as:

$$q = 0.5 * Rho * V^2$$

Rho = instantaneous atmospheric density

V = instantaneous velocity with respect to the atmosphere

Transient oscillations of ±10° in the orbital plane (pitch) and ±10° normal to the orbital plane (yaw) may occur early in each aerobraking pass.

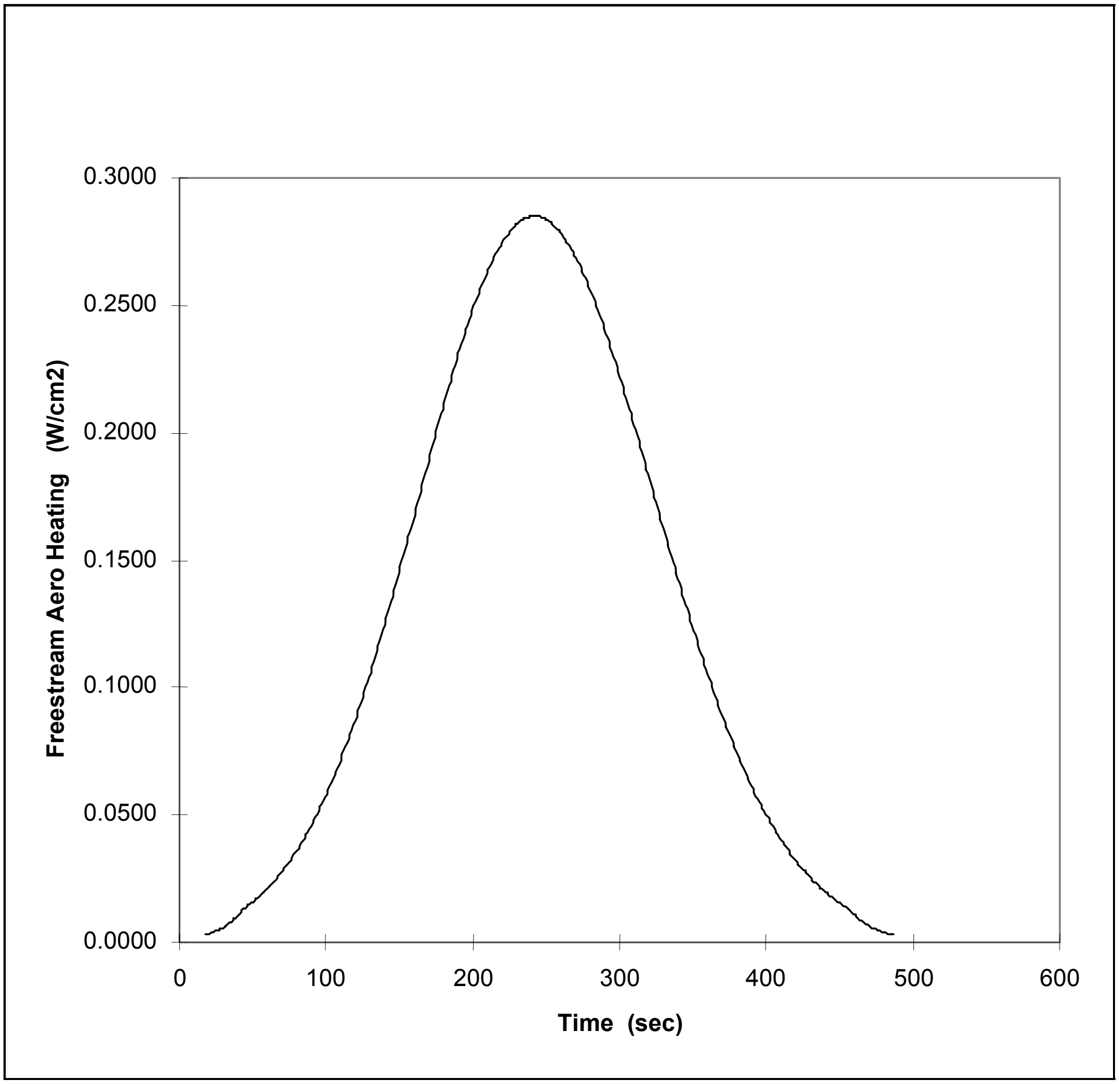

Figure 4.3.4.3-1 Representative Aerobraking Heating Pulse

4.3.5 Design and Operational Verification by Analysis

4.3.5.1 Thermal Math Model and Thermal Analysis

Thermal modeling and thermal analysis shall include internal heat and temperature distributions inside the instruments and assemblies, i.e., not confined to an overall analysis of the chassis or housing but extended to all boards, critical and high-powered parts, as a minimum. Thermal modeling and thermal analyses are performed by the project thermal engineer, packaging engineer, or their designee.

It shall be shown by thermal modeling and thermal analysis (validated by thermal balance test) that the thermal design of MTO assemblies are capable of maintaining assembly temperatures within the limits of the Allowable Flight Temperatures shown in the Temperature Requirement Table 4.3.6-2 for all phases of the mission. It shall also be shown by analysis that the materials of the assemblies will withstand the environmental test temperature levels in Table 4.3.6-1, Temperature Requirements, without degradation of performance.

4.3.5.2 Thermal Design Report

Thermal design report shall be a required item in the End Item Data Package. This report will be reviewed and approved by the thermal control engineer, the ERE, and the Cog E, or designees, before delivery.

4.3.5.3 Verification of Venting Adequacy

MTO assemblies shall be verified for venting adequacy by analysis and testing. Analytically, venting adequacy is established by satisfying the simple and conservative empirical rule:

$$(V/A) < 5080 \text{ cm (or 2000 inches)}$$

where V = the total internal "void" volume of the assembly to be vented in cubic centimeters and A is the total area of the vent hole(s) or path(s) in square centimeters.

If the assembly satisfies this rule, then no further analysis is necessary. Multilayer insulation (MLI) and honeycomb structures, however, must satisfy the following empirical rules in addition:

(i) For MLI

The perforation area across any interlayer shall be greater than 1% of the total area of the interlayer so that the vent flow across the interlayer is practically unrestricted.

(ii) For honeycomb structures

In the traverse direction (i.e., the "ribbon" direction), all single layer walls of each cell must be vented. Sizes of vent holes are to be based on supplier's test data.

For assemblies for which the (V/A) < 5080 cm (2000 inches) rule is not met, venting adequacy must be established by performing the following analyses:

(1) Flow and pressure drop analysis:

This analysis shall establish the adequacy for strength of materials and venting speed for the launch phase of the mission. 1-D, non-diffusive, non-viscous, compressible flow from a confined void space (spherical shape for simplicity) to a small, round hole against a prescribed external pressure profile is usually adequate. The air in the void can be assumed to be an ideal gas undergoing an isentropic expansion. That is, the void can be assumed to be large when compared with the vent hole and the pressure and density follow the relationship, p/ρ^{γ} = constant, where γ is the ratio of the specific heats.

The flow through the vent hole can be approximated by that for a sharp-edged orifice to account for the effects of gas compressibility and vena contracta of real gases (i.e., discharge coefficient). Normal pipe flow analysis including friction, however, should be avoided.

(2) Molecular venting and/or outgassing analysis:

This analysis shall establish that the remaining entrapped air or gas does not contribute significantly to the small-force disturbance for altitude/attitude control for mission phases subsequent to launch.

(3) For hermetically sealed assemblies where strength of materials is the primary concern, analysis can be performed where the external pressure is zero and the internal pressure is 1 Atmosphere. A factor of safety of 2 shall be used in this analysis.

(4) For hermetically sealed assemblies again, an analysis shall be performed to ascertain that the water condensate formed in space within the void is not detrimental to the operations and functions of the instruments or assemblies.

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4.3.6 Design and Operational Verification by Testing

No delivery of MTO flight hardware shall be made without completing thermal environmental testing. Developmental tests are not environmental tests.

Where testing is not practical (e.g., radiation, micrometeoroids, etc.), verification by analysis is acceptable on a case-by-case basis and when approved by the assembly Cog E and the Environmental Requirements Engineer.

Table 4.3.6-1 Thermal Environmental Test Requirement Summary(1)

Type of Assembly	**Qual/PF Test(3)**		
	Test Media	***Temperature Levels (^{o}C)(4)***	***Test Duration (Operating)***
Electronics	Vacuum(2)	<u>Cold</u>: AFT –15 <u>Hot</u>: AFT +20 OR -35 to +75, whichever is greater	<u>Cold</u>: 24 hrs <u>Hot</u>: 144 hrs
Optics, detectors, other unique assemblies	Vacuum(2)	<u>Cold</u>: AFT –15 <u>Hot</u>: AFT +20	<u>Cold</u>: 24 hrs <u>Hot</u>: 24 hrs
Mechanisms	Vacuum(2)	<u>Cold</u>: AFT –15 <u>Hot</u>: AFT +20 OR -35 to +75, whichever is greater	<u>Cold</u>: 24 hrs <u>Hot</u>: 24 hrs

Note: (1) Based on JPL DocId-60133 "Assembly and Subsystem Level Environmental Verification".
(2) Atmosphere testing may be considered on a case by case basis, upon approval by Project ERE.
(3) Flight Acceptance (FA): Level = AFT±5°C. Duration = 8 hrs cold / 60 hrs hot for electronics, 24 hrs cold / 24 hrs hot for optics, detectors, mechanisms, other unique assemblies
(4) Temperature is defined by the thermocouple reading at the mounting or thermal control surface. A minimum of two thermocouples should be available for this purpose.

4.3.6.1 Thermal Test Program

MTO assemblies shall undergo the thermal test levels and durations specified in Table 4.3.6-1.

4.3.6.2 Test Medium

Vacuum as a test medium is required for all MTO assemblies, unless approved by the Project ERE.

Testing for the on-pad air environment is not necessary since the thermal states under this atmospheric condition are encompassed by the flight conditions.

4.3.6.3 Number of Startups

Unless otherwise specified, MTO assemblies shall start-up (turn-on from electrically non-powered state) and survive without damage over the Non-Operational cold to Operational Hot PF temperature limits at least 3 times at hot and 3 times at cold during the test. For dedicated Qual units the start-up requirement is for 5 times at hot and 5 times at cold.

4.3.6.4 Test Temperature Levels

MTO assemblies shall be designed to operate within specification over the temperature range specified in Table 4.3.6-1, based on JPL DocId-60133 “Assembly and Subsystem Level Environmental Verification”.

The test temperature levels, along with the allowable flight temperatures are summarized in Table 4.3.6-2, Temperature Requirements.

4.3.6.5 Hot and Cold Dwell Times

The required hot and cold thermal dwell times are summarized in Table 4.3.6-1.

4.3.6.6 Functional Verification

Full functional verification is required during the hot operating test phase and the cold operating test phase. In addition, pre-test and post-test functional demonstrations are also required. Special thermal design features such as heater operations, louver operations, etc., as applicable, shall be demonstrated in this test.

4.3.6.7 Test Tolerances

Test tolerances are presented in Section 5.

4.3.6.8 Typical Test Profiles [TBR]

A typical Qual/PF test profile is shown in Figure 4.3.6-1.
A typical Flight Acceptance test profile is shown in Figure 4.3.6-2.

4.3.6.9 Testing for Venting Adequacy

Venting adequacy is typically verified by analysis, but may be verified during the pumpdown phase of the thermal vacuum test to the extent limited by the pumping capacity of the test facility. MTO assemblies that will be powered on and/or operating during the launch phase of the mission shall be powered on and/or operating during the pumpdown phase of the thermal vacuum test.

Dedicated depressurization tests for venting critical assemblies may be required on a case-by-case basis and shall be determined between the assembly Cog E and the ERE.

Table 4.3.6-2 Temperature Requirements [TBC]

MTO Temperature Requirements											
MTO Orbiter/Payload Assembly	Operating Temperatures(1)						Non-Operating Temperatures(2)				COMMENTS
	AFT Min (°C)	AFT Max (°C)	Qual/PF Min (°C)	Qual/PF Max (°C)	FA Min (°C)	FA Max (°C)	AFT Min (°C)	AFT Min (°C)	Qual/PF Min (°C)	Qual/PF Max (°C)	
Assembly Level											
Structures											
Orbiter Structure											
Solar Array Substrates											
Appendages											
HGA Gimbals											
HGA Gimbal Electronics	5	50	-35	75	0	55					
Solar Array Gimbals											
Solar Array Gimbals Electronics	5	50	-35	75	0	55					
Solar Array Dampers											
Solar Array Hinges											
Separation Nuts											
Electrical Power Subsystem											
Solar Array Panels Assembly											
Solar Array Switching Module											
42 Ahr NiH2 Batteries											
Power Distribution Unit	-20	50	-35	75	-25	55					
DC-DC Converter	-20	50	-35	75	-25	55					
Pyro Initiation Unit (PIU)	-20	50	-35	75	-25	55					
Attitude and Articulation Control Subsystem											
Star Tracker	-20	50	-35	75	-25	55					
Sun Sensors											
IMU/Accelerometers	-20	50	-35	75	-25	55					
Reaction Wheel Assemblies	-20	50	-35	75	-25	55					

Table 4.3.6-2 Temperature Requirements (cont) [TBC]

MTO Temperature Requirements											
MTO Orbiter/Payload Assembly	Operating Temperatures(1)						Non-Operating Temperatures(2)				COMMENTS
	AFT Min (°C)	AFT Max (°C)	Qual/PF Min (°C)	Qual/PF Max (°C)	FA M n (°C)	FA Max (°C)	AFT Min (°C)	AFT Min (°C)	Qual/PF Min (°C)	Qual/PF Max (°C)	
Assembly Level											
Telecommunications Subsystem											
Electra Tran ceiver	-20	50	-35	75	-25	55					
Electra UHF Coax Switch	-35	50	-50	75	-40	55					
Electra UHF Antenna	-110	115	-125	135	-115	120					
USO	-20	50	-35	75	-25	55					
High Gain A tenna											
Low Gain Antennas											
Medium Gain Antenna											
TWTA - Ka Band	-20	50	-35	75	-25	55					
TWTA - X-Band	-20	50	-35	75	-25	55					
X-Band SSPA, 15 Watt	-20	50	-35	75	-25	55					
SDST	-20	50	-35	60	-25	55					*PF=60C due to previous qualification*
X-Ba Diplexer											
Passive RF Components											
RF Switch, Transfer, Coax	-20	50	-35	75	-25	55					
RF Switch, Transfer, Waveguide	-20	50	-35	75	-25	55					
C&DH	-20	50	-35	75	-25	55					
Flight Computer											
CMIC (C&DH Module I/F Card)											
ULDL (Uplink/DownlinkCard)											
GIF (G&G I/F Card)											
AAC (Analog Acquisition Card)											
DTCI (Data, TLM & CMD I/F Card)											
Power Card											
SSR	-20	50	-35	75	-25	55					

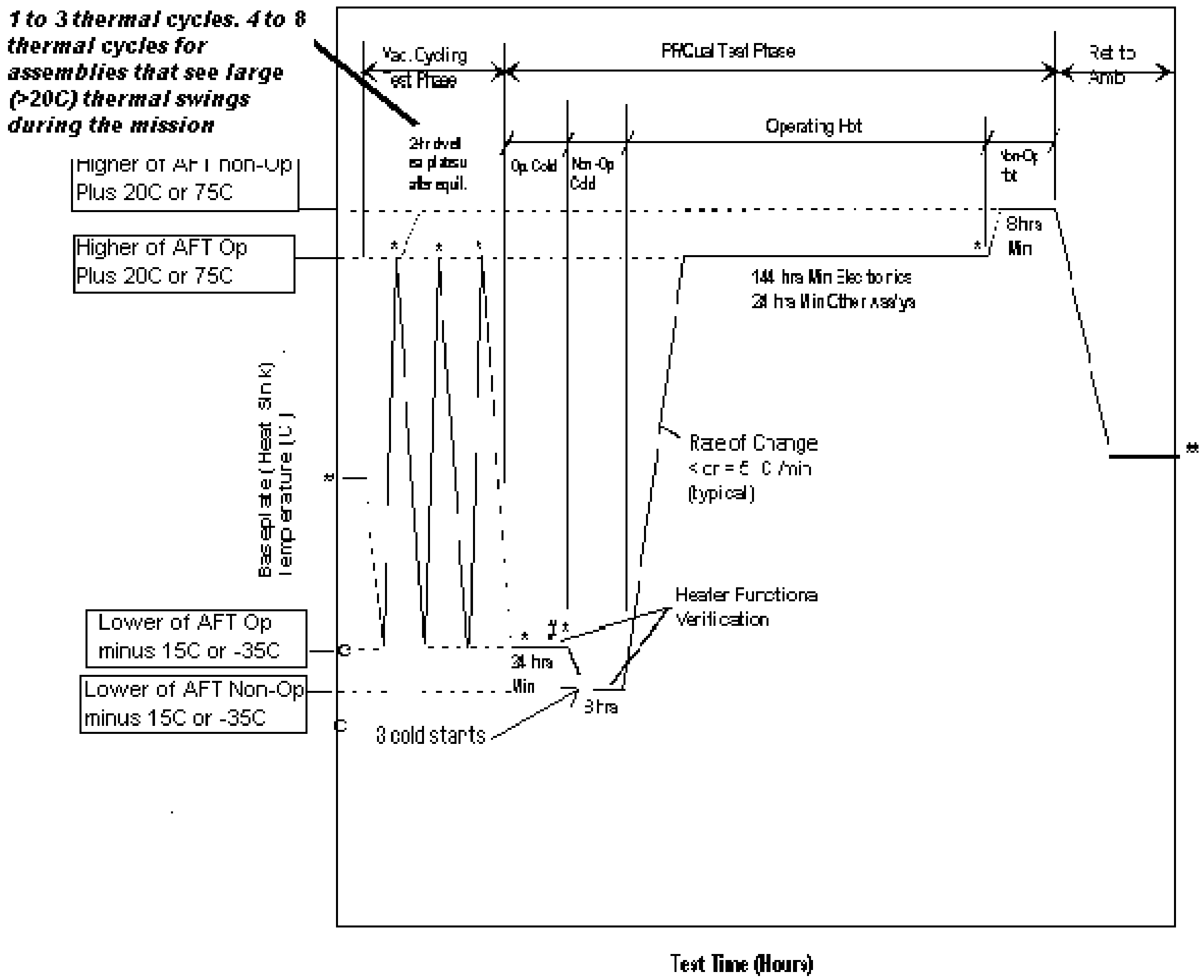
Table 4.3.6-2 Temperature Requirements (cont) [TBC]

MTO Temperature Requirements											
	Operating Temperatures[1]						Non-Operating Temperatures[2]				
MTO Orbiter/Payload Assembly	AFT Min (°C)	AFT Max (°C)	Qual/PF Min (°C)	Qual/PF Max (°C)	FA Min (°C)	FA Max (°C)	AFT Min (°C)	AFT Min (°C)	Qual/PF Min (°C)	Qual/PF Max (°C)	**COMMENTS**
Assemb y Level											
Propulsi											
Fuel Propellant Tank											
Fuel Tank PMD											
Helium Tank											
Dual Regulator											
Fill & Drain Valves HP											
Fill & Drain Valves LP											
Fill & Drain Valves Liq											
Fill & Drain Valves Liq1/											
Filters HP Gas											
Filters Fuel 3/8											
Pyro Valves NO Gas											
Pyro Valv s HP NC Gas											
Pyro Valves NC 1/2											
Latch Valve 3/4"											
Latch Valves 1/4 Fuel											
Transduc s HP Gas											
Transducers LP											
0.9N Thrusters											
22N Thrusters											
44.5N Thr sters											

Table 4.3.6-2 Temperature Requirements (cont) [TBC]

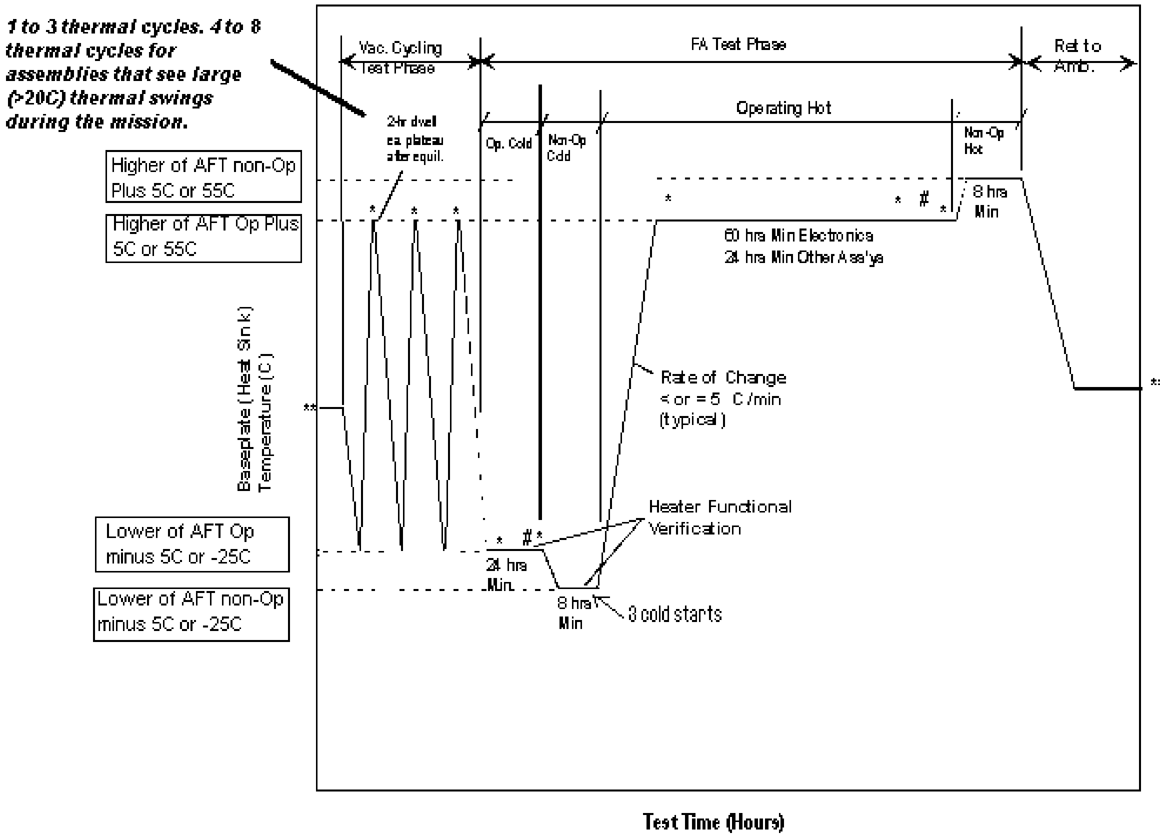
MTO Temperature Requirements											
MT biter/Payload Assembly	**Operating Temperatures[1]**						**Non-Operating Temperatures[2]**				**COMMENTS**
	AFT Min (°C)	AFT Max (°C)	Qual/PF Min (°C)	Qual/PF Max (°C)	FA Min (°C)	FA Max (°C)	AFT Min (°C)	AFT Min (°C)	Qual/PF Min (°C)	Qual/PF Max (°C)	
Assembly Level											
Thermal											
Heaters											
Thermostats											
Temperature Sensors											
MLI											
Harnesses											
Payload											
Optical Comm	-20	50	-35	75	-25	55					
Imaging	-20	50	-35	75	-25	55					
Narrow Angle Camera	-20	50	-35	75	-25	55					
1 DOF Gimbal	-20	50	-35	75	-25	55					

(1) Operating AFTs are exampales and are typically determined by thermal control conside
(2) Non-Operating AFTs are exampales and are typically determined by thermal control considerations



Notes
(1) Level shown is for electronics. Level for non-electronics or mechanisms is AFT plus 20 C.
(2) Level shown is for electronics. Level for non-electronics or mechanisms is AFT minus 15C.
(3) Test environment is vacuum (i.e., pressure < 1.0E-5 torr).
(4) # indicates hot or cold starts - 3 times minimum, cold and hot.
(5) ** indicates pre- or post- test functional tests.
(6) * indicates required performance/functional tests after thermal equilibrium is established.
(7) Thermal equilibrium is defined as |dT/dt| <1 C/hour.
(8) Power on/off cycle test is not described in this profile.

Figure 4.3.6-1 Typical Thermal Qualification/Protoflight Test Profile [TBC]



Notes
(1) Level shown is for electronics and mechanisms. Levels for other assemblies are AFT plus 5 C.
(2) Level shown is for electronics and mechanisms. Levels for other assemblies are AFT minus 5 C.
(3) Test environment is vacuum (i.e., pressure < 1.0E-5 torr).
(4) # indicates hot or cold starts - 3 times minimum, cold and hot.
(5) ** indicates pre- or post- test functional tests.
(6) * indicates required performance/functional tests after thermal equilibrium is established.
(7) Thermal equilibrium is defined as |dT/dt| <1 C/hour.
(8) Power on/off cycle test is not described in this profile.

Figure 4.3.6-2 Typical Thermal Flight Acceptance Test Profile [TBC]

4.4 Dynamics Environments and Structural Loads

Dynamics environments and structural loads are induced in the instrument system and assemblies during the ground handling and shipping, launch and space operation phases of the mission.

4.4.1 Ground Handling and Shipping Vibration and Shock

Ground operation and handling encompass the environments that the flight hardware will encounter during assembly, integration, alignment, and pre-launch operations. The ground handling environments also include transportation and storage of the hardware in shipping containers. Shipping containers and transportation procedures for flight hardware shall be designed so that shipping and transportation vibrations, acceleration and shock environments are less severe than the launch phase dynamic environments specified herein.

4.4.2 Launch Vehicle Induced Dynamics Environments and Loads

The mass acceleration curve provides quasi-static structural design loads that represent the combined quasi-steady accelerations and the low frequency mechanically transmitted dynamic accelerations occurring during launch. The random vibration design and test requirements represent acoustically excited vibration during liftoff, transonic and max q events (maximum aerodynamic pressure events).

Acoustic design and test requirements are based on maximum internal payload fairing sound pressure level spectra at launch.

Pyroshock design and test requirements are intended to represent the structurally-transmitted transients induced by the explosive devices used to achieve various separations/releases, including spacecraft separation from the launch vehicle and deployment of various spacecraft subsystems, such as the solar panels, and other instruments.

4.4.2.1 Minimum Frequency Requirement

The spacecraft shall have a minimum frequency of 27 Hz in the thrust axis and 10 Hz in the lateral axis while hard-mounted at the separation plane.

In order to meet this requirement all MTO assemblies with a mass less than 25 kg shall have fundamental natural frequencies above 100 Hz. All MTO assemblies with a mass more than 25 kg shall have fundamental natural frequencies above 60 Hz.

This requirement shall be verified by either a modal test or a shaker vibration test.

4.4.3 Structural Safety Margins

Table 4.4.3-1 gives the minimum design and test factors of safety that shall be used for all MTO structures.

4.4.4 Quasi-Static Design Loads

Accelerations associated with quasi-steady flight events are generated by engine-induced and external forces, which change slowly with time and for which the elastic responses are relatively small. Vibratory accelerations induced by various launch vehicle dynamic events are added to the appropriate quasi-static accelerations to produce worst case quasi-static acceleration loads for spacecraft structural design purposes. Preliminary instrument subsytem and assembly c.g. design requirements for quasi-static acceleration environments are specified by the physical Mass Acceleration Curve (MAC) in Figure 4.4.4-1.

Quasi-static loads on primary structure are updated by the coupled loads analyses. The physical Mass Acceleration Curve (MAC) in Figure 4.4.4-1 gives the design criteria for secondary structures and equipment support structure.

Subsystems and assemblies having a resonance below 80 Hz shall be test verified to the Coupled Loads Analysis (CLA) loads, or the loads of Figure 4.4.4-1, in three axes. Protoflight test verification margin is given in Table 4.4.3-1. Test verification may be conducted either a) using static loading, b) using a centrifuge, c) using a shaker with a relatively low frequency (60 Hz or less) input. The sine pulse test input shall consist of a modulated sine pulse, which excites the center of gravity of the assembly to its limit load times the appropriate test factor at a discrete frequency. The test c.g. acceleration shall be determined by dividing the peak reaction force, measured with force transducers at the assembly interface, by the assembly mass. The frequency of excitation should be selected to be an octave or more below the fundamental resonance of the assembly.

The following guidelines are applicable for quasi-static load testing on a shaker:

a) The details of the shaker acceleration waveform and frequency are left to the testing laboratory. Typical waveforms include a half-sine waveform, or modification thereof, a sine burst, or a sine dwell. The fundamental frequency of the input should be as low as prudent, respecting shaker displacement limits, in order to minimize the resonant response. If a non-symmetric pulse (e.g. a half-sine) is used, the pulse must be applied in both directions.
b) Some measure of response of the test item, e.g. the interface force or the acceleration near the CG, is necessary since some resonant amplification of the test article is possible.
c) For open loop test, a pretest should be conducted without the test article. The drive signal generated by the shaker controller should be measured in this pretest and compared with that generated for the actual test, before commanding the actual test.

It may also be possible to demonstrate that the random vibration test induces loads that envelope the quasi-static loads requirement.

Table 4.4.3-1 Minimum Factor of Safety Requirement

No.	Structure/Assembly	Design Factor of Safety		Test Factors	
		Yield FS_y (1)	Ultimate FS_{ult} (1)	Proto-Flight	Proof
1	Metallic Structures Qualified by Testing	1.25	1.40	1.2	-
2	Metallic Structures Qualified by Analysis only	1.60	2.00	-	-
3	Composite Structures (non-discontinuity sections)	-	1.50	1.2	1.2
4	Composite Structural joints/Discontinuities and Bonded Joints	-	1.75	1.2	1.2
5	Bolted Joints:				
6	Bolt Strength	1.25	1.40	1.2	-
7	Joint Separation and Slippage for Safety Critical Joints	-	1.40	1.2	-
8	Joint Separation and Slippage for other than Safety Critical Joints	-	1.25	-	-
9	Ground Support Equipment (GSE)	1.88	2.50	-	1.5

Note (1) An additional uncertainty factor of 1.10 shall be applied for general buckling instability and/or crippling failure analysis.

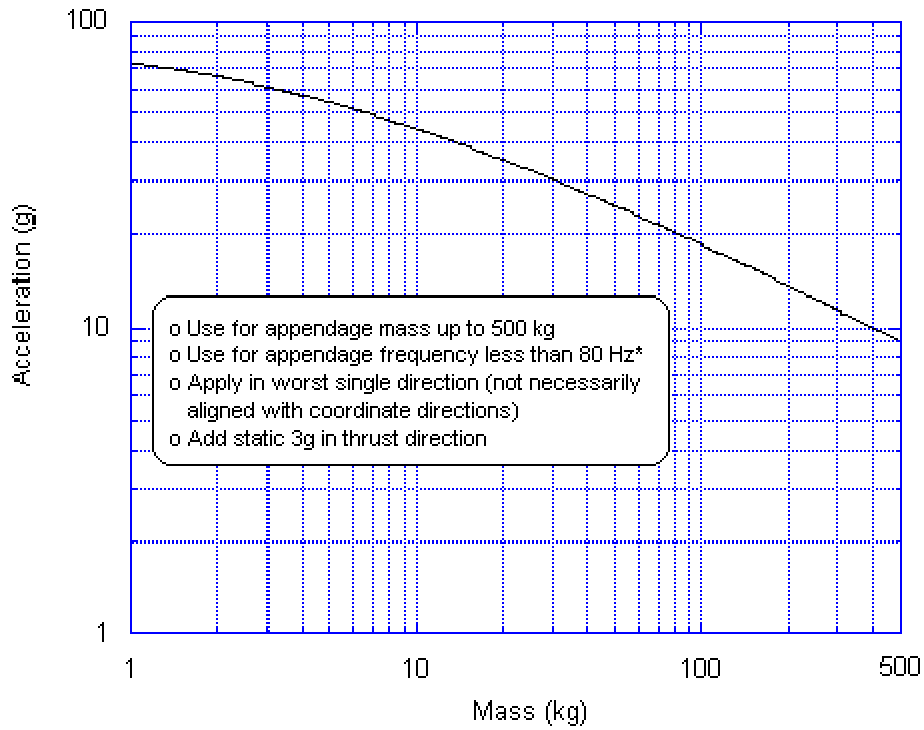


Figure 4.4.4-1 Preliminary Mass Acceleration Curve for MTO [TBC]

4.4.5 Spacecraft Random Vibration (Launch Configuration)

The gaussian random vibration test input for the MTO flight spacecraft in its launch mechanical and electrical configuration is specified in Table 4.4.5-1. The spacecraft shall be mounted on the test Payload Attachment Fitting. This environment shall be applied for 1 minute in each of 3 orthogonal axes. Test control accelerometer(s) are located at fixture-to-test article interface(s) and test limiting force gauges are sandwiched between the test article and the shaker fixture. The test is controlled in the extremal mode. The accelerometers, force gauges and data acquisition system shall have flat frequency response characteristics within ±1 dB from 5 Hz to 2 kHz.

Table 4.4.5-1 Spacecraft Random Vibration Test Level (PF Level) [TBC]

Frequency, Hz	Acceleration Spectral Density Level
10 - 20	+ 3 dB / Oct.
20 – 200	0.03 g^2 / Hz
Overall	2.3 grms

1g = standard acceleration due to gravity = 9.81 m/s^2
Duration: 1 minute in each of three orthogonal axes, one of which is the launch thrust axis.

The test shall be force limited to reduce over-test at hard mounted resonance frequencies. The spacecraft random vibration force limit specification is provided in Table 4.4.5-2 .

Table 4.4.5-2 Spacecraft Random Vibration Force Limit Specifications [TBC]

Frequency, Hz	**Force Spectral Density Level**
$f < f_o$	$S_{FF} = C^2 M_o^2 S_{AA}$
$f >/= f_o$	$S_{FF} = C^2 M_o^2 S_{AA} (f_o/f)^2$

where f is frequency, f_o is the frequency of the primary mode, i.e. the mode with the greatest effective mass, S_{FF} is the force spectral density, C is a dimensionless constant which depends on the configuration, M_o is the total mass of the test item, and S_{AA} is the acceleration spectral density level from Table 4.4.5-1. The value C shall be derived for the MTO spacecraft using the methodology of NASA-HDBK-7004B. The equations of Table 4.4.5-2 must be in consistent units. If it is desired to use metric units, the acceleration specification of Table 4.4.5.1-1 must be expressed in meters per second squared.

Additional notching of random vibration input may be required at spacecraft natural frequencies to ensure that primary structure verification loads are not exceeded. The force and acceleration limit values may also be modified based on information gathered during shaker testing.

4.4.6 Random Vibration

The random vibration design and verification requirements for subsystems are as specified in Table 4.4.6-1. These spectra shall be applied in each of the three orthogonal axes at the mounting interface of the assembly. The design exposure time is 2 minutes per axis. The assemblies shall be tested to the random vibration requirements per Table 4.4.6-1.

The preliminary force spectrum in Table 4.4.6-2 may be used to notch the input acceleration. Refined force limits may be calculated using the simple or complex method described in NASA-HDBK-7004B when details of the assemblies and the spacecraft mounting structure are available. The JPL Dynamics Environment group should be consulted for derivation of refined force limits. The interface force must be measured and controlled via force transducers installed for the vibration test.

Table 4.4.6-1 MTO Random Vibration Requirements

Assembly/ Assembly	Frequency, Hz	FA Level	Qual, PF Level
Electra	20 20-55 55 - 300 300-2000 2000 OA	0.055 g^2/Hz 3 dB/octave 0.15 g^2/Hz -5 dB/octave 0.02 g^2/Hz 10.7 grms	0.11 g^2/Hz 3 dB/octave 0.3 g^2/Hz -5 dB/octave 0.04 g^2/Hz 15.1 grms

Qualification exposure time, 2 minutes in each of 3 axes
Protoflight and Flight Acceptance exposure time, 1 minute in each of 3 axes

Table 4.4.6-2 Assembly Random Vibration Force Limit Specifications

Frequency, Hz	Force Spectral Density Level
$f < f_o$ $f \geq f_o$	$S_{FF} = C^2 M_o^2 S_{AA}$ $S_{FF} = C^2 M_o^2 S_{AA} (f_o/f)^2$

Where:
f = frequency, Hz
f_0 = frequency of the primary mode, i.e. the mode with the greatest effective mass, Hz
S_{FF} = the Force Spectral Density
C = a dimensionless constant which depends on the configuration
M_0 = total mass of the test item, kg
S_{AA} = Acceleration Spectral Density

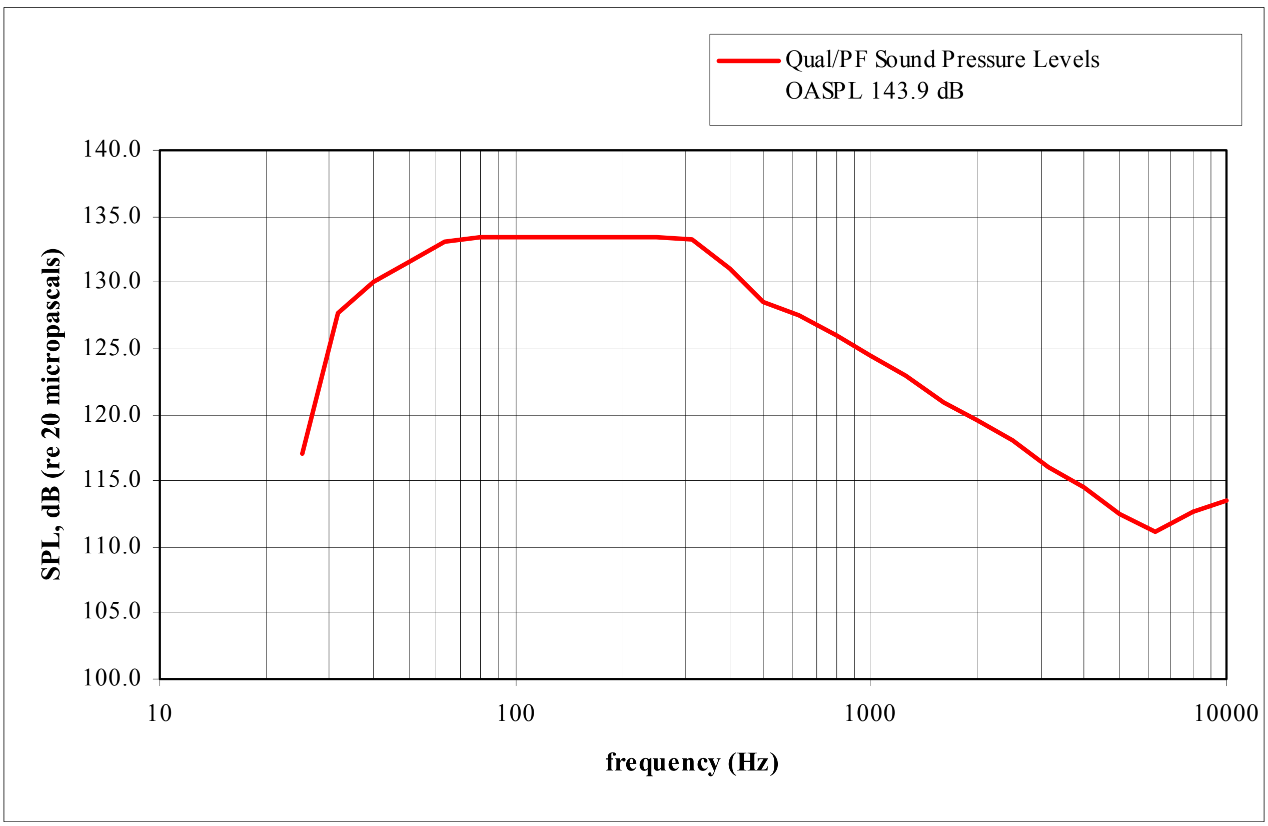
Where f is frequency, f_o is the frequency of the primary mode, i.e. the mode with the greatest effective mass, S_{FF} is the force spectral density, C is a dimensionless constant which depends on the configuration, M_o is the total mass of the test item, and S_{AA} is the acceleration spectral density level from Table 4.4.6-2. The value of C shall be derived or approved by the JPL Dynamics Environments Group based on spacecraft and assembly configuration details using the methodology of NASA-HDBK-7004B. The equations of Table 4.4.6-2 must be in consistent units. If it is desired to use metric units, the acceleration specification of Table 4.4.6-2 must be expressed in meters per second squared.

4.4.7 Acoustic Noise

The acoustic noise requirement for both the system and assemblies is a reverberant random-incidence acoustic field specified in 1/3 octave bands. The acoustic noise spectra for the candidate launch vehicles are specified in Table 4.4.7-1 and Figure 4.4.7-1. The exposure duration is two minutes for Qualification test and one minute for Protoflight test. The test article shall be in its launch mechanical and electrical configuration. The flight spacecraft shall be installed on the test Payload Adapter Fitting. Assemblies shall be hung by bungee cords or otherwise vibration isolated from acoustic chamber surfaces.

The overall acoustic sound pressure level (OASPL) shall be controlled to within ±1dB (true RMS) of the specification values. The test should be controlled so that the square root of the average mean-square sound pressure at several locations surrounding the test article meets the test levels specified in the table, in 1/3 octave bands centered on the specified frequency. The control microphone locations should be 30.5 to 45.7 cm (12 to 18 inches) from major exterior surfaces of the assembly or subsystem. The control microphones and their data acquisition systems shall have flat frequency response characteristics within $\pm$1 dB from 30 Hz to 10 kHz. A minimum of four microphones shall be used to control the test.

Figure 4.4.7-1 Qual/PF Sound Pressure Test Levels for Candidate Launch Vehicles*



* Candidate launch vehicles enveloped are: Delta IV 4450-14; Atlas V 401, 511, 531, 541, 551

EXPORT CONTROLLED INFORMATION

PRELIMINARY

Table 4.4.7-1 Qual/PF Sound Pressure Test Levels for Candidate Launch Vehicles

1/3 Octave Band Center Frequency (Hz)	Qual/PF Sound Pressure Levels (dB re 20 μPa)	Test Tolerances (dB)
25	117.0	+5, -3
31.5	127.6	+5, -3
40	130.0	+5, -3
50	131.5	+5, -3
63	133.0	+3, -3
80	133.5	+3, -3
100	133.5	+3, -3
125	133.5	+3, -3
160	133.5	+3, -3
200	133.5	+3, -3
250	133.5	+3, -3
315	133.2	+3, -3
400	131.0	+3, -3
500	128.5	+3, -3
630	127.5	+3, -3
800	126.0	+3, -3
1000	124.5	+3, -3
1250	123.0	+3, -3
1600	121.0	+3, -3
2000	119.5	+3, -3
2500	118.0	+3, -3
3150	116.0	+3, -3
4000	114.5	+3, -3
5000	112.5	+3, -3
6300	111.1	+3, -3
8000	112.7	+3, -3
10000	113.5	+3, -3
OASPL (dB)	**143.9**	**+1, -1**

4.4.8 Pyrotechnic Shock

Pyrotechnic shock design and verification requirements are dependent on the configuration and type of pyro device. The pyroshock requirement is defined in terms of shock response spectrum (SRS) and is intended to represent the structurally transmitted transients from pyrotechnic devices used to achieve launch vehicle separation and various deployments.

4.4.8.1 Spacecraft Induced Shock

Spacecraft level pyro shock testing shall be conducted by actual firing of the pyrotechnic devices. For protoflight testing, each device that generates the dominant shock source for any potentially susceptible hardware shall be fired twice. All other pyro devices shall be fired once. Embedded pyro devices, such as propulsion systems may be tested at a lower level of assembly.

4.4.8.2 Assembly Pyro shock

The shock pulse, with an SRS corresponding to this specification, shall be applied at the assembly interface in each of three orthogonal axes. The synthesized shock waveform shall meet the following criteria:

1. The time history shall be oscillatory in nature, and
2. The pulse shall decay to less than 10% of its peak value within 20 milliseconds.

The pyroshock test can be conducted either using electro-dynamic shaker or using a shock-generating apparatus.

One pulse shall be applied twice for Qualification (once for PF) in each of the three orthogonal axes of the assembly for a total of 6 applications (3 applications for PF).

MTO subsystems shall be designed to withstand the spacecraft induced pyrotechnic shock environment as shown in Table 4.4.8-1. The shock shall be applied at the subsystem mounting points in each of three orthogonal axes.

Table 4.4.8-1 MTO Assembly Pyroshock Requirements

Subsystem	Frequency, Hz	FA SRS Level	Qual, PF SRS Level
Electra	100 100 - 1000 1000 - 10,000	20 g +10.5 dB/octave 1420 g	40.0 g +10.5 dB/octave 2000 g

Note: SRS (Q=10); Above levels are specified at the at the hardware interface.

4.4.9 Jitter

The Optical Communications Experiment shall operate and maintain communication with Earth while exposed to the random vibration of Figure 4.4.9-1.

Figure 4.4.9-1 Operational Random Vibration Requirements

4.5 Electromagnetic Compatibility (EMC)

4.5.1 Spacecraft System

Radiated emissions, and radiated susceptibility tests shall be performed at the system level to verify that the spacecraft is compatible with its operational environment, launch site environment, launch vehicle environment and that it is self compatible.

4.5.1.1 Spacecraft Electromagnetic Environment

The spacecraft in its pre-launch, launch, cruise and on-orbit operating configurations shall meet the requirements for radiated emissions and radiated susceptibility as specified herein. Those assemblies deemed inactive and turned off during specific operational phases must not incur damage due to the application of these radiated susceptibility fields.

4.5.1.1.1 Radiated Emissions

Unintentional radiated narrowband electric field emissions produced by the spacecraft and assemblies shall not exceed the limits specified in the section 4.5.2.4.

4.5.1.1.2 Radiated Susceptibility

The spacecraft and assemblies shall operate without indications of interference, degradation of performance, or malfunction when subjected to the electric field strengths specified in section 4.5.2.8.

4.5.1.2 System Compatibility

4.5.1.2.1 Electromagnetic Interference Safety Margin (EMISM)

Requirements from MIL-E-6051D to demonstrate that there is a 12 dB Electromagnetic Safety Margin (EMISM) from Category I critical circuit upset due to crosstalk coupling, or common mode coupling from radiated RF ambient fields shall be applicable to the spacecraft system. The EMISM requirement is 6 dB for Category II critical circuits and 20 dB for electro-explosive circuits.

4.5.1.2.2 System Margin

Spacecraft assemblies shall have 6 dB margin (as a minimum) between measured (or tested) susceptibility and measured interference of each assembly to each and every other assembly.

4.5.2 Subsystems, Assemblies and Sensors

Subsystems, assemblies and sensors of the spacecraft shall be designed to meet the requirements of MIL-STD-461C/462, Part 3, for Class A2a equipment as modified herein to which the following emission and susceptibility requirements are applicable:

CE01 Conducted Emissions; Power 30 Hz to 20 kHz
CE03 Conducted Emissions; Power 20 kHz to 50 MHz
CE06 Conducted Emissions; Antenna Terminals 10 kHz to 18 GHz
CE07 Conducted Emissions; Power Leads, Spikes, Time Domain
RE02 Radiated Emissions; Electric Field, 10 kHz to 10 GHz
CS01 Conducted Susceptibility; Power Leads 30 Hz to 50 kHz
CS02 Conducted Susceptibility; Power Leads 50 kHz to 50 MHz
CS04 Rejection of Undesired Signals; 30 Hz to 10 GHz (Receivers Only)
CS06 Conducted Susceptibility; Spikes, Power Leads
RS03 Radiated Susceptibility; Electric Field, 14 kHz to 10 GHz
Surge Voltage (special test as defined herein)
Inrush
Radiated Susceptibility, Electrostatic Discharge

MIL-STD-461E is the latest issue of that specification. MIL-STD-461C has been used extensively and may be considered for compliance to this document if the test procedure is reviewed and approved by the JPL EMC Group with respect to the requirements for MTO. Newly designed assemblies, modified assemblies, or off-the-shelf assemblies that have had no previous EMC testing, shall be tested to verify compliance with requirements shown in Table 4.5.2-1. EMC test data (from prior testing) for off-the-shelf or heritage spare assemblies shall be reviewed and evaluated to determine their level of compliance.

The compliance status of the assemblies of each subsystem, and instrument will be tabulated and presented in an EMC compliance analysis.

Table 4.5.2-1 Subsystem and Assembly EMC Test Requirements [TBC]

Subsystem	CE01 CE03	CE06	CE07	RE02	CS01 CS02	CS04	CS06	RS03	Surge	Inrush	Isolation
Command and Data Handling (C&DH)											
C&DH Unit	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES
SSR Unit	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES
Telecommunications (Telecom)											
(2) 35w KA-band TWTA's	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES
(1) 100w KA-band TWTA's	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES
(2) 15w X-band SSPA's	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES
(1) 100w X-band TWTA	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES
(2) Small Deep Space Transponder (SDST)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
UHF Transceiver (ELECTRA)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Ultra Stable Oscillator (USO)	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES
Guidance, Navigation and Control (GN&C)											
Star Tracker (ST)	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES
Sun Sensor (SS)	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	YES
Inertial Measurement Unit (IMU)	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES
Reaction Wheel (RW)	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES
Electrical Power Subsystem (EPS)											
Battery Assembly (BA) Telemetry	NO	NO	NO	NO	YES	NO	NO	YES	YES	NO	YES
Charge Control Unit (CCU)	YES	NO	YES	YES	YES	NO	YES	YES	YES	NO	YES
Power Distribution Driver Unit (PDDU)	YES	NO	YES	YES	YES	NO	NO	YES	YES	NO	YES
Pyrotechnic Initiation Unit (PIU)	YES	NO	YES	YES	YES	NO	NO	YES	YES	NO	YES
Mechanisms (Mech)											
1 DOF Gimbal Motor and Electronics	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES
Gimbal Assembly	NO	NO	NO	YES	NO	NO	NO	YES	NO	NO	YES
Payload (P/L)											
Optical Communication	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES

4.5.2.1 Conducted Emissions Power Quality: Ripple and Noise (CE01/03)

The requirements of MIL-STD-461C/462 methods CE01 and CE03 shall be applied to all subsystems and assemblies. The limits as defined in Figure 4.5.2-1 for CE01/CE03 as tailored herein shall be used.

Note: Ripple and noise will not be measured on the power bus during systems level testing. Compatibility of systems using the spacecraft power bus will be demonstrated when all of the subsystems and assemblies operate together and as required by their respective specifications during mission simulations. If the system meets all of its performance requirements during a mission simulation, power quality will be deemed acceptable.

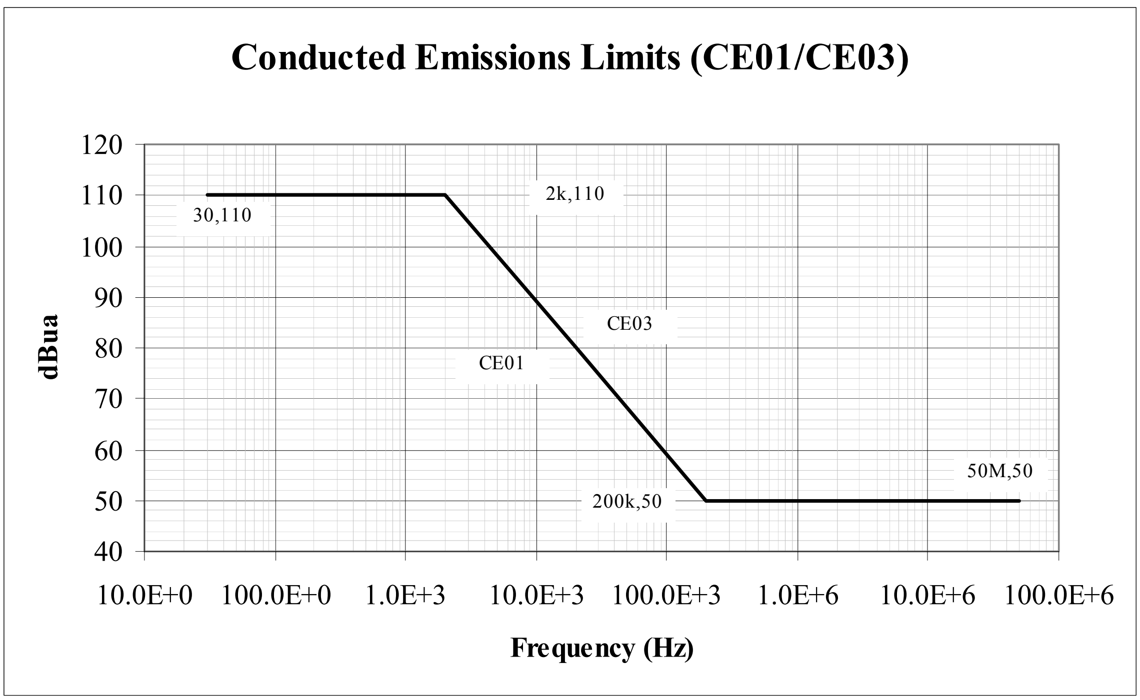


Figure 4.5.2-1 Conducted Emissions Limits (CE01/CE03)

4.5.2.2 Antenna Conducted Emissions (CE06)

The requirements of MIL-STD-461C/462 method CE06 shall be applied to all subsystems and assemblies containing R.F. receivers.

4.5.2.3 Conducted Emissions Spikes, DC Power Lines (CE07)

The requirements of MIL-STD-461 CE07 method shall be applied. Conducted switching spikes equal to or less than 100 microseconds in duration on dc power leads shall not exceed +/- 15 volts peak from nominal line voltage. For the purposes of this requirement spike duration is defined as the time interval between the 50% amplitude point on the transient leading edge and the 50% amplitude point on the transient trailing edge; high frequency (above 10MHz) ringing superimposed on the pulse leading or trailing edge should be ignored.

4.5.2.4 Radiated Emissions (RE02)

Unintentional radiated narrowband electric field emissions produced by subsystems and assemblies shall not exceed the limits shown in Figure 4.5.2-2. Table 4.5.2-2 shows the limits in tabular form.

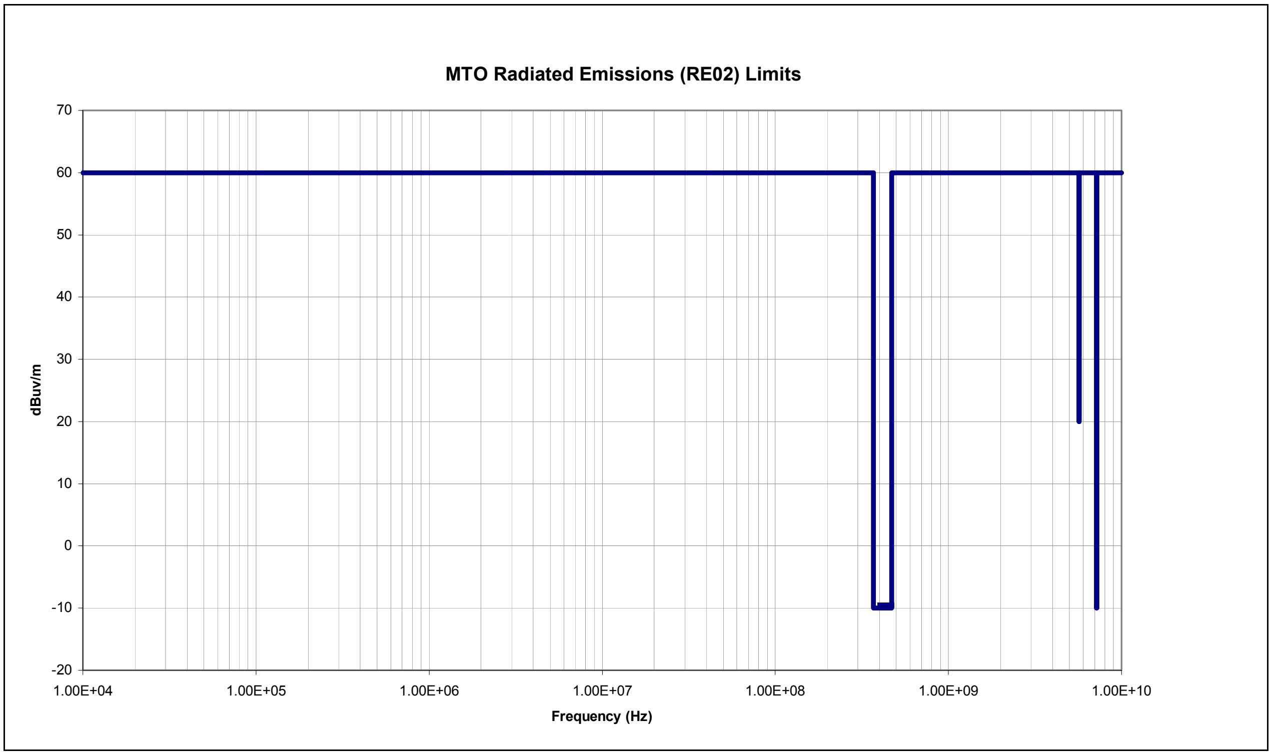


Figure 4.5.2-2 Radiated Emissions (RE02) Limits [TBC]

Table 4.5.2-2 Radiated Emissions (RE02) Limits [TBC]

Frequency Range	Limit (dBuv/m)	Potential Victim
10 kHz to 10 GHz	60	Baseline Maximum Allowable Radiated Emissions Limits
390 MHz to 450 MHz	-10	Spacecraft UHF Receiver ELECTRA
410 MHz to 430 MHz	20	Atlas V FTS Receiver
5.6850 GHz to 5.6950 GHz	20	Atlas V C Band
7.145 GHz to 7.190 GHz	-10	Spacecraft X Band

4.5.2.5 Conducted Susceptibility Narrowband Ripple (CS01/02)

Subsystems and assemblies shall operate without indications of interference, degradation of performance or malfunction when subjected to the susceptibility conditions specified herein. Subsystems and assemblies shall meet the requirements of MIL-STD-461C/462 methods CS01 and CS02 as modified herein. The limits shown in Figure 4.5.2-3 shall apply. Test signals for method CS02 shall be modulated with a minimum of 30 % amplitude at the worst case internal operating frequency or 1 kHz square wave if no modulation frequency identified. Additionally, signal injection points for method CS02 shall be performed on high side to return, high side to chassis, and return to chassis.

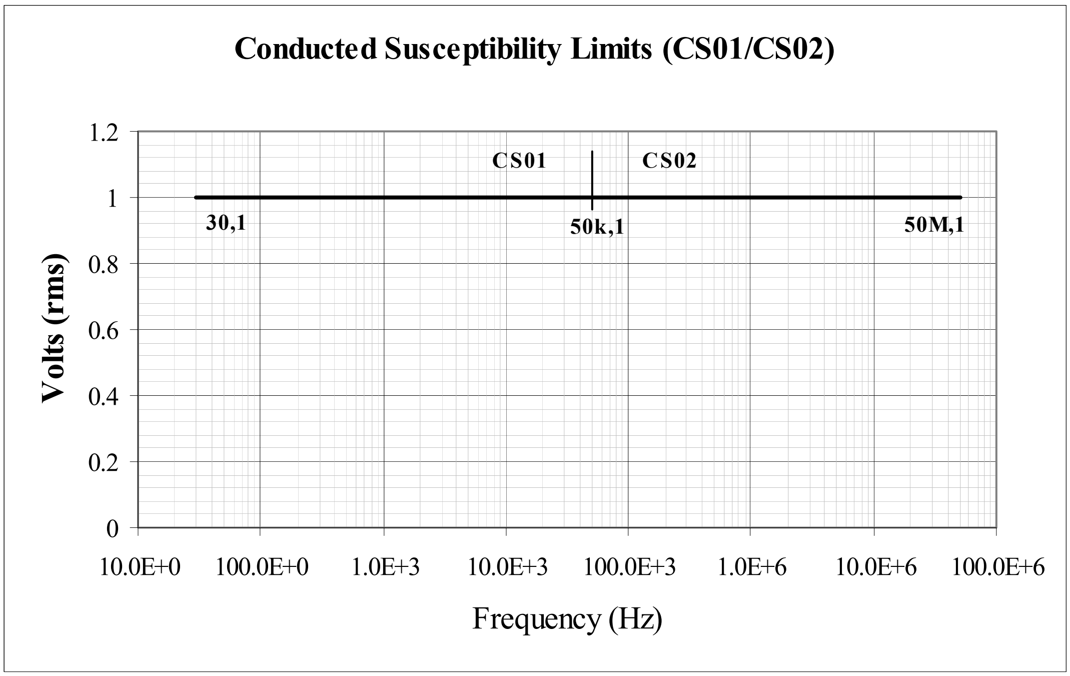


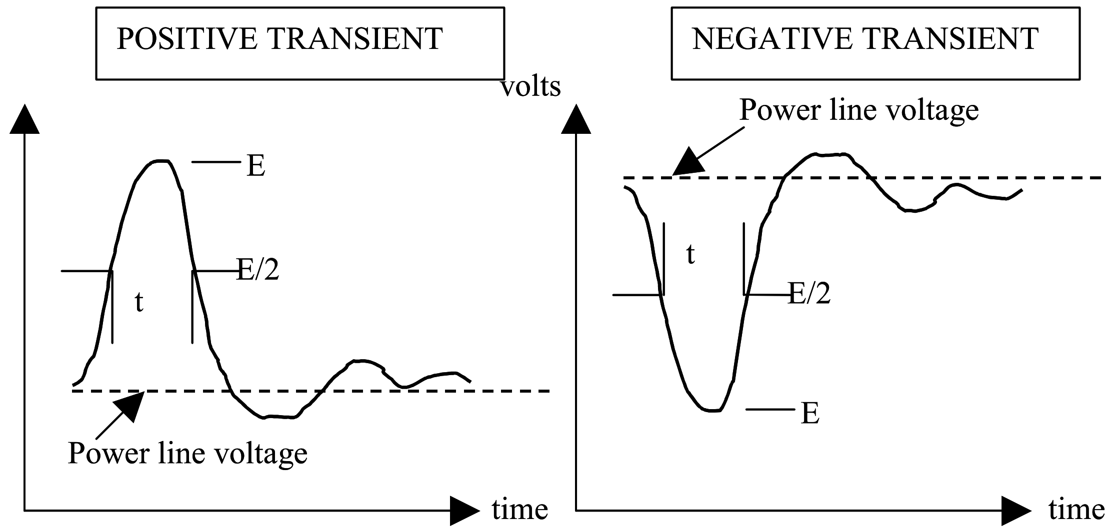
Figure 4.5.2-3 Conducted Susceptibility Limits (CS01/CS02)

4.5.2.6 Conducted Susceptibility Rejection of Undesired Signals (CS04)

Subsystems and assemblies with receiving antenna terminals shall meet the requirements of MIL-STD-461C/462 method CS04. Subsystems and assemblies shall meet performance requirements defined in their respective specifications when subjected to the requirements described herein.

4.5.2.7 Conducted Susceptibility Switching Transients (CS06)

Subsystems and assemblies shall meet the requirements of MIL-STD-461C/462 methods CS06 as modified herein. Limits for this test are: ±30 volts line to line and ±15 volts primary and return lines to chassis or 6 amps peak current whichever is attained first during compliance verification. Subsystems and assemblies shall meet performance requirements defined in their respective specifications when subjected to the requirements described herein. See Figure 4.5.2-4.



Notes: E never goes negative: i.e. below 0.0 volts.
E= + or - 30 volts peak line to return, and + and – 15 volts peak line and return to chassis.
t= 10 microseconds, and 150 nanoseconds.
Duration of application for each test condition is 5 minutes minimum.

Figure 4.5.2-4 Transient Susceptibility Waveshape

4.5.2.8 Radiated Susceptibility (RS03)

Subsystems and assemblies shall operate without indications of interference, degradation of performance, or malfunction when subjected to the electric field strengths shown in Figure 4.5.2-5. Table 4.5.2-3 shows the limits in tabular form.

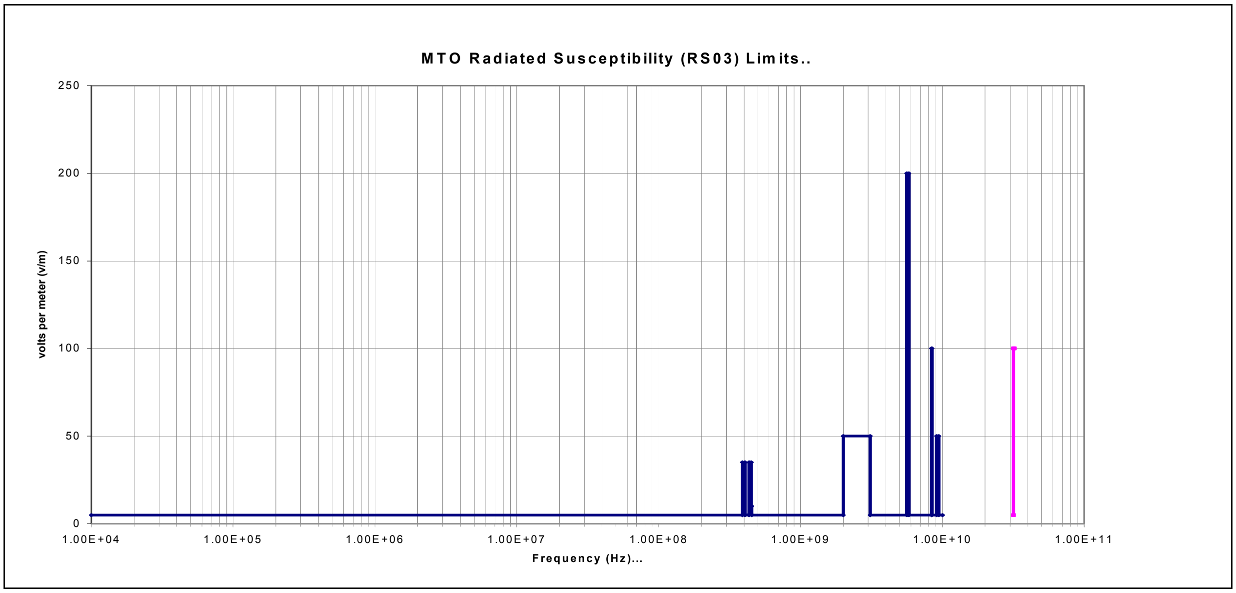


Figure 4.5.2-5 Radiated Susceptibility Limits [TBC]

Table 4.5.2-3 Radiated Susceptibility Limits [TBC]

Frequency Range	**Limit (v/m)**	**Source**
10 kHz to 10 GHz	5	Baseline Minimum Allowable Radiated Susceptibility Limits
390 MHz to 450 MHz	35	Spacecraft UHF Receiver ELECTRA
432.5 MHz to 452.5 MHz	10	Fl, Cape, FPS-66
2.0 GHz to 3.1 GHz	50	Fl, Cape, NASA STDN GND STA: ATLAS V S-BAND; FL, CAPE, NCAR CP-2; FL, Cape, WSR-88D; Cobra Gemini, ESWR-band & Ground shuttle Radar
5.6 GHz to 5.8 GHz	200	Various KSC Range Emitters & Atlas V C-Band
8.400 GHz to 8.450 GHz	100	Spacecraft X Band
9.1 GHz to 9.4 GHz	50	Cobra Gemini ESWR -X Bank; FL, Cape, NCAR X-Band
31.8 GHz to 32.3 GHz	100	Spacecraft Ka Band

Table 4.5.2-3 (continued) Radiated Susceptibility Limits [TBC]

Worst-Case RF Environment for CCAFS

Emitter Name	Frequency, MHz	Theoretical Intensity, V/m	Duty Cycle	Mitigation
Combined LC-36				
Radar 0.14	5,690	103.6	0.0016	Procedure Mask
Radar 1.16	5,690	158.2	0.00064	Procedure Mask
Radar 1.39	5,690 & 5,800	77.5	0.005	Procedure Mask
Radar 19.14	5,690	158.6	0.0016	Procedure Mask
Radar 19.17	5,690	26.8	0.0008	Procedure Mask
Radar 28.14	5,690	16.7	0.0016	Topography
Radar 1.8	9,410	4.8	0.0012	No (OD10040)
Radar ARSR-4	1,244.06 & 1,326.92	1.6	0.0006	None
Radar GPN-20	2,750 & 2,840	7.5	0.0008	None
WSR-74C	5,625	15.8	0.0064	None
WSR-88D	2,879	16.3	0.006	None
GPS Gnd Station	1,784	7.1	CW	Ops Min 3°
NASA STDN	2,025 & 2,120	1.0	CW	None
Astrotech				
Emitter Name	**Frequency, MHz**	**Theoretical Intensity, V/m**	**Duty Cycle**	**Mitigation**
Radar 0.14	5,690	71.8	0.0016	Procedure Mask
Radar 1.16	5,690	24.5	0.00064	Procedure Mask[1]
Radar 1.39	5,690 & 5,800	17.4	0.005	Procedure Mask
Radar 19.14	5,690	108.9	0.0016	Procedure Mask[1]
Radar 19.17	5,690	34.2	0.0008	Procedure Mask[1]
Radar 28.14	5,690	15.4	0.0016	Topography
Radar 1.8	9,410	0.8	0.0012	Procedure Mask
Radar ARSR-4	1,244.06 & 1,326.92	1.7	0.0006	None
Radar GPN-20	2,750 & 2,840	5.2	0.0008	None
WSR-74C	5,625	10.6	0.0064	None
WSR-88D	2,879	13.8	0.006	None
GPS Gnd Station	1,784	0.9	CW	Ops Min 3°
NASA STDN	2,025 & 2,120	1.0	CW	None
LC-41				
Emitter Name	**Frequency, MHz**	**Theoretical Intensity, V/m**	**Duty Cycle**	**Mitigation**
Radar 0.14	5690	71.7	0.0016	Procedure Mask
Radar 1.16	5690	52.6	0.00064	Procedure Mask
Radar 1.39	5690 & 5800	57.5	0.005	Procedure Mask
Radar 19.14	5690	106.5	0.0016	Procedure Mask
Radar 19.17	5690	55.1	0.0008	Procedure Mask
Radar 28.14	5690	15.5	0.0016	Topography
Radar 1.8	9410	2.0	0.0012	Procedure Mask
Radar ARSR-4	1,244.06 & 1,326.92	1.4	0.0006	None
Radar GPN-20	2750 & 2840	5.2	0.0008	None
WSR-74C	5625	10.6	0.0064	None
WSR-88D	2879	12.7	0.006	None
GPS Gnd Station	1784	2.3	CW	Ops Min 3°
NASA STDN	2025 & 2120	1.0	CW	None

Note: Sources Taken from Aerospace Report TOR-2001 (1663)-1, "Cape Canaveral Spaceport Radio Frequency Environment," October 2000
[1]See TOR-2001 (1663)-1, Sect. 2.2.1 Astrotech
Avg V/m = Pk, V/m*sqrt (Duty Cycle); CW = Continuous Wave
Shaded Blocks Indicate Emitters Without Specific Mechanical or Software Mitigation Measures
In-Flight Levels for Tracking Radars (0.14, 1.16, 1.39, 19.14, & 19.17) Are 20 V/m

4.5.2.9 Surge Voltage

Subsystems and assemblies shall operate without indication of interference, degradation in performance or malfunction, when surge voltages are applied on their primary power lines. Limits for this test are; ≥ +6 volts and ≤ -6 volts imposed on the 30.0 ± 4.0 volts dc primary power lines with a pulse width of 30.0 ± 6.0 milliseconds and, rise and fall times of 100 ± 10 microseconds and a repetition rate of 1.0 ± 0.1 Hz, for a minimum of 1 minute per polarity, as indicated in Figure 4.5.2-6. Verification shall be accomplished at one selected primary power input voltage.

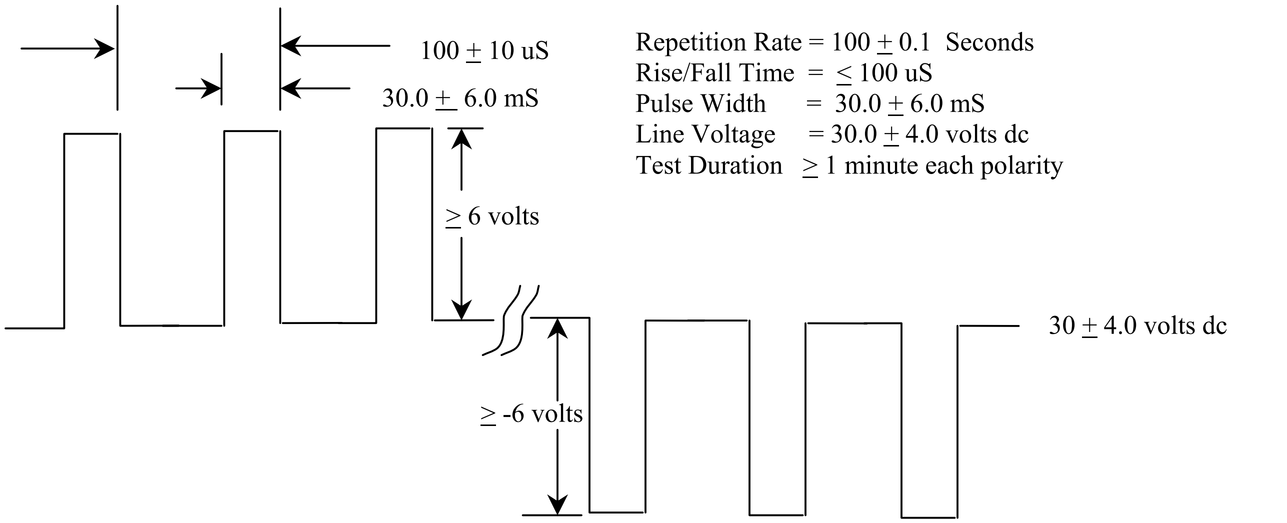


Figure 4.5.2-6 Surge Voltage Waveform

4.5.2.10 In-rush Current

Subsystems and assemblies powered by Universal Switch Module (USM) switches shall meet the turn on in rush current requirements shown Table 4.5.2-4.

Table 4.5.2-4 Power Switch Current Requirements [TBC]

Switch Type	Maximum Voltage Rate of Rise (a), (b)	Switch Rating Steady State Current NTE (Amps)	Maximum Inrush Current NTE (Amps)	Settling Time To Steady State Current +10% NTE (ms)	Average Inrush Current During the (X) ms period (e) NTE (Amps)
Load Switch (c)	10 V/ms	3.0 (d)	10	20	Steady State + 1.0 Amps
High Current Switch (c)	10 V/ms	10.0	25.0	10	Steady State + 4.0 Amps
Latching Switch (f)	10 V/ms	2.0	8.0	20	4.0
Low Current Switch (f)	10 V/ms	1.65	4.0	20	3.0

(a) Minimum switch rate of rise may be as low as 1.5V/ms.
(b) The switch module controls maximum switch rate of rise limitations.
(c) Steady state current may be exceeded for by mode or function changes for these switches provided:
Compliance with the last three columns is not violated,
Frequency of occurrence is low, i.e. < once every 5 minutes.
(d) If steady state current of load is greater than 3 amps, two switches will be placed in parallel to accommodate the steady state load.
(e) Calculating the area under the turn-on current trace for a period of 20 milliseconds and dividing that area by 20 milliseconds shall determine average inrush current. See Figure 4.5.2-7.
(f) For this switch type, steady state current includes all load related mode and function changes after initial application of power to the load.

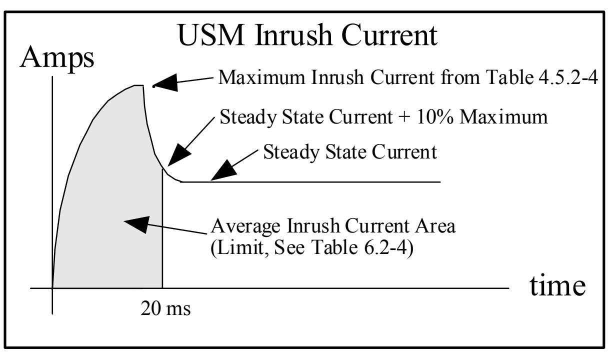


Figure 4.5.2-7 USM Inrush Current Limits

4.5.3 Magnetics Field Constraints

The magnetic environment for the mission never exceeds the earth's mean magnetic field strength. No special considerations are required for magnetic cleanliness or interference beyond satisfactory operation on earth prior to launch.

4.5.4 Radiated Susceptibility, Electrostatic Discharge (RS11)

The spacecraft shall be designed to perform per specifications when radiated with an electrostatic discharge (ESD) spark source having the following characteristics per MIL-STD-1541:

Table 4.5.4-1 ESD Radiated Susceptibility (RS11) [TBC]

Gap Voltage	10 kV
Pulse Rate	1 per second
Distance between gap and equipment under test	25 cm
Discharge Energy	3 mJ

4.5.5 Electrical Ground Support Equipment (EGSE)

The EGSE design shall be such that it will not produce interfering emissions or be susceptible to the test environment or the spacecraft assemblies, subsystems or payload items. Each EGSE set shall be equipped with a power bus impedance simulator appropriate for the assembly or subsystem being supported as described in Figure 4.5.5-1.

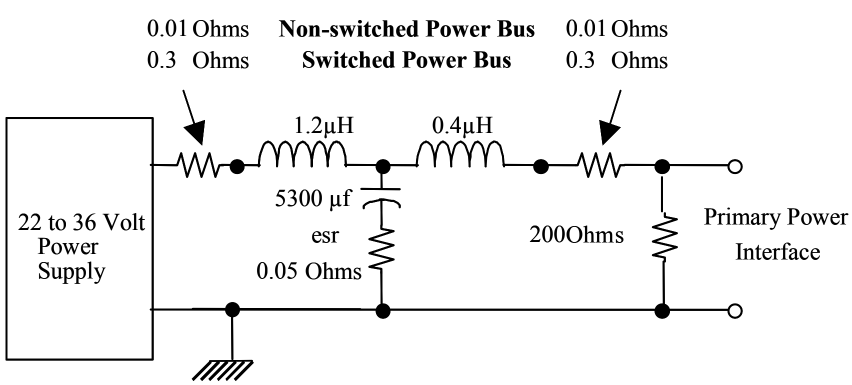


Figure 4.5.5-1 Power Bus Impedance Simulator for EGSE

4.5.6 Grounding, Referencing, Isolation and Bonding

4.5.6.1 Structure Bonding

Electrical bonding of mechanical faying surfaces shall comply with the requirements of NASA-STD-4003. The requirements and methods for class "R" electrical bonding shall apply to electro-mechanical assembly metal-to-metal mating surfaces. The maximum allowable electrical bonding resistance of 2.5 milliohms (0.0025 ohms) per mechanical joint and 25 milliohms to the equipotential ground plane for the spacecraft (0.025 ohms) shall be maintained for electro-mechanical assemblies. Non electro-mechanical assemblies, i.e. propulsion lines and tanks, solar array appendages shall have a maximum allowable electrical bonding resistance of 10 ohms as a static bleed path. The spacecraft interface shall provide a launch vehicle/spacecraft conductive path for electrical bonding of the spacecraft to the launch vehicle. The electrical bonding resistance between the spacecraft and launch vehicle shall be 2.5 milliohms or less, and shall be verified by measurement when they are mated.

4.5.6.2 Bond Straps

Where direct bonding is not possible and/or movable metal-to-metal joints are present, bonding straps shall be used. The length-to-width ratio of these bond straps shall be no greater than five-to-one (three-to-one is preferred). Minimum strap width shall be 1" (2.5 cm) metal strip; braided wire is not considered an acceptable bond strap material.

Serial connection of two or more bonding straps is not permitted.

4.5.6.3 Connectors

Connector shells shall be bonded to the chassis and/or cable shielding. Bonding resistance shall be 2.5 milliohms maximum to chassis.

4.5.6.4 Power Referencing and Isolation

The EPS 28 vdc primary power bus return shall be Single Point Grounded to spacecraft structure. The primary input power leads of subsystems and assemblies shall be isolated from their secondary power returns and chassis ground by a minimum of 1.0 megohm. Chassis shall not be used to intentionally conduct power currents under normal conditions. Only fault and leakage currents shall be conducted through chassis grounds.

Secondary power lines, inherently galvanic-isolated from the primary power by DC-to-DC converters or isolation transformers, shall maintain an isolation of at least 1 Megohm shunted with a capacitance of less than 50 nF with primary power return lines before any grounding of the secondary reference is made.

4.5.6.5 Signal Referencing and Isolation

All signal circuits, including analog and digital signals shall be referenced to the equipotential reference plane at one end and only at one end. Chassis shall not be used to intentionally conduct signal currents under normal conditions. Only fault and leakage currents shall be conducted through chassis grounds.

4.5.7 Electrostatic Discharge (ESD) Control

The spacecraft must be designed so that ESD does not occur when subjected to spacecraft charging effects. To accomplish this, all isolated conductive external surfaces shall be connected to the spacecraft ground plane via static drain wires.

a) Reliable electrostatic grounding of all metallic elements and the ground plane shall be provided. The dc resistance of the static ground connection shall be less than 1 kilo ohms.

b) The dc resistance from any point on the High Gain Antenna to any point on the spacecraft ground plane shall be equal to or less than 10 kohms.

c) All thermal blanket layers shall be grounded. This rule applies to any blanket surface area over 232 cm^2. The number of grounding straps, location and attachment requirements shall be in accordance with this EMC Control Plan or otherwise approved by EMC engineering. Evidence of approval by EMC engineering shall be by appropriate signature on build drawings.

d) Conductive materials including tapes with areas greater than 232 cm^2 shall be grounded. The number, location and resistance of ground straps shall be in accordance with this EMC Control Plan or otherwise approved by EMC engineering. Evidence of approval by EMC engineering shall be by appropriate signature on build drawings.

e) There shall be no ungrounded (floating) conductors > 15 cm in length.

4.5.8 EMC Verification Matrix

Table 4.5.8-1 summarizes the EMC verification requirements for MTO. Definitions of A(analysis), T(test), I(inspection), and D(demonstration) are contained in the table *Notes*.

Table 4.5.8-1 EMC Verification Matrix [TBC]

Para.	Requirement	A[1]	T[2]	I[3]	D[4]
4.5	EMI/EMC REQUIREMENTS	Title			
4.5.1	Spacecraft System	Title			
4.5.1.1	Spacecraft Electromagnetic Environment	Title			
4.5.1.1.1	Radiated Emissions		X		
4.5.1.1.2	Radiated Susceptibility		X		
4.5.1.2	System Compatibility	Title			
4.5.1.2.1	Electromagnetic Interference Safety Margin (EMISM)	X			
4.5.1.2.2	System Margin	X			
4.5.2	Subsystems and Assemblies			X	
4.5.2.1	Conducted Emissions Power Quality: Ripple and Noise		X		
4.5.2.2	Antenna Conducted Emissions		X		
4.5.2.3	Conducted Emissions Spikes, DC Power Lines		X		
4.5.2.4	Radiated Emissions		X		
4.5.2.5	Conducted Susceptibility Narrowband Ripple		X		
4.5.2.6	Conducted Susceptibility Rejection of Undesired Signals (CS04)		X		
4.5.2.7	Conducted Susceptibility Switching Transients (CS06)		X		
4.5.2.8	Radiated Susceptibility (RS03)		X		
4.5.2.9	Surge Voltage		X		
4.5.2.10	In-rush Current		X		
4.5.3	Magnetics				X
4.5.4	Radiated Susceptibility, Electrostatic Discharge (RS11)			X	
4.5.5	Electrical Ground Support Equipment (EGSE)				X
4.5.6	Grounding, Referencing, Isolation and Bonding	Title			
4.5.6.1	Electrical Bonding		X	X	
4.5.6.1	Structure Bonding		X	X	
4.5.6.2	Bond Straps		X	X	
4.5.6.3	Connectors		X	X	
4.5.6.4	Power Referencing and Isolation		X		
4.5.6.5	Signal Referencing and Isolation		X		
4.5.7	Electrostatic Discharge (ESD) Control		X		

Notes:

1. (A): Analysis is an analytical evaluation or calculation that considers the parameters of a design or hardware implementation of a design and compares the result with stated requirements for compliance. Tests may be used to augment an analysis.
2. (T): Test is the application of detailed test procedures that verify compliance with a set of measurable parameters. Analysis may be used to augment a test.
3. (I): Inspection is the visual examination of hardware or released engineering documentation or data to verify compliance with stated requirements for compliance.
4. (D): Demonstration is the operation of equipment in conjunction with other equipment to demonstrate compatibility.

4.6 Charged Particle Radiation Environment

All MTO assemblies shall be designed to operate within performance specification during and after the exposure to these environments with a designated radiation design factor. This section covers the naturally occurring space radiation environments to which the spacecraft and MTO assemblies will be exposed. Unless otherwise stated, all tables and graphs within this section represent environments external to the spacecraft/instrument and do not contain a design factor. The radiation design factor (RDF), when applied, is defined as:

$$RDF = \frac{\text{Radiation-resisting capability of a part or Assembly in a given application}}{\text{Radiation environment present at the location of the part or assembly}}$$

4.6.1 Mission Fluence

The total mission charged particle fluence of protons in Solar Energetic Particle (SEP) events are given in Table 4.6.1-1 and Figure 4.6.1-1. The only significant space radiation exposure of MTO hardware will come from Solar protons. The flux of galactic cosmic rays (GCR) contributes approximately 0.02 Rad-Si /day to the mission dose, independent of shielding. For the MTO mission, it will be neglected. The exposure of MTO to the Earth's radiation belts is negligible. Mars has no radiation belts. On-board radiation sources such as radioisotope heater units (RHUs) are TBD.

Table 4.6.1-1 Solar Proton Fluence for the MTO Mission

Energy	FLUENCE (protons/cm2)		
(MeV)	Cruise	On-orbit	Total
1	1.05E+11	5.41E+11	6.46E+11
4	3.51E+10	1.81E+11	2.16E+11
10	1.36E+10	7.00E+10	8.35E+10
30	3.72E+09	1.92E+10	2.29E+10
60	1.67E+09	8.61E+09	1.03E+10
100	9.28E+08	4.79E+09	5.71E+09
150	5.80E+08	2.99E+09	3.57E+09
200	4.16E+08	2.15E+09	2.56E+09
300	2.60E+08	1.34E+09	1.60E+09
500	1.45E+08	7.46E+08	8.90E+08
1000	6.46E+07	3.33E+08	3.98E+08
2000	2.91E+07	1.50E+08	1.79E+08
3000	6.40E-01	3.30E+00	3.94E+00

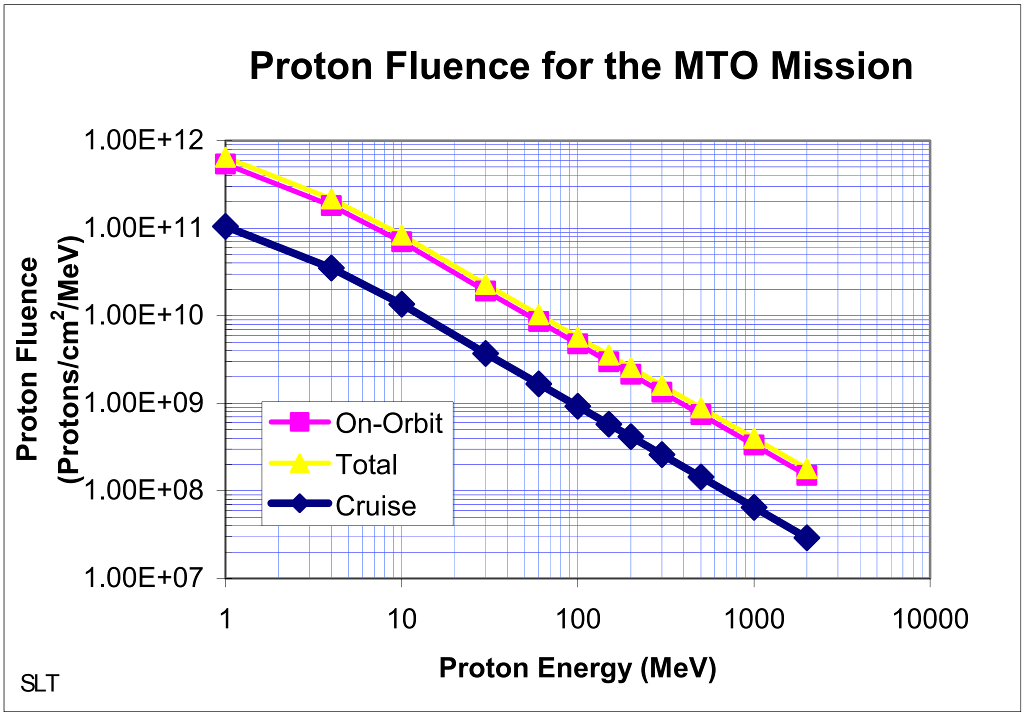


Figure 4.6.1-1 Proton Fluence for the MTO Mission

4.6.2 Total Ionizing Dose (TID)

Flight assemblies shall be designed to operate within performance specification during and after the total ionizing dose (TID) exposure as shown in Table 4.6.2-1 and Figure 4.6.2-1, at a radiation design factor (RDF) of 2 times the TID level present at the location of the device.

Devices that require spot shielding shall be evaluated at a radiation design factor (RDF) of 3 times the dose level present at the location of the device.

Table 4.6.2-1: Solar Proton Total Ionizing Dose (TID) and Non-Ionizing Energy Loss (NIEL) Dose in silicon, at the center of a Spherical Shell Shield of Aluminum. NIEL dose response assumes a 21 eV NIEL threshold for silicon. (JPL '91 Model)

Aluminum Shield Thickness			MTO TID (rad-Si)	MTO NIEL (MeV/g -Si)	MTO NIEL (equiv. 1 Mev Neutron/cm²)	MTO TID (rad-Si)	MTO NIEL (MeV/g -Si)	MTO NIEL (equiv. 1 Mev Neutron/cm²)
mm	g / cm²	mils	RDF = 1	RDF = 1	RDF = 1	RDF = 2	RDF = 2	RDF = 2
0.037	1.00E-02	1.46	6.30E+05	1.41E+10	6.89E+12	1.26E+06	2.81E+10	1.38E+13
0.047	1.26E-02	1.84	5.12E+05	1.11E+10	5.44E+12	1.02E+06	2.22E+10	1.09E+13
0.059	1.59E-02	2.32	4.18E+05	8.75E+09	4.29E+12	8.35E+05	1.75E+10	8.57E+12
0.074	2.00E-02	2.92	3.50E+05	7.13E+09	3.49E+12	7.01E+05	1.43E+10	6.99E+12
0.093	2.51E-02	3.66	2.89E+05	5.87E+09	2.88E+12	5.78E+05	1.17E+10	5.75E+12
0.117	3.16E-02	4.61	2.45E+05	4.81E+09	2.36E+12	4.91E+05	9.61E+09	4.71E+12
0.147	3.98E-02	5.80	2.05E+05	4.02E+09	1.97E+12	4.11E+05	8.04E+09	3.94E+12
0.186	5.01E-02	7.31	1.63E+05	3.05E+09	1.50E+12	3.26E+05	6.11E+09	2.99E+12
0.234	6.31E-02	9.20	1.32E+05	2.47E+09	1.21E+12	2.65E+05	4.95E+09	2.42E+12
0.254	6.86E-02	10.00	1.17E+05	2.15E+09	1.05E+12	2.34E+05	4.30E+09	2.11E+12
0.294	7.94E-02	11.58	1.00E+05	1.87E+09	9.15E+11	2.01E+05	3.74E+09	1.83E+12
0.370	1.00E-01	14.58	8.16E+04	1.43E+09	7.01E+11	1.63E+05	2.86E+09	1.40E+12
0.467	1.26E-01	18.37	6.62E+04	1.16E+09	5.70E+11	1.32E+05	2.32E+09	1.14E+12
0.507	1.37E-01	19.98	5.95E+04	1.04E+09	5.10E+11	1.19E+05	2.08E+09	1.02E+12
0.589	1.59E-01	23.18	5.20E+04	9.10E+08	4.46E+11	1.04E+05	1.82E+09	8.92E+11
0.741	2.00E-01	29.16	4.26E+04	7.41E+08	3.63E+11	8.51E+04	1.48E+09	7.26E+11
0.763	2.06E-01	30.04	3.93E+04	6.86E+08	3.36E+11	7.86E+04	1.37E+09	6.72E+11
0.930	2.51E-01	36.60	3.20E+04	5.67E+08	2.78E+11	6.39E+04	1.13E+09	5.56E+11
1.015	2.74E-01	39.95	2.88E+04	5.08E+08	2.49E+11	5.77E+04	1.02E+09	4.98E+11
1.170	3.16E-01	46.08	2.56E+04	4.45E+08	2.18E+11	5.12E+04	8.90E+08	4.36E+11
1.270	3.43E-01	50.01	2.27E+04	3.92E+08	1.92E+11	4.53E+04	7.84E+08	3.84E+11
1.474	3.98E-01	58.03	1.97E+04	3.50E+08	1.71E+11	3.94E+04	7.00E+08	3.43E+11
1.526	4.12E-01	60.08	1.82E+04	3.23E+08	1.58E+11	3.64E+04	6.46E+08	3.17E+11
1.778	4.80E-01	69.99	1.62E+04	2.85E+08	1.40E+11	3.24E+04	5.70E+08	2.79E+11
1.856	5.01E-01	73.05	1.49E+04	2.59E+08	1.27E+11	2.99E+04	5.18E+08	2.54E+11
2.033	5.49E-01	80.05	1.35E+04	2.36E+08	1.16E+11	2.70E+04	4.73E+08	2.32E+11
2.285	6.17E-01	89.97	1.23E+04	2.18E+08	1.07E+11	2.45E+04	4.37E+08	2.14E+11
2.337	6.31E-01	92.01	1.15E+04	2.06E+08	1.01E+11	2.30E+04	4.13E+08	2.02E+11
2.541	6.86E-01	100.03	1.06E+04	1.89E+08	9.25E+10	2.11E+04	3.77E+08	1.85E+11
2.941	7.94E-01	115.78	9.30E+03	1.67E+08	8.19E+10	1.86E+04	3.34E+08	1.64E+11
3.048	8.23E-01	120.01	8.51E+03	1.54E+08	7.53E+10	1.70E+04	3.07E+08	1.51E+11
3.556	9.60E-01	139.98	7.53E+03	1.37E+08	6.72E+10	1.51E+04	2.74E+08	1.34E+11
3.704	1.00E+00	145.82	6.97E+03	1.28E+08	6.26E+10	1.39E+04	2.55E+08	1.25E+11
4.074	1.10E+00	160.40	6.38E+03	1.16E+08	5.70E+10	1.28E+04	2.32E+08	1.14E+11
4.556	1.23E+00	179.35	5.71E+03	1.06E+08	5.21E+10	1.14E+04	2.13E+08	1.04E+11
4.667	1.26E+00	183.73	5.32E+03	1.00E+08	4.92E+10	1.06E+04	2.01E+08	9.85E+10
5.074	1.37E+00	199.77	4.89E+03	9.38E+07	4.59E+10	9.77E+03	1.88E+08	9.19E+10
5.593	1.51E+00	220.18	4.57E+03	8.67E+07	4.25E+10	9.14E+03	1.73E+08	8.49E+10
5.889	1.59E+00	231.85	4.33E+03	8.23E+07	4.03E+10	8.67E+03	1.65E+08	8.07E+10
6.111	1.65E+00	240.59	4.06E+03	7.76E+07	3.80E+10	8.12E+03	1.55E+08	7.61E+10
6.593	1.78E+00	259.55	3.76E+03	7.29E+07	3.57E+10	7.53E+03	1.46E+08	7.14E+10

Table 4.6.2-1: (Continued) Solar Proton Total Ionizing Dose (TID) and Non-Ionizing Energy Loss (NIEL) Dose within a Spherical Shell of Aluminum. NIEL dose response assumes a 21 eV NIEL threshold for silicon. (JPL '91 Model)

Aluminum Shield Thickness			MTO TID (rad-Si)	MTO NIEL (MeV/g -Si)	MTO NIEL (equiv. 1 Mev Neutron/cm^2)	MTO TID (rad-Si)	MTO NIEL (MeV/g - Si)	MTO NIEL (equiv. 1 Mev Neutron/cm^2)
mm	g / cm^2	mils	RDF = 1	RDF = 1	RDF = 1	RDF = 2	RDF = 2	RDF = 2
7.111	1.92E+00	279.97	3.42E+03	6.82E+07	3.34E+10	6.85E+03	1.36E+08	6.68E+10
7.407	2.00E+00	291.63	3.24E+03	6.46E+07	3.17E+10	6.49E+03	1.29E+08	6.33E+10
7.630	2.06E+00	300.38	3.07E+03	6.15E+07	3.01E+10	6.15E+03	1.23E+08	6.02E+10
9.296	2.51E+00	366.00	2.66E+03	5.24E+07	2.57E+10	5.33E+03	1.05E+08	5.14E+10
10.148	2.74E+00	399.53	2.35E+03	4.77E+07	2.34E+10	4.70E+03	9.53E+07	4.67E+10
11.704	3.16E+00	460.78	2.04E+03	4.26E+07	2.09E+10	4.08E+03	8.51E+07	4.17E+10
12.704	3.43E+00	500.15	1.83E+03	3.83E+07	1.87E+10	3.66E+03	7.65E+07	3.75E+10
14.741	3.98E+00	580.34	1.58E+03	3.35E+07	1.64E+10	3.16E+03	6.69E+07	3.28E+10
18.556	5.01E+00	730.53	1.25E+03	2.68E+07	1.31E+10	2.51E+03	5.37E+07	2.63E+10
23.370	6.31E+00	920.09	9.77E+02	2.19E+07	1.08E+10	1.95E+03	4.39E+07	2.15E+10
29.407	7.94E+00	1157.77	7.72E+02	1.77E+07	8.69E+09	1.54E+03	3.55E+07	1.74E+10
37.037	1.00E+01	1458.00	5.87E+02	1.42E+07	6.97E+09	1.17E+03	2.84E+07	1.39E+10

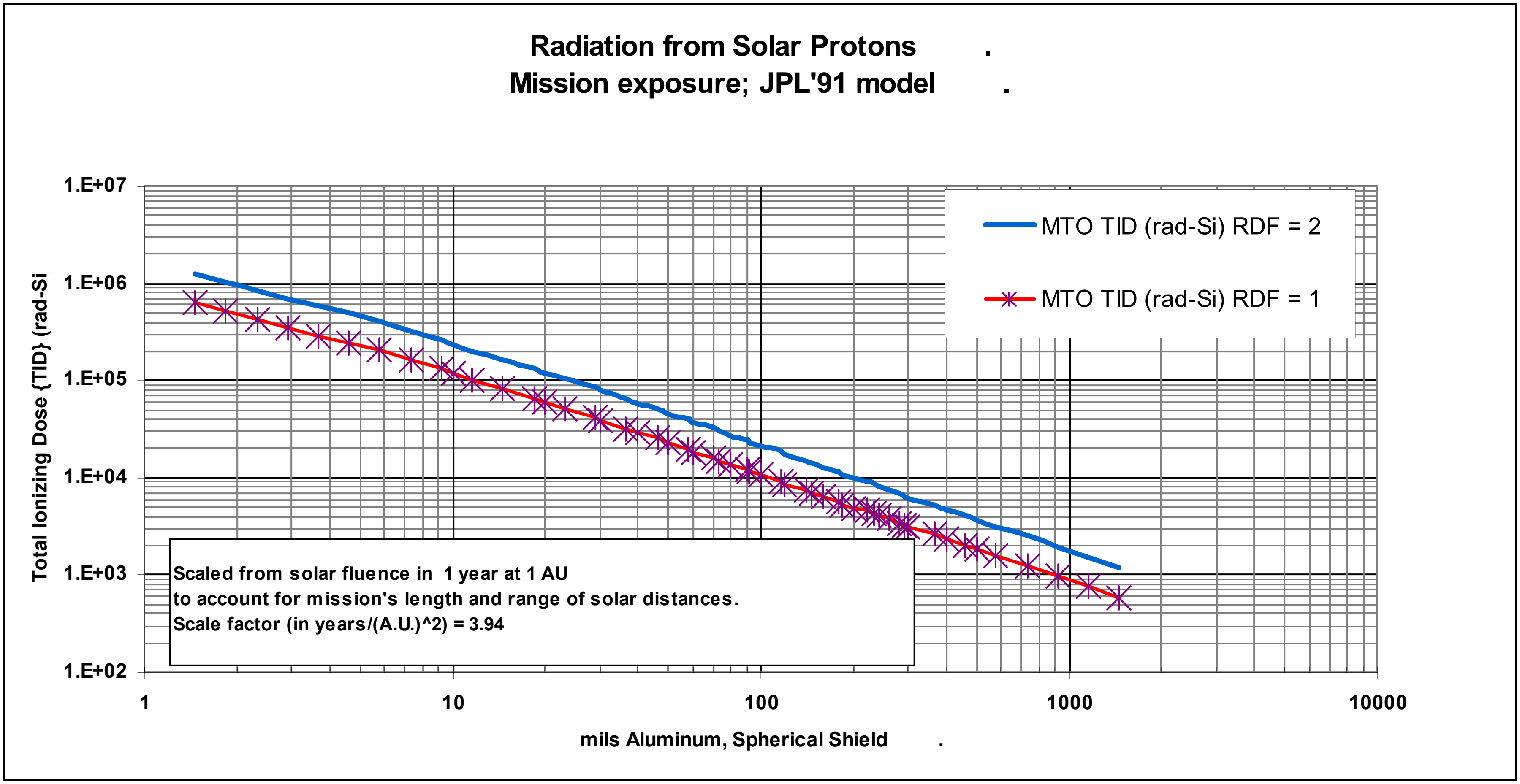


Figure 4.6.2-1 Total Ionizing Dose for MTO Mission in units of rad-Si

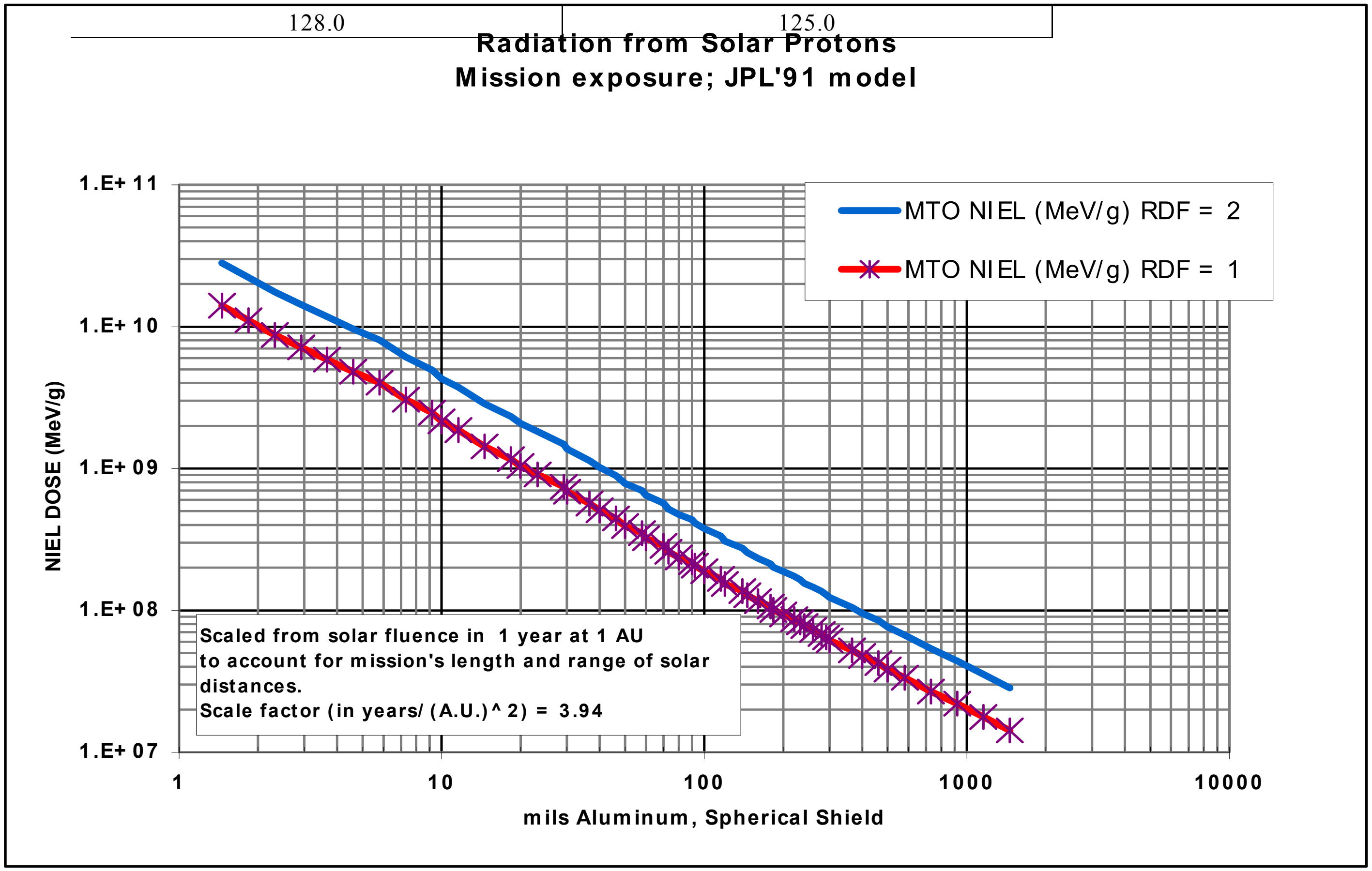


Figure 4.6.3-1 Non-Ionizing Energy Loss Dose in Silicon, for MTO Mission in units of MeV / g

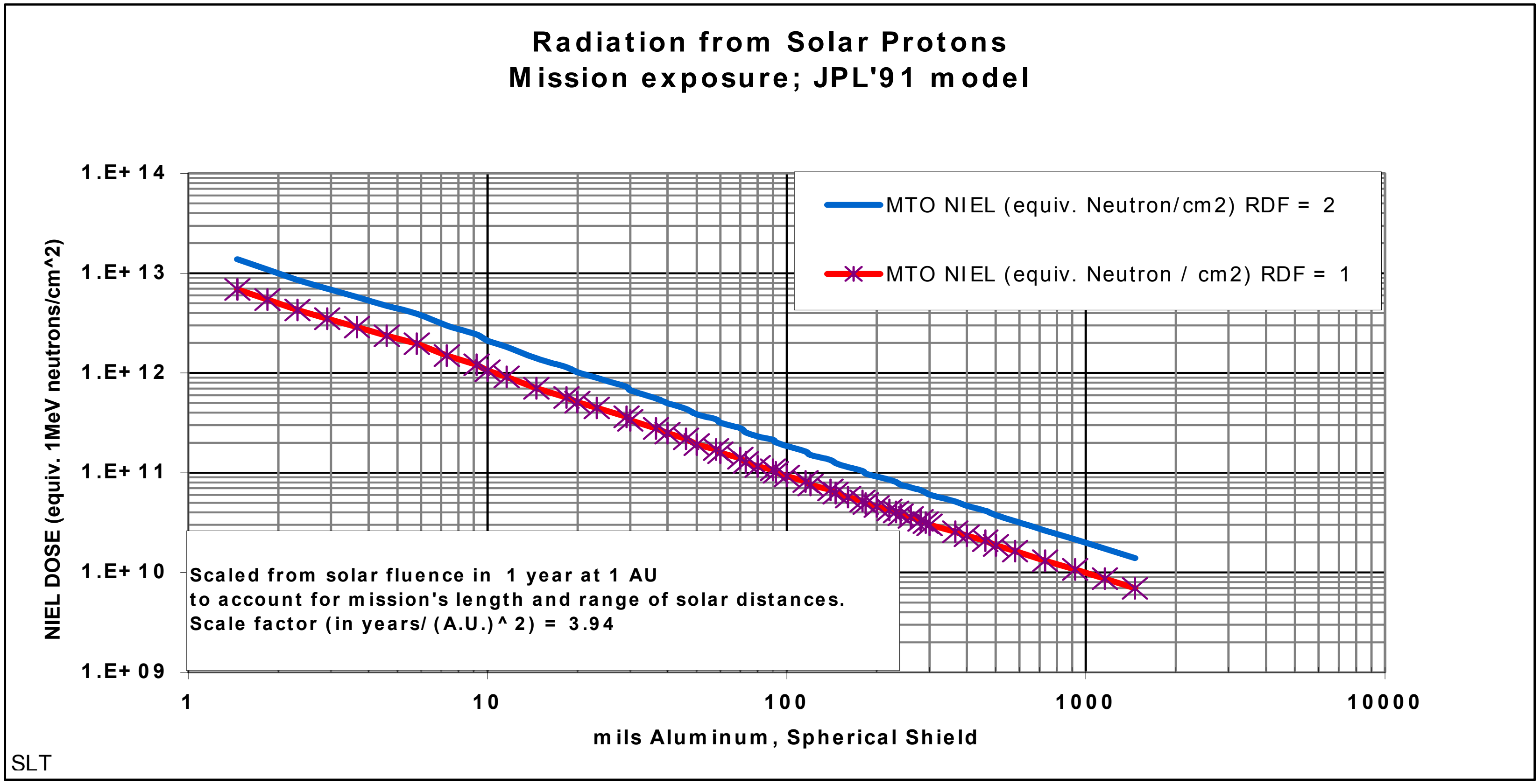


Figure 4.6.3-2 **Non-Ionizing Energy Loss Dose in Silicon, for MTO Mission in units of equivalent 1 MeV /Neutron/cm^2**

4.6.3 Displacement Damage

The radiation degradation of certain electronic devices (solar cells and opto-couplers, among others) can not be adequately characterized in terms of TID. The particle type, energy, and fluence must be considered.

Flight assemblies shall be designed to operate within performance specification during and after the non-ionizing energy loss (NIEL) dose exposure of charged particles, as shown in Table 4.6.2-1 and Figures 4.6.3-1 and 4.6.3-2, at a radiation design factor (RDF) of 2 times the dose level present at the location of the device. Devices that require spot shielding shall be evaluated at a radiation design factor (RDF) of 3 times the level present at the location of the device.

4.6.4 Single Event effects

Electronics may be susceptible to so-called single event effects, or SEE, which include reversible, non-destructive actions (termed single event upsets, or SEUs) such as memory bit-flips; or potentially destructive actions such as device latch-up. SEEs are caused by high-energy ions. The term "heavy ion", as used below, refers to any ion having atomic number Z > 1; i.e. anything larger than a proton. If the part's SEE threshold LET (linear energy transfer) is less than 15 MeV-cm^2/mg, then high-energy protons can also cause SEE. These types of high-energy particles are found in Earth's trapped radiation belts, galactic cosmic rays and solar particle events.

In electronic sensors, SEE can manifest itself as spurious signals, i.e. radiation-induced background noise. This may be caused by high-energy ions and by high-energy protons from Earth trapped radiation belts, SEP events, and GCR.

The subsystem and system-level requirements regarding performance with respect to SEE during operation are as follows:

1)
2) Temporary loss of function or loss of data shall be permitted provided that the loss does not compromise subsystem/system health, full performance can be recovered rapidly, and there is no time in the mission that the loss is mission critical.
3)
4) Normal operation and function shall be restored via internal correction methods without external intervention in the event of a SEU.
5)
6) Fault traceability shall be provided in the telemetry stream to the greatest extent practical for all anomalies involving SEEs.

Flight assemblies shall be designed to operate within performance specification during and after exposure to the high-energy radiation environments specified in the following sub-sections with a RDF of 1 applied.

4.6.4.1 Solar Proton Peak Flux

The solar proton peak flux environment, which is to be used for proton-induced SEE in parts having an SEE threshold less than 15 MeV-cm^2/mg, is given by the CREME96 model for the worst-case (5 minute average) solar event protons as seen by the part (that is, behind the available shielding). The environment behind 25 mils (0.635 mm) of aluminum shielding, as shown in Figure 4.6.4-1, may be used in the absence of part-specific shielding information.

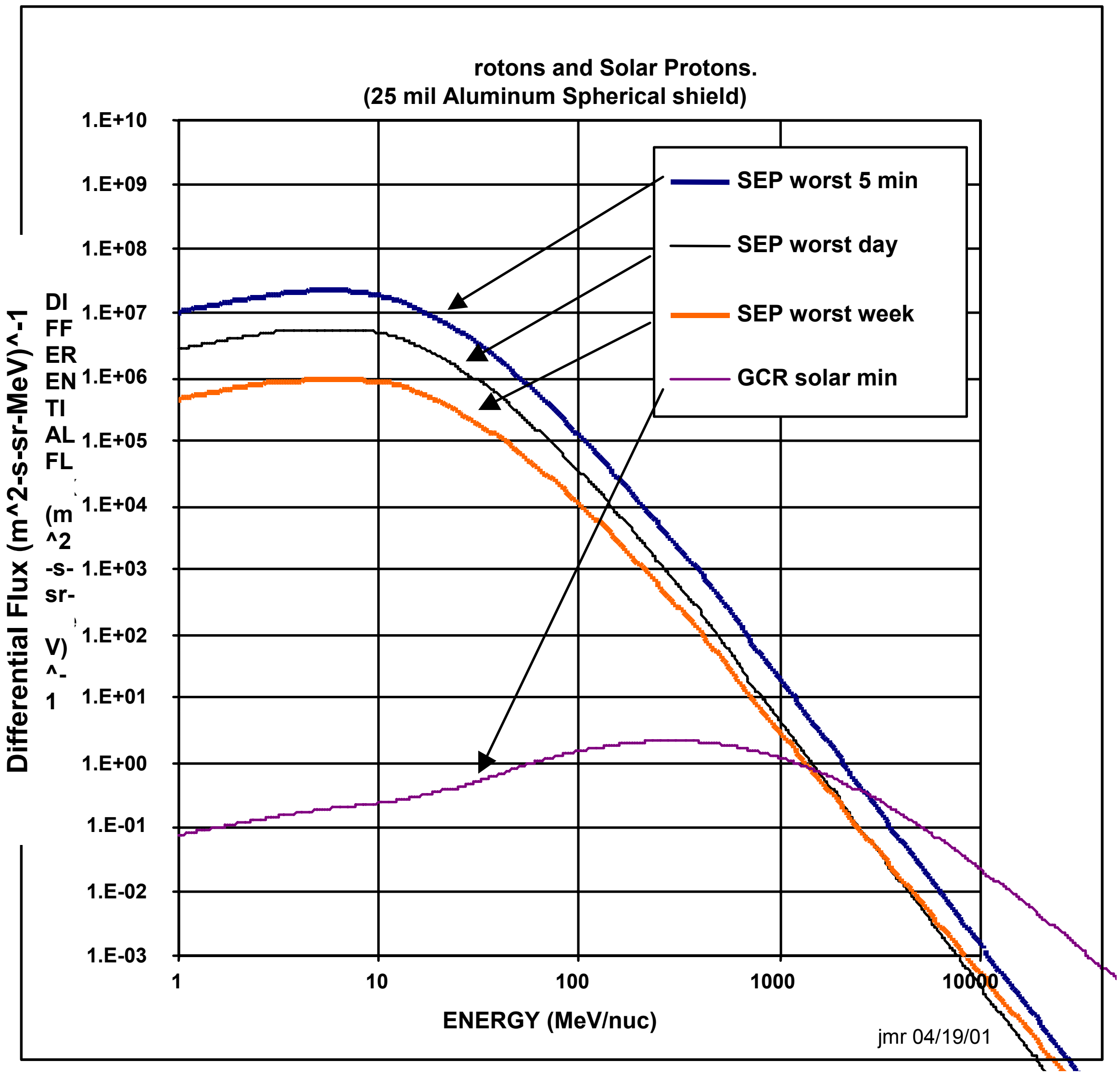


Figure 4.6.4-1 Solar Energetic Particle (SEP) event and GCR proton fluxes behind 25 mils (0.635 mm) aluminum shielding (CREME96 model)

4.6.4.2 Solar Heavy Ion Peak Flux

The solar particle event heavy ion peak flux environment is given by the CREME96 model for the worst case (5 minute average) solar event heavy ions as seen by the part (that is, behind the available shielding). The environment behind 25 mils (0.635 mm) of aluminum shielding, as shown in Figure 4.6.4-2, may be used in the absence of part-specific shielding information.

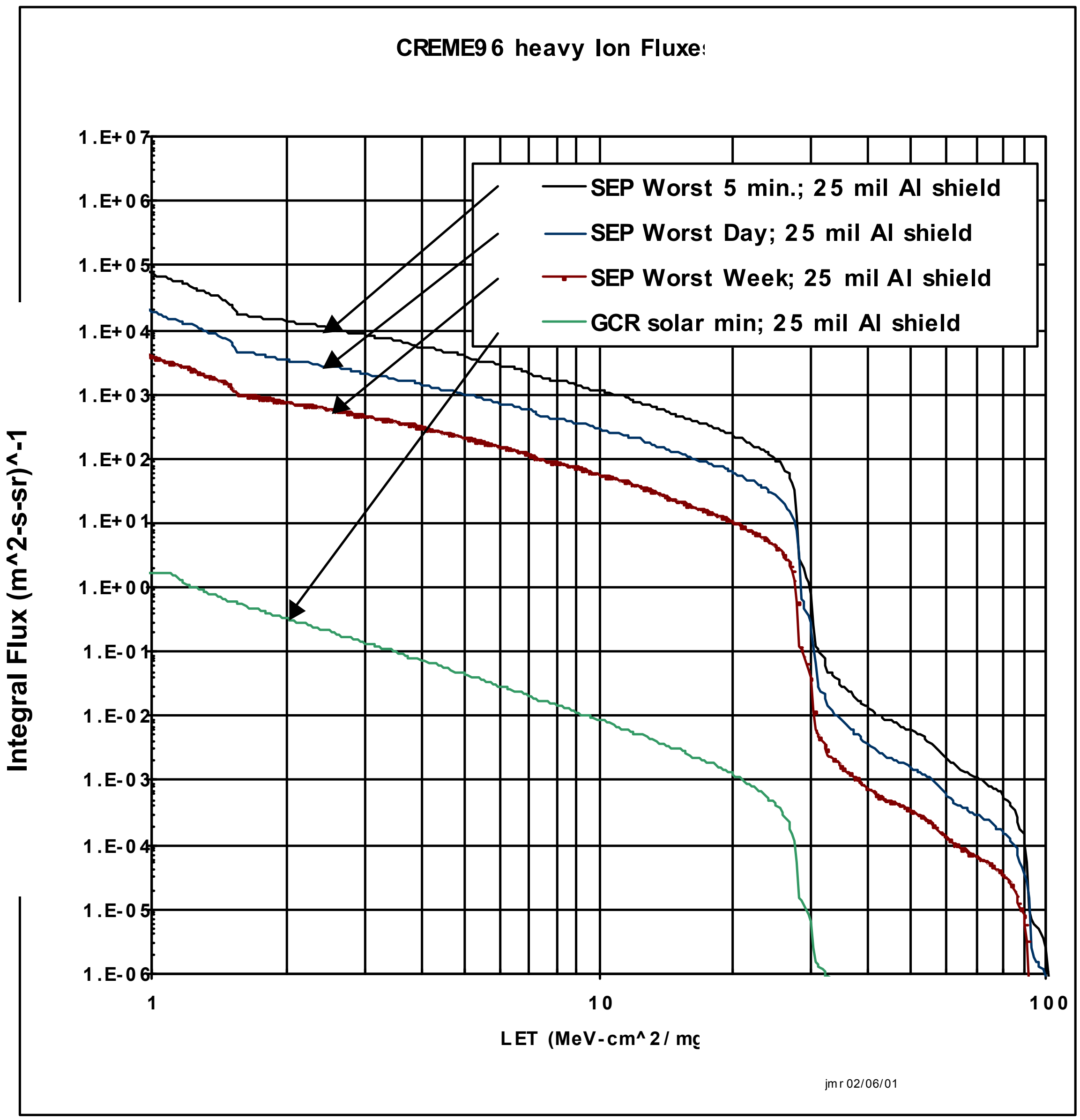


Figure 4.6.4-2 Solar Energetic Particle (SEP) event and GCR heavy ion fluxes behind 25 mils (0.635 mm) aluminum shielding (CREME96 model)

4.6.4.3 Galactic Cosmic Ray Proton Flux

The GCR proton environment, to be used for proton-induced SEE in parts having an SEE threshold less than 15 MeV-cm^2/mg, is given by the CREME96 model for GCR protons at solar minimum as seen by the part (that is, behind the available shielding). The environment behind 25 mils (0.635 mm) of aluminum shielding, as shown in Figure 4.6.4-1, may be used in the absence of part-specific shielding information.

4.6.4.4 Galactic Cosmic Ray Heavy Ion Flux

The GCR heavy ion environment is given by the CREME96 model for heavy ions at solar minimum environment as seen by the part (that is, behind the available shielding). The environment behind 25 mils (0.635 mm) of aluminum shielding, as shown in Figure 4.6.4-2, may be used in the absence of part-specific shielding information.

4.7 Solid Particle Environment

4.7.1 Micrometeoroid

MTO hardware shall be designed to have a greater than 98% probability of meeting performance specification after exposure to the meteoroid environment specified herein. These requirements are to be verified by analysis.

Omni-directional micrometeoroid fluence on the trip to Mars is displayed in Table 4.7.1-1 as a function of mass and velocity for the 11-year mission. Table 4.7.1-2 and Table 4.7.1-3 show the omni-directional micrometeoroid fluence while in Mars orbit and the total mission fluence. Figure 4.7.1-1 shows the omni-directional micrometeoroid fluence as a function of mass for the trip to Mars. Figures 4.7.1-2 and 4.7.1-3 show similar plots for the micrometeoroid fluence while in Mars orbit and the total mission fluence.

The omnidirectional fluence is the number of particles that impact the surface of a spherical object, divided by the cross sectional area of the sphere. (The omnidirectional fluence is equivalent to 4 times the fluence to one side of a surface, averaged over all orientations of the surface.) These results do not include meteor streams from comets, which may be neglected.

For design, the directional dependence of the environment can be ignored; assume the environment is isotropic. Equivalently, assume that a given spacecraft surface moves through all spatial orientations in the course of the mission.

4.7.2 Orbital Debris

Orbital debris is not a design requirement due to the short time in Earth orbit.

Table 4.7.1-1: MTO Micrometeoroid Fluence from Earth to Mars; 10/20/2009 to 9/6/2010 (321 Total Days)

Mass (g)	1.E-12	1.E-11	1.E-10	1.E-09	1.E-08	1.E-07	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01
Total omni-Fluence (m^-2)	2.86E+03	1.37E+03	6.43E+02	2.87E+02	1.09E+02	2.61E+01	4.24E+00	6.00E-01	8.40E-02	7.02E-03	3.94E-04	1.86E-05	8.69E-07	4.05E-08
Velocity (m/s)														
0	7.58E-02	3.55E-02	1.60E-02	7.40E-03	2.96E-03	7.46E-04	1.15E-04	1.13E-05	8.66E-07	5.61E-08	2.93E-09	1.36E-10	6.20E-12	2.87E-13
1000	1.94E+00	9.10E-01	4.08E-01	1.89E-01	7.59E-02	1.93E-02	3.11E-03	3.89E-04	4.70E-05	3.75E-06	2.08E-07	9.87E-09	4.57E-10	2.13E-11
2000	9.11E+00	4.27E+00	1.92E+00	8.91E-01	3.57E-01	9.12E-02	1.54E-02	2.33E-03	3.47E-04	2.93E-05	1.65E-06	7.85E-08	3.66E-09	1.71E-10
3000	2.53E+01	1.18E+01	5.31E+00	2.47E+00	9.87E-01	2.54E-01	4.37E-02	7.23E-03	1.16E-03	9.96E-05	5.65E-06	2.68E-07	1.25E-08	5.84E-10
4000	5.40E+01	2.54E+01	1.14E+01	5.29E+00	2.12E+00	5.44E-01	9.59E-02	1.72E-02	2.91E-03	2.54E-04	1.44E-05	6.84E-07	3.19E-08	1.49E-09
5000	8.64E+01	4.07E+01	1.84E+01	8.50E+00	3.39E+00	8.69E-01	1.52E-01	2.67E-02	4.45E-03	3.86E-04	2.20E-05	1.04E-06	4.86E-08	2.27E-09
6000	1.38E+02	6.49E+01	2.93E+01	1.36E+01	5.41E+00	1.38E+00	2.41E-01	4.12E-02	6.77E-03	5.88E-04	3.33E-05	1.59E-06	7.38E-08	3.45E-09
7000	1.70E+02	8.01E+01	3.63E+01	1.68E+01	6.65E+00	1.70E+00	2.91E-01	4.76E-02	7.55E-03	6.49E-04	3.67E-05	1.74E-06	8.14E-08	3.80E-09
8000	1.88E+02	8.88E+01	4.03E+01	1.86E+01	7.36E+00	1.87E+00	3.19E-01	5.05E-02	7.82E-03	6.69E-04	3.77E-05	1.80E-06	8.37E-08	3.90E-09
9000	1.80E+02	8.51E+01	3.88E+01	1.78E+01	7.03E+00	1.79E+00	3.05E-01	4.89E-02	7.64E-03	6.55E-04	3.70E-05	1.76E-06	8.19E-08	3.83E-09
10000	1.75E+02	8.28E+01	3.79E+01	1.73E+01	6.82E+00	1.72E+00	2.93E-01	4.63E-02	7.13E-03	6.10E-04	3.44E-05	1.63E-06	7.62E-08	3.55E-09
11000	1.83E+02	8.65E+01	3.97E+01	1.82E+01	7.10E+00	1.80E+00	3.01E-01	4.48E-02	6.58E-03	5.55E-04	3.13E-05	1.49E-06	6.91E-08	3.22E-09
12000	1.68E+02	7.96E+01	3.66E+01	1.67E+01	6.51E+00	1.64E+00	2.73E-01	3.98E-02	5.71E-03	4.80E-04	2.69E-05	1.28E-06	5.96E-08	2.78E-09
13000	1.53E+02	7.28E+01	3.36E+01	1.53E+01	5.94E+00	1.49E+00	2.46E-01	3.49E-02	4.86E-03	4.05E-04	2.27E-05	1.08E-06	5.02E-08	2.34E-09
14000	1.37E+02	6.53E+01	3.03E+01	1.37E+01	5.30E+00	1.33E+00	2.17E-01	2.93E-02	3.89E-03	3.20E-04	1.79E-05	8.49E-07	3.95E-08	1.84E-09
15000	1.38E+02	6.57E+01	3.04E+01	1.38E+01	5.32E+00	1.33E+00	2.14E-01	2.73E-02	3.37E-03	2.71E-04	1.50E-05	7.13E-07	3.31E-08	1.54E-09
16000	1.19E+02	5.69E+01	2.66E+01	1.20E+01	4.58E+00	1.14E+00	1.84E-01	2.33E-02	2.87E-03	2.31E-04	1.28E-05	6.05E-07	2.81E-08	1.31E-09
17000	1.09E+02	5.19E+01	2.44E+01	1.10E+01	4.16E+00	1.02E+00	1.64E-01	2.00E-02	2.32E-03	1.84E-04	1.01E-05	4.79E-07	2.22E-08	1.03E-09
18000	9.87E+01	4.73E+01	2.23E+01	9.96E+00	3.76E+00	9.22E-01	1.46E-01	1.71E-02	1.86E-03	1.44E-04	7.91E-06	3.73E-07	1.72E-08	8.03E-10
19000	9.03E+01	4.34E+01	2.07E+01	9.20E+00	3.44E+00	8.39E-01	1.33E-01	1.54E-02	1.66E-03	1.28E-04	7.03E-06	3.31E-07	1.53E-08	7.14E-10
20000	7.31E+01	3.55E+01	1.72E+01	7.55E+00	2.76E+00	6.67E-01	1.04E-01	1.18E-02	1.23E-03	9.32E-05	5.10E-06	2.40E-07	1.11E-08	5.16E-10
21000	6.60E+01	3.22E+01	1.58E+01	6.86E+00	2.48E+00	5.92E-01	9.18E-02	9.96E-03	9.50E-04	6.96E-05	3.77E-06	1.77E-07	8.16E-09	3.79E-10
22000	5.37E+01	2.66E+01	1.33E+01	5.68E+00	1.99E+00	4.69E-01	7.19E-02	7.67E-03	7.11E-04	5.12E-05	2.77E-06	1.29E-07	5.97E-09	2.78E-10
23000	4.81E+01	2.40E+01	1.22E+01	5.16E+00	1.77E+00	4.10E-01	6.25E-02	6.48E-03	5.65E-04	3.95E-05	2.11E-06	9.87E-08	4.53E-09	2.10E-10
24000	4.94E+01	2.46E+01	1.25E+01	5.30E+00	1.82E+00	4.21E-01	6.35E-02	6.27E-03	4.87E-04	3.19E-05	1.68E-06	7.74E-08	3.55E-09	1.64E-10
25000	4.40E+01	2.21E+01	1.14E+01	4.79E+00	1.61E+00	3.65E-01	5.46E-02	5.19E-03	3.63E-04	2.22E-05	1.14E-06	5.21E-08	2.38E-09	1.10E-10
26000	3.18E+01	1.64E+01	8.81E+00	3.58E+00	1.13E+00	2.45E-01	3.62E-02	3.45E-03	2.45E-04	1.51E-05	7.79E-07	3.57E-08	1.63E-09	7.53E-11
27000	2.32E+01	1.23E+01	6.90E+00	2.71E+00	7.95E-01	1.61E-01	2.32E-02	2.23E-03	1.65E-04	1.05E-05	5.48E-07	2.52E-08	1.15E-09	5.33E-11
28000	1.87E+01	1.01E+01	5.88E+00	2.25E+00	6.26E-01	1.19E-01	1.66E-02	1.58E-03	1.13E-04	7.12E-06	3.68E-07	1.69E-08	7.72E-10	3.57E-11
29000	1.64E+01	8.88E+00	5.19E+00	1.97E+00	5.40E-01	9.87E-02	1.34E-02	1.24E-03	8.34E-05	4.98E-06	2.53E-07	1.15E-08	5.25E-10	2.42E-11
30000	1.48E+01	7.97E+00	4.66E+00	1.76E+00	4.82E-01	8.50E-02	1.13E-02	1.01E-03	6.17E-05	3.40E-06	1.68E-07	7.54E-09	3.40E-10	1.56E-11
31000	1.50E+01	8.02E+00	4.55E+00	1.75E+00	5.04E-01	9.19E-02	1.23E-02	1.05E-03	5.50E-05	2.56E-06	1.16E-07	5.03E-09	2.22E-10	1.01E-11
32000	1.10E+01	5.93E+00	3.48E+00	1.30E+00	3.49E-01	5.41E-02	6.47E-03	5.41E-04	2.91E-05	1.41E-06	6.55E-08	2.86E-09	1.27E-10	5.78E-12
33000	9.41E+00	5.05E+00	2.95E+00	1.09E+00	2.94E-01	4.16E-02	4.54E-03	3.63E-04	1.84E-05	8.29E-07	3.71E-08	1.59E-09	6.98E-11	3.15E-12
34000	8.96E+00	4.66E+00	2.62E+00	9.87E-01	2.84E-01	4.07E-02	4.37E-03	3.39E-04	1.54E-05	5.83E-07	2.33E-08	9.41E-10	3.96E-11	1.74E-12
35000	7.86E+00	3.97E+00	2.16E+00	8.17E-01	2.48E-01	3.30E-02	3.16E-03	2.33E-04	1.01E-05	3.53E-07	1.34E-08	5.17E-10	2.12E-11	9.17E-13
36000	7.04E+00	3.40E+00	1.76E+00	6.74E-01	2.20E-01	2.66E-02	2.10E-03	1.39E-04	5.69E-06	1.85E-07	6.55E-09	2.41E-10	9.50E-12	4.02E-13
37000	7.33E+00	3.42E+00	1.66E+00	6.56E-01	2.35E-01	2.92E-02	2.34E-03	1.54E-04	5.91E-06	1.65E-07	4.89E-09	1.52E-10	5.19E-12	1.94E-13
38000	7.21E+00	3.27E+00	1.52E+00	6.06E-01	2.31E-01	2.57E-02	1.58E-03	8.37E-05	3.03E-06	8.12E-08	2.27E-09	6.63E-11	2.09E-12	7.24E-14
39000	7.90E+00	3.51E+00	1.58E+00	6.36E-01	2.53E-01	2.72E-02	1.46E-03	6.60E-05	2.26E-06	5.86E-08	1.55E-09	4.23E-11	1.22E-12	3.76E-14
40000	1.15E+02	5.13E+01	2.28E+01	9.18E+00	3.69E+00	3.73E-01	1.56E-02	4.51E-04	1.25E-05	3.15E-07	7.97E-09	2.02E-10	5.17E-12	1.34E-13

Table 4.7.1-2: MTO Mission Micrometeoroid Fluence for Mars Orbit; 9/6/2010 to 9/6/2020 (3653 Total Days)

Mass (g)	1.E-12	1.E-11	1.E-10	1.E-09	1.E-08	1.E-07	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01
Total Omni-Fluence (m^-2)	2.61E+04	1.21E+04	5.47E+03	2.50E+03	9.99E+02	2.42E+02	3.99E+01	6.17E+00	9.40E-01	8.01E-02	4.52E-03	2.15E-04	1.00E-05	4.68E-07
Velocity (m/s)														
0	1.70E+00	7.99E-01	3.59E-01	1.67E-01	6.70E-02	1.73E-02	3.12E-03	5.93E-04	1.04E-04	9.20E-06	5.22E-07	2.49E-08	1.16E-09	5.42E-11
1000	3.53E+01	1.66E+01	7.44E+00	3.46E+00	1.39E+00	3.58E-01	6.47E-02	1.23E-02	2.18E-03	1.91E-04	1.09E-05	5.19E-07	2.42E-08	1.13E-09
2000	1.92E+02	9.00E+01	4.04E+01	1.88E+01	7.55E+00	1.95E+00	3.52E-01	6.77E-02	1.20E-02	1.06E-03	6.01E-05	2.86E-06	1.34E-07	6.24E-09
3000	5.05E+02	2.37E+02	1.06E+02	4.95E+01	1.98E+01	5.13E+00	9.26E-01	1.77E-01	3.13E-02	2.75E-03	1.56E-04	7.45E-06	3.47E-07	1.62E-08
4000	9.12E+02	4.27E+02	1.92E+02	8.93E+01	3.58E+01	9.24E+00	1.66E+00	3.12E-01	5.45E-02	4.80E-03	2.72E-04	1.30E-05	6.05E-07	2.82E-08
5000	1.24E+03	5.82E+02	2.61E+02	1.21E+02	4.88E+01	1.25E+01	2.24E+00	4.11E-01	7.07E-02	6.20E-03	3.52E-04	1.68E-05	7.82E-07	3.65E-08
6000	1.48E+03	6.94E+02	3.12E+02	1.45E+02	5.81E+01	1.50E+01	2.64E+00	4.75E-01	8.06E-02	7.04E-03	4.00E-04	1.90E-05	8.87E-07	4.15E-08
7000	1.60E+03	7.50E+02	3.37E+02	1.57E+02	6.27E+01	1.61E+01	2.83E+00	4.98E-01	8.33E-02	7.26E-03	4.11E-04	1.95E-05	9.13E-07	4.26E-08
8000	1.70E+03	7.96E+02	3.58E+02	1.66E+02	6.66E+01	1.71E+01	2.98E+00	5.13E-01	8.47E-02	7.36E-03	4.17E-04	1.98E-05	9.25E-07	4.32E-08
9000	1.75E+03	8.22E+02	3.69E+02	1.71E+02	6.86E+01	1.75E+01	3.04E+00	5.05E-01	8.13E-02	7.01E-03	3.97E-04	1.89E-05	8.80E-07	4.11E-08
10000	1.73E+03	8.10E+02	3.64E+02	1.69E+02	6.76E+01	1.72E+01	2.95E+00	4.77E-01	7.49E-02	6.43E-03	3.63E-04	1.73E-05	8.04E-07	3.75E-08
11000	1.66E+03	7.76E+02	3.49E+02	1.62E+02	6.48E+01	1.65E+01	2.78E+00	4.29E-01	6.49E-02	5.53E-03	3.12E-04	1.48E-05	6.89E-07	3.22E-08
12000	1.54E+03	7.18E+02	3.23E+02	1.50E+02	5.98E+01	1.52E+01	2.55E+00	3.80E-01	5.60E-02	4.74E-03	2.66E-04	1.26E-05	5.89E-07	2.75E-08
13000	1.44E+03	6.71E+02	3.03E+02	1.40E+02	5.59E+01	1.42E+01	2.35E+00	3.36E-01	4.75E-02	3.97E-03	2.23E-04	1.05E-05	4.92E-07	2.30E-08
14000	1.31E+03	6.11E+02	2.75E+02	1.28E+02	5.08E+01	1.29E+01	2.10E+00	2.93E-01	4.01E-02	3.32E-03	1.86E-04	8.82E-06	4.11E-07	1.91E-08
15000	1.17E+03	5.48E+02	2.47E+02	1.14E+02	4.55E+01	1.14E+01	1.87E+00	2.53E-01	3.35E-02	2.75E-03	1.54E-04	7.29E-06	3.39E-07	1.58E-08
16000	1.02E+03	4.80E+02	2.17E+02	9.98E+01	3.98E+01	9.97E+00	1.62E+00	2.14E-01	2.75E-02	2.24E-03	1.25E-04	5.92E-06	2.75E-07	1.29E-08
17000	9.27E+02	4.34E+02	1.96E+02	9.04E+01	3.59E+01	8.98E+00	1.45E+00	1.83E-01	2.26E-02	1.81E-03	1.01E-04	4.77E-06	2.22E-07	1.03E-08
18000	7.92E+02	3.70E+02	1.68E+02	7.71E+01	3.06E+01	7.61E+00	1.21E+00	1.53E-01	1.84E-02	1.48E-03	8.19E-05	3.88E-06	1.80E-07	8.37E-09
19000	6.59E+02	3.09E+02	1.40E+02	6.42E+01	2.54E+01	6.27E+00	9.99E-01	1.23E-01	1.47E-02	1.16E-03	6.46E-05	3.06E-06	1.42E-07	6.60E-09
20000	5.35E+02	2.50E+02	1.14E+02	5.20E+01	2.05E+01	5.03E+00	7.97E-01	9.79E-02	1.15E-02	9.12E-04	5.05E-05	2.39E-06	1.10E-07	5.16E-09
21000	4.26E+02	1.99E+02	9.09E+01	4.13E+01	1.62E+01	3.94E+00	6.19E-01	7.50E-02	8.68E-03	6.84E-04	3.78E-05	1.78E-06	8.28E-08	3.86E-09
22000	3.06E+02	1.43E+02	6.55E+01	2.95E+01	1.15E+01	2.73E+00	4.27E-01	5.28E-02	6.32E-03	5.03E-04	2.79E-05	1.32E-06	6.12E-08	2.85E-09
23000	2.33E+02	1.08E+02	5.01E+01	2.24E+01	8.66E+00	2.00E+00	3.10E-01	3.79E-02	4.51E-03	3.58E-04	1.98E-05	9.38E-07	4.35E-08	2.03E-09
24000	1.91E+02	8.91E+01	4.12E+01	1.83E+01	7.04E+00	1.59E+00	2.39E-01	2.80E-02	3.13E-03	2.44E-04	1.35E-05	6.33E-07	2.93E-08	1.37E-09
25000	1.64E+02	7.61E+01	3.52E+01	1.55E+01	5.97E+00	1.31E+00	1.90E-01	2.08E-02	2.09E-03	1.57E-04	8.55E-06	4.02E-07	1.86E-08	8.64E-10
26000	1.35E+02	6.20E+01	2.87E+01	1.25E+01	4.82E+00	9.99E-01	1.41E-01	1.45E-02	1.31E-03	9.31E-05	5.01E-06	2.34E-07	1.08E-08	5.01E-10
27000	1.01E+02	4.62E+01	2.15E+01	9.16E+00	3.51E+00	6.61E-01	8.64E-02	8.48E-03	7.16E-04	4.95E-05	2.64E-06	1.22E-07	5.65E-09	2.62E-10
28000	8.79E+01	4.00E+01	1.84E+01	7.79E+00	3.01E+00	5.24E-01	6.40E-02	5.78E-03	4.13E-04	2.57E-05	1.33E-06	6.09E-08	2.78E-09	1.29E-10
29000	7.78E+01	3.50E+01	1.60E+01	6.71E+00	2.61E+00	4.20E-01	4.70E-02	3.92E-03	2.36E-04	1.29E-05	6.28E-07	2.82E-08	1.28E-09	5.83E-11
30000	6.94E+01	3.10E+01	1.40E+01	5.81E+00	2.29E+00	3.33E-01	3.28E-02	2.51E-03	1.28E-04	5.83E-06	2.63E-07	1.13E-08	4.98E-10	2.26E-11
31000	6.49E+01	2.88E+01	1.30E+01	5.33E+00	2.13E+00	2.85E-01	2.49E-02	1.74E-03	7.58E-05	2.75E-06	1.06E-07	4.20E-09	1.74E-10	7.61E-12
32000	6.01E+01	2.67E+01	1.18E+01	4.86E+00	1.94E+00	2.34E-01	1.66E-02	1.00E-03	3.94E-05	1.21E-06	4.08E-08	1.44E-09	5.48E-11	2.26E-12
33000	5.94E+01	2.63E+01	1.17E+01	4.77E+00	1.91E+00	2.18E-01	1.36E-02	7.35E-04	2.70E-05	7.49E-07	2.20E-08	6.79E-10	2.29E-11	8.45E-13
34000	5.94E+01	2.64E+01	1.17E+01	4.76E+00	1.91E+00	2.08E-01	1.16E-02	5.56E-04	1.93E-05	5.07E-07	1.37E-08	3.83E-10	1.13E-11	3.68E-13
35000	5.92E+01	2.63E+01	1.16E+01	4.71E+00	1.89E+00	1.95E-01	8.95E-03	3.18E-04	9.86E-06	2.53E-07	6.61E-09	1.76E-10	4.88E-12	1.44E-13
36000	6.05E+01	2.69E+01	1.19E+01	4.81E+00	1.93E+00	1.95E-01	8.25E-03	2.44E-04	6.87E-06	1.74E-07	4.43E-09	1.13E-10	2.98E-12	7.99E-14
37000	6.29E+01	2.79E+01	1.24E+01	5.00E+00	2.01E+00	2.02E-01	8.27E-03	2.26E-04	6.03E-06	1.52E-07	3.83E-09	9.65E-11	2.45E-12	6.25E-14
38000	6.67E+01	2.96E+01	1.32E+01	5.29E+00	2.13E+00	2.13E-01	8.51E-03	2.18E-04	5.54E-06	1.40E-07	3.50E-09	8.79E-11	2.22E-12	5.57E-14
39000	7.23E+01	3.21E+01	1.43E+01	5.74E+00	2.31E+00	2.31E-01	9.18E-03	2.31E-04	5.82E-06	1.46E-07	3.67E-09	9.22E-11	2.32E-12	5.83E-14
40000	1.53E+03	6.80E+02	3.03E+02	1.21E+02	4.89E+01	4.88E+00	1.94E-01	4.88E-03	1.22E-04	3.08E-06	7.73E-08	1.94E-09	4.88E-11	1.22E-12

Table 4.7.1-3: Total Micrometeoroid Fluence for the MTO Mission.

Mass (g)	1.E-12	1.E-11	1.E-10	1.E-09	1.E-08	1.E-07	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01
Total omni-Fluence (m^-2)	2.90E+04	1.35E+04	6.12E+03	2.79E+03	1.11E+03	2.68E+02	4.41E+01	6.77E+00	1.02E+00	8.72E-02	4.92E-03	2.33E-04	1.09E-05	5.08E-07
Velocity (m/s)														
0	1.78E+00	8.35E-01	3.75E-01	1.74E-01	6.99E-02	1.80E-02	3.23E-03	6.04E-04	1.05E-04	9.25E-06	5.25E-07	2.50E-08	1.17E-09	5.45E-11
1000	3.73E+01	1.75E+01	7.85E+00	3.65E+00	1.46E+00	3.77E-01	6.78E-02	1.27E-02	2.22E-03	1.95E-04	1.11E-05	5.29E-07	2.46E-08	1.15E-09
2000	2.01E+02	9.42E+01	4.23E+01	1.97E+01	7.91E+00	2.04E+00	3.68E-01	7.00E-02	1.24E-02	1.09E-03	6.18E-05	2.94E-06	1.37E-07	6.41E-09
3000	5.30E+02	2.49E+02	1.12E+02	5.20E+01	2.08E+01	5.38E+00	9.70E-01	1.84E-01	3.24E-02	2.85E-03	1.61E-04	7.72E-06	3.60E-07	1.68E-08
4000	9.66E+02	4.52E+02	2.04E+02	9.45E+01	3.79E+01	9.78E+00	1.76E+00	3.29E-01	5.74E-02	5.05E-03	2.87E-04	1.36E-05	6.37E-07	2.97E-08
5000	1.33E+03	6.23E+02	2.79E+02	1.30E+02	5.22E+01	1.34E+01	2.39E+00	4.37E-01	7.52E-02	6.59E-03	3.74E-04	1.78E-05	8.31E-07	3.88E-08
6000	1.62E+03	7.59E+02	3.41E+02	1.58E+02	6.35E+01	1.64E+01	2.88E+00	5.16E-01	8.74E-02	7.63E-03	4.33E-04	2.06E-05	9.61E-07	4.49E-08
7000	1.77E+03	8.30E+02	3.73E+02	1.74E+02	6.94E+01	1.78E+01	3.12E+00	5.45E-01	9.08E-02	7.90E-03	4.48E-04	2.13E-05	9.94E-07	4.64E-08
8000	1.89E+03	8.85E+02	3.99E+02	1.85E+02	7.39E+01	1.90E+01	3.29E+00	5.64E-01	9.25E-02	8.03E-03	4.55E-04	2.16E-05	1.01E-06	4.71E-08
9000	1.93E+03	9.07E+02	4.08E+02	1.89E+02	7.56E+01	1.93E+01	3.34E+00	5.54E-01	8.89E-02	7.67E-03	4.34E-04	2.07E-05	9.62E-07	4.49E-08
10000	1.91E+03	8.92E+02	4.02E+02	1.86E+02	7.44E+01	1.89E+01	3.25E+00	5.23E-01	8.20E-02	7.04E-03	3.98E-04	1.89E-05	8.81E-07	4.11E-08
11000	1.84E+03	8.63E+02	3.89E+02	1.80E+02	7.19E+01	1.83E+01	3.08E+00	4.74E-01	7.14E-02	6.08E-03	3.43E-04	1.63E-05	7.58E-07	3.54E-08
12000	1.71E+03	7.98E+02	3.59E+02	1.66E+02	6.63E+01	1.68E+01	2.82E+00	4.20E-01	6.17E-02	5.22E-03	2.93E-04	1.39E-05	6.49E-07	3.03E-08
13000	1.59E+03	7.44E+02	3.36E+02	1.55E+02	6.18E+01	1.57E+01	2.59E+00	3.71E-01	5.23E-02	4.37E-03	2.45E-04	1.16E-05	5.42E-07	2.53E-08
14000	1.44E+03	6.77E+02	3.05E+02	1.41E+02	5.61E+01	1.42E+01	2.32E+00	3.23E-01	4.40E-02	3.64E-03	2.04E-04	9.67E-06	4.50E-07	2.10E-08
15000	1.31E+03	6.14E+02	2.77E+02	1.28E+02	5.09E+01	1.28E+01	2.09E+00	2.80E-01	3.69E-02	3.02E-03	1.69E-04	8.00E-06	3.72E-07	1.73E-08
16000	1.14E+03	5.37E+02	2.43E+02	1.12E+02	4.44E+01	1.11E+01	1.80E+00	2.37E-01	3.04E-02	2.47E-03	1.38E-04	6.52E-06	3.03E-07	1.42E-08
17000	1.04E+03	4.86E+02	2.21E+02	1.01E+02	4.01E+01	1.00E+01	1.61E+00	2.03E-01	2.49E-02	1.99E-03	1.11E-04	5.24E-06	2.44E-07	1.14E-08
18000	8.91E+02	4.18E+02	1.90E+02	8.71E+01	3.43E+01	8.53E+00	1.36E+00	1.70E-01	2.03E-02	1.62E-03	8.98E-05	4.25E-06	1.97E-07	9.17E-09
19000	7.49E+02	3.52E+02	1.60E+02	7.34E+01	2.88E+01	7.11E+00	1.13E+00	1.39E-01	1.63E-02	1.29E-03	7.16E-05	3.39E-06	1.57E-07	7.31E-09
20000	6.08E+02	2.85E+02	1.32E+02	5.96E+01	2.33E+01	5.70E+00	9.02E-01	1.10E-01	1.28E-02	1.00E-03	5.56E-05	2.63E-06	1.21E-07	5.68E-09
21000	4.92E+02	2.32E+02	1.07E+02	4.81E+01	1.87E+01	4.53E+00	7.11E-01	8.49E-02	9.63E-03	7.54E-04	4.16E-05	1.96E-06	9.09E-08	4.23E-09
22000	3.59E+02	1.69E+02	7.88E+01	3.52E+01	1.35E+01	3.20E+00	4.99E-01	6.05E-02	7.04E-03	5.54E-04	3.07E-05	1.44E-06	6.72E-08	3.13E-09
23000	2.81E+02	1.32E+02	6.23E+01	2.75E+01	1.04E+01	2.41E+00	3.72E-01	4.44E-02	5.08E-03	3.98E-04	2.19E-05	1.04E-06	4.80E-08	2.24E-09
24000	2.41E+02	1.14E+02	5.37E+01	2.36E+01	8.86E+00	2.01E+00	3.02E-01	3.43E-02	3.61E-03	2.76E-04	1.51E-05	7.11E-07	3.29E-08	1.53E-09
25000	2.08E+02	9.82E+01	4.67E+01	2.03E+01	7.58E+00	1.67E+00	2.45E-01	2.60E-02	2.46E-03	1.79E-04	9.69E-06	4.54E-07	2.10E-08	9.74E-10
26000	1.66E+02	7.84E+01	3.75E+01	1.61E+01	5.95E+00	1.24E+00	1.77E-01	1.79E-02	1.55E-03	1.08E-04	5.79E-06	2.69E-07	1.25E-08	5.76E-10
27000	1.24E+02	5.85E+01	2.84E+01	1.19E+01	4.31E+00	8.22E-01	1.10E-01	1.07E-02	8.82E-04	6.00E-05	3.19E-06	1.48E-07	6.80E-09	3.15E-10
28000	1.07E+02	5.01E+01	2.43E+01	1.00E+01	3.63E+00	6.43E-01	8.06E-02	7.36E-03	5.26E-04	3.28E-05	1.69E-06	7.78E-08	3.55E-09	1.64E-10
29000	9.42E+01	4.39E+01	2.12E+01	8.68E+00	3.15E+00	5.19E-01	6.03E-02	5.15E-03	3.19E-04	1.78E-05	8.81E-07	3.98E-08	1.80E-09	8.25E-11
30000	8.42E+01	3.89E+01	1.86E+01	7.57E+00	2.77E+00	4.18E-01	4.40E-02	3.51E-03	1.89E-04	9.23E-06	4.31E-07	1.89E-08	8.38E-10	3.82E-11
31000	7.99E+01	3.69E+01	1.75E+01	7.09E+00	2.63E+00	3.77E-01	3.72E-02	2.79E-03	1.31E-04	5.31E-06	2.22E-07	9.23E-09	3.96E-10	1.77E-11
32000	7.11E+01	3.26E+01	1.53E+01	6.16E+00	2.29E+00	2.88E-01	2.31E-02	1.54E-03	6.85E-05	2.63E-06	1.06E-07	4.30E-09	1.82E-10	8.04E-12
33000	6.88E+01	3.14E+01	1.47E+01	5.85E+00	2.21E+00	2.59E-01	1.81E-02	1.10E-03	4.55E-05	1.58E-06	5.90E-08	2.27E-09	9.27E-11	4.00E-12
34000	6.84E+01	3.11E+01	1.44E+01	5.74E+00	2.20E+00	2.49E-01	1.60E-02	8.95E-04	3.47E-05	1.09E-06	3.70E-08	1.32E-09	5.09E-11	2.11E-12
35000	6.71E+01	3.03E+01	1.38E+01	5.52E+00	2.14E+00	2.28E-01	1.21E-02	5.51E-04	1.99E-05	6.06E-07	2.00E-08	6.93E-10	2.61E-11	1.06E-12
36000	6.76E+01	3.03E+01	1.37E+01	5.48E+00	2.15E+00	2.22E-01	1.04E-02	3.83E-04	1.26E-05	3.59E-07	1.10E-08	3.54E-10	1.25E-11	4.82E-13
37000	7.03E+01	3.14E+01	1.41E+01	5.65E+00	2.25E+00	2.32E-01	1.06E-02	3.80E-04	1.19E-05	3.17E-07	8.71E-09	2.49E-10	7.64E-12	2.56E-13
38000	7.39E+01	3.29E+01	1.47E+01	5.90E+00	2.36E+00	2.38E-01	1.01E-02	3.01E-04	8.56E-06	2.21E-07	5.77E-09	1.54E-10	4.31E-12	1.28E-13
39000	8.01E+01	3.56E+01	1.58E+01	6.37E+00	2.56E+00	2.58E-01	1.06E-02	2.97E-04	8.08E-06	2.04E-07	5.22E-09	1.35E-10	3.53E-12	9.59E-14
40000	1.64E+03	7.31E+02	3.25E+02	1.31E+02	5.26E+01	5.25E+00	2.10E-01	5.33E-03	1.35E-04	3.39E-06	8.53E-08	2.14E-09	5.39E-11	1.36E-12

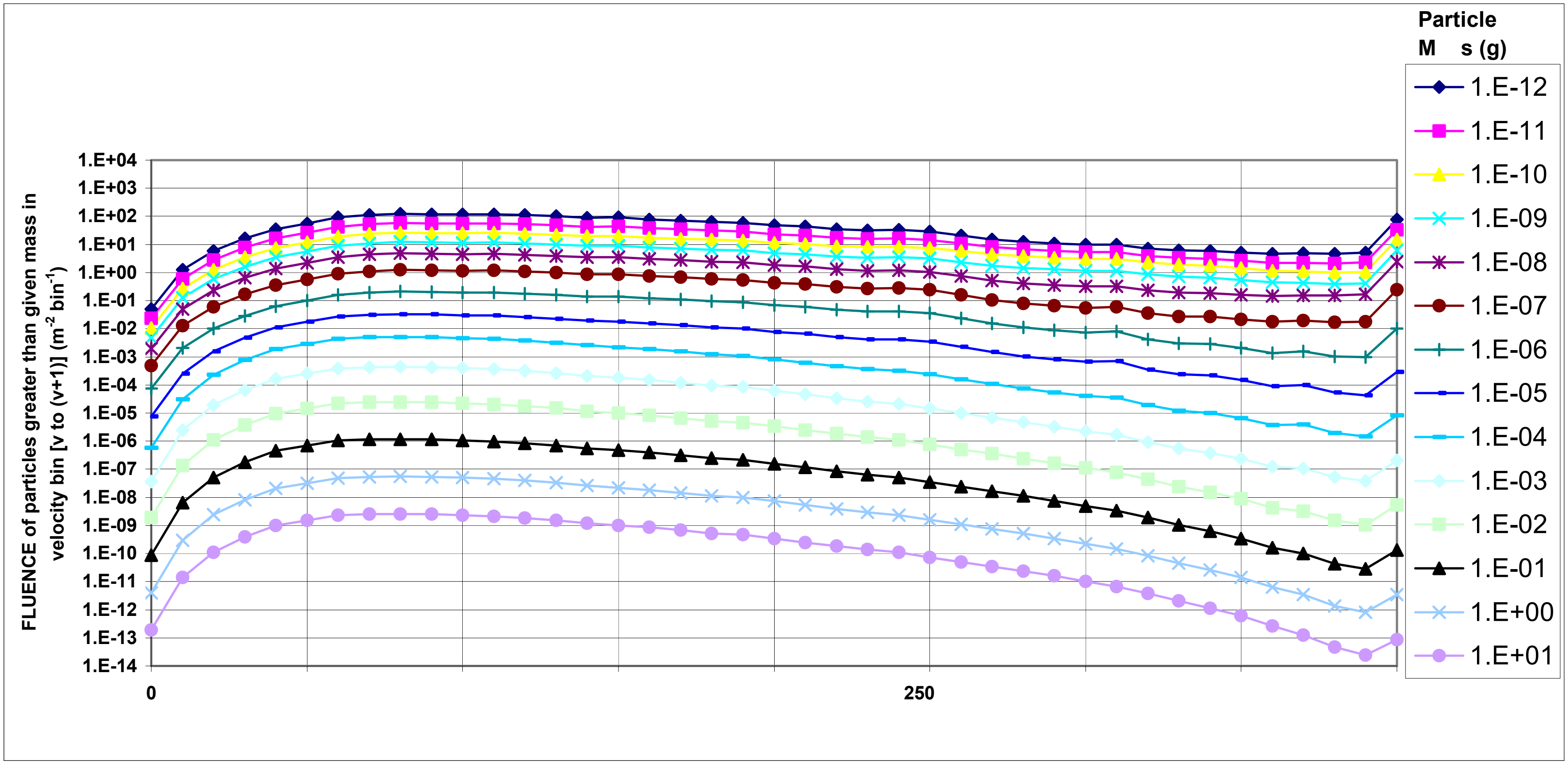


Figure 4.7.1-1: Earth to Mars Omni-Directional Fluence for the MTO Mission

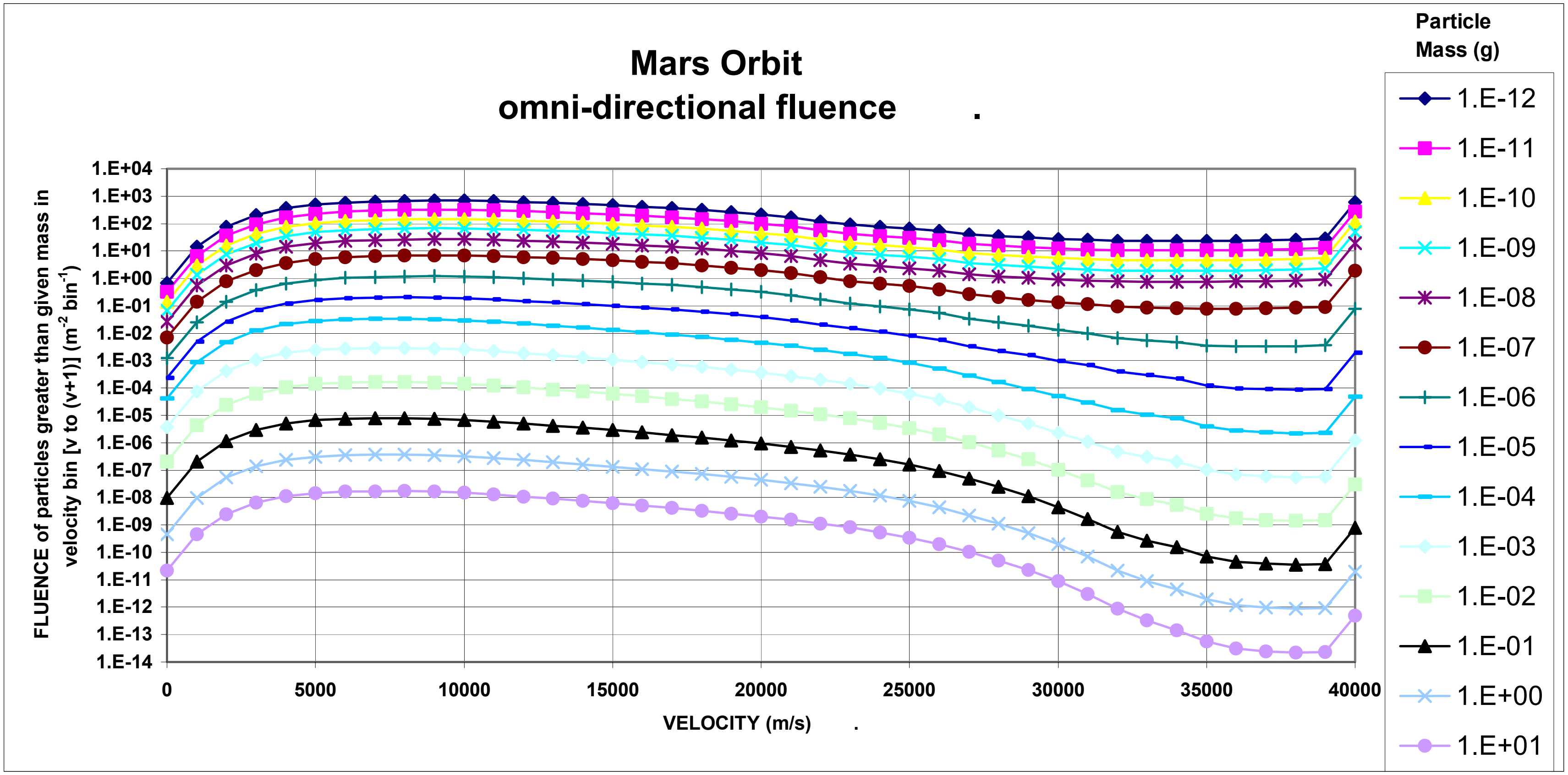


Figure 4.7.1-2: Mars Orbit Omni-Directional Fluence for the MTO Mission

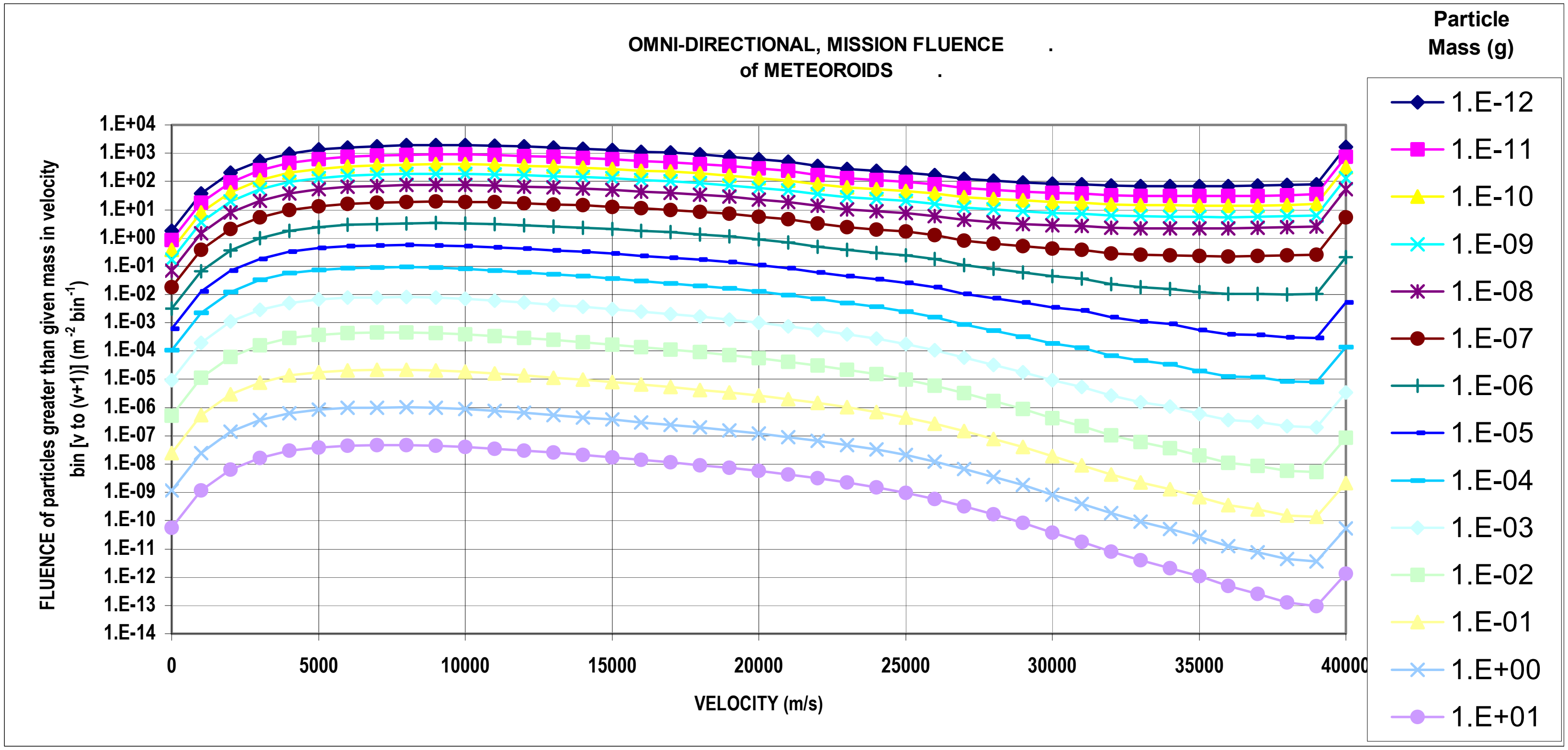


Figure 4.7.1-3: Omni-Directional Total Fluence for the MTO Mission

4.7.3 Atomic Oxygen

The atomic oxygen fluence in low Mars orbit (e.g., during possible aerobraking excursions) will depend upon the total duration of time in that environment. A worst case estimate (from the Mars Reconnaissance Orbiter Environmental Requirements document) is on the order of 5×10^{20} atoms/cm^2 [TBC]. If MTO does not utilize aero braking to refine its mission orbit, then there will be no significant exposure to atomic oxygen.

5.0 ENVIRONMENTAL TEST IMPLEMENTATION

This section provides detail requirements for environmental testing of the MTO assemblies delivered by JPL. The test requirements regarding test levels and durations are presented in Sections 3 and 4, along with the design requirements for each environment.

5.1 Test Configurations

In all tests, the electrical cabling, connectors, and other hardware associated with the assembly shall be used and considered part of the assembly. Each test article will be comprised of the serial numbered subassemblies that are intended to remain with the assembly or subsystem through delivery.

5.2 Environmental Test Tolerances

Test parameters shall not exceed the following tolerances, unless otherwise specified.

5.2.1 Dynamics Test Tolerances

The dynamics test tolerances shall be as follows:

a) Time: + 1%, -5%
b) Frequency: Within ± 5% or ± 1 Hz, whichever is greater
c) Acoustic Spectral Shape: See Table 4.4.7-1
d) Acoustic Overall Level: within ± 1.0 dB (true RMS) of the specified level.
e) Random Vibration Spectral Shape: The Power Spectral Density (PSD) shall be within ± 3.0 dB when measured in frequency bands no wider than 25 Hz.
f) Random Vibration Level: within ± 1.0 dB (true RMS) of the specified level.
g) Pyro Shock: Measured with a minimum resolution of 1/6 octave frequency band. For shaker test, the spectrum shall be within ± 3 dB of the specified shock spectrum level, above 3000 Hz the lower tolerance may be eliminated if the test hardware shock sensitive frequency is far below this frequency. For other shock-generating apparatus tests, the tolerance shall be within +/- 6 dB, but at least 50% of the spectrum values shall exceed the nominal values.
h) Static Acceleration: ± 5 % of the specified value.

5.2.2 Thermal/Vacuum and Temperature/Atmosphere Test Tolerances

The thermal/vacuum and temperature/atmosphere test tolerances shall be as follows:

a) Pressure: +2 to -5 percent from atmospheric to 10 percent of atmospheric. At vacuum conditions, tolerances shall be such that a pressure of 1.33 x 10^{-6} kPa ($1x10^{-5}$ torr) or less is assured.

b) Time: +10, -0 minutes

c) Temperature: $\pm 2^{\circ}$C

d) Rate of Temperature Change: <300°C/hr and not to exceed 10°C in any one minute.

5.2.3 EMC/Magnetic Test Tolerances

The EMC/Magnetic test values shall be measured within the following tolerances:

a) Voltage: ±10 percent of the peak value

b) Current: ±10 percent of the peak value

c) RF Amplitudes: ±5 dB

d) Frequency: ±2 percent

e) Resistance: ±10 percent

f) Distance: ±5 percent of specified distance or ±5.0 cm, whichever is less.

6.0 ACRONYMS and ABBREVIATIONS

A	Ampere
AFT	Allowable Flight Temperature
AM	Amplitude Modulation
ATLO	Assembly, Test, & Launch Operation
AU	Astronomical Unit
BB	Broadband
BCE	Bench Checkout Equipment
BOL	Beginning of Life
C&DH	Command and Data Handling
CDRL	Contract Data Requirements List
CE	Conducted Emission
CE01	Conducted Emissions (30 Hz-20 kHz)
CE02	Conducted Emissions (.020-50 MHz)
CE03	Conducted Emissions; Power 20 kHz – 50 MHz
CE06	Conducted Emissions; Antenna
CE07	Conducted Emissions (Transient)
CEP	Conducted Emissions Power
CFE	Customer Furnished Equipment
cg	Center of Gravity
CM	Common Mode
Cog-E	Cognizant Engineer
CREME	Cosmic Ray Effects on Micro Electronics
CS01	Conducted Susceptibility (Audio Freq.
CS02	Conducted Susceptibility (Radio Freq.)
CS04	Rejection of Undesired Signals; 30 Hz - 10 GHz (Receivers Only)
CS06	Conducted Susceptibility (Transient)
CSP	Conducted Susceptibility Power
CTM	Contract Technical Manager
DB	decibels
DC	Direct Current
DD	Displacement Damage
DL	Design Load
DM	Differential Mode
DSPG	Distributed Single Point Grounding
DUT	Device Under Test
EA	Electronics Assembly
EACS	Environmental Analysis Completion Statement
ECN	Engineering Change Notice
ECR	Engineering Change Request
EED	Electro-Explosive Device

EGSE	Electrical Ground Support Equipment
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMISM	EMI Safety Margin
EOL	End of Life
EPS	Electrical Power Subsystem
ERD	Environmental Requirements Document
ERE	Environmental Requirements Engineer
ESD	Electrostatic Discharge
ETAS	Environmental Test Authorization and Summary
EU	Engineering Unit
F	Farad, Unit of capacitance
FA	Flight Acceptance
FM	Frequency Modulation
FR	Functional Requirements
GCR	Galactic Cosmic Rays
GN&C	Guidance Navigation and Control
GSE	Ground Support Equipment
H	Henries unit of inductance
H/W	Hardware
HGA	High Gain Antenna
HRCR	Hardware Review/Certification Requirement
Hz	Hertz, cycles/sec
I&T	Integration and Test
ICD	Interface Control Document
IOM	Interoffice Memorandum
IRD	Interface Requirements Document
ITO	Indium Tin Oxide
JPL	Jet Propulsion Laboratory
Ka Band	12.5 - 18 GHz
LET	Linear Energy Transfer
MAC	Mass Acceleration Curve
MEFL	Maximum Expected Flight Level
MLI	Multilayer Insulation
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NB	Narrowband
NIEL	Non Ionizing Energy Loss
NOP	Non-Operating
NTE	Not to Exceed
OP	Operating
PDR	Preliminary Design Review

PEM	Project Element Manager
PF	Protoflight
PFR	Problem Failure Report
PSD	Power Spectral Density
QA	Quality Assurance
QM	Qualification Model
QUAL	Qualification
RACS	Radiation Analysis Completion Statement
RDF	Radiation Design Factor
RE02	Radiated Emissions (.014-10,000 MHz)
RF	Radio Frequency
RFE	Radiated Electric Field Emissions
RMS	Radiated Magnetic Field Susceptibility
RS03	Radiated Susceptibility (10 kHz-10 GHz)
S/C	Spacecraft
SEE	Single Event Effects
SEP	Solar Energetic Particle
SEU	Single Event Upsets
SPL	Sound Pressure Level
SRS	Shock Response Spectrum
STE	Special Test Equipment
T/V	Thermal Vacuum
TBD	To Be Determined
TCS	Thermal Control Subsystem
TID	Total Ionizing Dose
TMM	Thermal Math Model
UHF	Ultra-High Frequency (300 MHz -3 GHz)
USM	Universal Switch Module
UUT	Unit Under Test
V	Volt
WCA	Worst Case Analysis
wrt	With Respect To

APPENDIX A RETEST GUIDELINES

Environmental re-tests of subsystems/assemblies are performed to:

1) complete the protoflight or flight acceptance testing of hardware that has failed during its environmental test program;

2) re-qualify flight hardware design where design changes, modifications, or configuration changes occur after completion of environmental testing;

3) verify the flight worthiness of refurbished units as flight spares; and

4) verify the flight acceptability of workmanship performed as part of rework not covered by Items 1) to 3).

Failures of spacecraft hardware resulting from assembly-level environmental testing in general invalidate the protoflight or flight acceptance test program for that assembly. Re-testing to prescribed environments is essential after the cause of the failure is corrected.

Any design change, modification, or configuration change occurring after completion of the environmental testing in general invalidates the environmental test program and, depending upon the nature of the change, will be the cause for re-testing under certain selected environments. Any design change or modification occurring after protoflight testing requires an assessment to determine if reiteration of protoflight testing is required. The necessity for re-testing spacecraft hardware as a result of environmental test equipment malfunction or failure should be determined by the project in consultation with the Project ERE.

APPENDIX B DEFINITIONS

Assembly
The assembly is the lowest level of "line replaceable unit" in the subsystem/system configuration. An assembly is a functional unit that is viewed as an entity for purposes of analysis, manufacturing, testing, maintenance, and record keeping. Examples are valves, electrical harnesses, sensor packages, inertial measurement units, star trackers, radars, gyros, reaction wheels, and individual electronic boxes such as transmitters, receivers, or multiplexers.

Subsystem
A subsystem consists of one or more assemblies and any interconnecting cables or tubing. A subsystem is composed of functionally related assemblies that perform one or more prescribed functions. Typical spacecraft subsystems are electric power, attitude control, telemetry, instrumentation, command and data handling, structure, thermal control, and propulsion.

Test Article
Test article is the item under test. Consists of one or more assemblies aggregated together for the purpose of environmental test exposure. May be a complete or partial subsystem.

Verification
Verification provides objective evidence through test and/or analysis that specified design and workmanship requirements have been fulfilled (i.e., Did we build the thing right?)

Qualification Test
Qualification test is formal environmental test performed on test-dedicated flight-quality hardware such as Qualification Model or flight like Engineering Model, whose configuration represents the flight unit, at levels with reliability margins over worst case predicted flight environments. The test verifies that the flight equipment design is adequate to perform as required throughout the ground and mission environment exposures with sufficient margin such that subsequent units of the same design may be tested for workmanship only.

Thermal environmental qualification testing is equal to Protoflight level testing. Dynamics environmental testing is equal to Protoflight level testing in magnitude and exceeds it in duration. Qualification implies meeting all functional specifications in the operating environments.

Qualification by similarity

May be defined as the procedure of comparing an item which has not undergone Qualification testing to another item having only minor differences in configuration and functional characteristics which has been:

Tested to stress levels at least as severe as those specified for the item to be qualified;

Tested under equivalent program controls;

Manufactured by the same supplier using similar application.

The item also may be identical to one previously qualified and successfully flown.

Protoflight Test

Protoflight (PF) testing is performed on hardware that is intended to be flown and having no previous qualification test article. Protoflight testing verifies the adequacy of the design for the mission environments and the integrity of the flight hardware workmanship. Protoflight testing accomplishes in one test the combined purposes of design qualification and flight acceptance. PF testing includes meeting functional specifications under protoflight environments.

Protoflight thermal test levels and durations are identical to qualification test levels and durations. Protoflight dynamics test levels are equivalent to qualification test levels; however, the duration is lowered to flight acceptance duration.

Flight Acceptance Test

Flight Acceptance (FA) environmental test is typically performed on flight hardware and spares to verify flight workmanship quality, but only when a previous protoflight or qualification test has been performed on an identical item to qualify the design. FA test levels may also be used to verify the quality of reworked flight hardware. FA testing includes meeting functional specifications under flight acceptance environments.

Flight Acceptance testing should be evaluated for use on a case-by-case basis. If it is determined by a Heritage Review that previous qualification or protoflight test levels on a heritage assembly envelope those required for the MTO assembly, and the heritage design and operation is not modified in such a way as to negate the previous qualification, then the assembly may be Flight Acceptance tested.

Operating Allowable Flight Temperature

Operating Allowable Flight Temperatures (AFT) are the mission temperature limits (including allowance for prediction uncertainties) in a worst case powered-on, operational (operating within functional specifications) mode that the thermal control is designed to maintain for specified assemblies and subsystems (hot or cold). All temperatures are measured at the thermal control surface (e.g. mounting surface, radiator surface, etc.), as specified by Thermal Engineering.

Non-Operating Allowable Flight Temperature

Non-operating Allowable Flight Temperatures (AFT) are the mission temperature limits (including allowance for prediction uncertainties) in a worst case powered-off, non-operational mode that the thermal control is designed to maintain for specified assemblies and subsystems (hot or cold). Unless otherwise specified, assemblies are required to start up from a non-powered state within the Non-op. AFT and operate within functional specifications once within the operating AFT range.

Design Temperature Limits

Temperature limits at the thermal control surface to which assemblies are designed to meet functional and performance specifications; normally equivalent to the Qualification/Protoflight limits.

APPENDIX C SAMPLE OF ENVIRONMENTAL FORMS

ENVIRONMENTAL TEST AUTHORIZATION AND SUMMARY (ETAS)

AUTHORIZATION SECTION

PROJECT		LOG NO.	
SUBSYSTEM / ASSEMBLY TITLE			DATE ISSUED
REFERENCE DESIGNATION NO.	PART NO. (IF MULTIPLE, ATTACH LIST)	REV.	SERIAL NO.

HARDWARE TYPE
☐ EM QUAL ☐ FLIGHT ☐ FLIGHT SPARE ☐ OTHER ________

PRE-ENVIRONMENTAL INSPECTION REPORT NUMBER (ATTACH IR)

WIRING HARNESS ☐ FLIGHT ☐ FLIGHT SPARE ☐ EM ☐ S.E.	PART NO.	REV.	SERIAL NO.

TEST DESCRIPTION (CHECK ALL APPLICABLE)
☐ SINE VIBRATION ☐ PYROSHOCK ☐ ACOUSTIC ☐ EMC ☐ OTHER ________
☐ RANDOM VIBRATION ☐ THERMAL VAC ☐ THERMAL ATMOSPHERE

TYPE OF TEST
☐ QUALIFICATION ☐ FLIGHT ACCEPTANCE
☐ PROTO FLIGHT ☐ RETEST

WILL ALL TESTS/LEVELS/DURATIONS REQUIRED BY THE PROJECT DOCUMENTS BE PERFORMED ON THIS UNIT?
☐ YES ☐ NO (IF NO, ATTACH EXCEPTIONS LIST) ENTER PROJ. DOC. NO. AND REV. ________

HAS THE UNIT PASSED ALL PRE-ENVIRONMENTAL FUNCTIONAL TESTS?
☐ YES ☐ NO (IF NO, ATTACH EXPLANATION)
BRIEF EXPLANATION

HAVE ALL DESIGN ANALYSES BEEN COMPLETED AND REQUIRED CHANGES BEEN IMPLEMENTED?
☐ YES ☐ NO (IF NO, ATTACH EXPLANATION)
BRIEF EXPLANATION

IS THE TEST ARTICLE IDENTICAL TO OTHER FLIGHT UNITS?
☐ YES ☐ NO (IF NO, LIST DIFFERENCES AND ATTACH)
BRIEF EXPLANATION

ARE ALL PFRs AGAINST THIS UNIT CLOSED?
☐ YES ☐ NO (IF NO, WILL ANY OPEN PFRs AFFECT ENVIRONMENTAL TESTING? HOW?)
BRIEF EXPLANATION

HAVE ALL WAIVERS AND ECRs BEEN APPROVED AND ARE THEY INCORPORATED?
☐ YES ☐ NO (IF NO, ATTACH EXPLANATION) ☐ N/A
BRIEF EXPLANATION

TEST AUTHORIZED BY

COGNIZANT ENG.	DATE	TECHNICAL MGR./INSTR MGR./PI REP.	DATE	ENVIRONMENTAL REQUIREMENTS ENG.	DATE

SUMMARY SECTION

TEST AGENCY (IF MULTIPLE, ATTACH SUMMARY AND TEST DATES)	TEST INITIATION DATE	ACCUMULATED OPERATING HOURS PRIOR TO FIRST ENVIRONMENTAL TEST
SERIAL NUMBERS ACTUALLY TESTED	TEST TERMINATION DATE	OPERATING HOURS DURING ENVIRONMENTAL EXPOSURE

TEST DESCRIPTION

VIBRATION
AXES: X Y Z
SINE VIBRATION ☐ ☐ ☐
RANDOM VIBRATION ☐ ☐ ☐

ACOUSTIC ☐

PYROTECHNIC SHOCK
AXES: X Y Z ☐ ☐ ☐
SHOCKS/AXIS:

☐ THERMAL VACUUM
PRESSURE:
NO. OF CYCLES:

☐ TEMPERATURE ATMOSPHERE
NO. OF CYCLES:

☐ OTHER ________

EMC ☐ COND. SUSC. ☐ COND. EMIS. ☐ ISOLATION
☐ ESD ☐ RAD. SUSC. ☐ RAD. EMIS. ☐ MAGNETICS

TEMP. LEVEL (°C) AND ACCUMULATED DURATION (HRS.)
HOT: ______°C, ______h COLD: ______°C, ______h
HOT: ______°C, ______h COLD: ______°C, ______h

WERE THERE ANY PFRs GENERATED DURING ENVIRONMENTAL TESTS?
☐ YES ☐ NO (IF YES, ATTACH A COPY OF THE PFRs)
LIST PFR NOS. / BRIEF EXPLANATION

ARE THE POST ENVIRONMENTAL DAMAGE INSPECTIONS COMPLETE?
☐ YES ☐ NO (IF YES, ATTACH A COPY OF THE INSPECTION REPORTS. IF NO, ATTACH EXPLANATION.)
BRIEF EXPLANATION

WERE ALL PLANNED TESTS/LEVELS/DURATIONS ACHIEVED?
☐ YES ☐ NO (IF NO, ATTACH EXPLANATION)
BRIEF EXPLANATION

☐ TESTS HAVE NOT BEEN SUCCESSFULLY COMPLETED. SEE THE ATTACHED SUMMARY FOR ACTIONS THAT NEED TO BE TAKEN.

COGNIZANT ENG.	DATE	TECHNICAL MGR./INSTR MGR./PI REP.	DATE	ENVIRONMENTAL REQUIREMENTS ENG.	DATE

☐ HARDWARE HAS SUCCESSFULLY COMPLETED THE ENVIRONMENTAL TESTS LISTED ON THIS FORM OR REMAINING ACTIONS HAVE BEEN TAKEN, INCLUDING RETEST.

COGNIZANT ENG.	DATE	TECHNICAL MGR./INSTR MGR./PI REP.	DATE	ENVIRONMENTAL REQUIREMENTS ENG.	DATE

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ENVIRONMENTAL TEST AUTHORIZATION AND SUMMARY (ETAS)

OTHER AUTHORIZATION PROVISIONS AND EXPLANATIONS

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ENVIRONMENTAL TEST AUTHORIZATION AND SUMMARY (ETAS)
ENVIRONMENTAL TEST SUMMARY

HARDWARE	S/N	ETAS	TEST ENVIRONMENT LEVELS & DURATION	DATE TEST PERFORMED	TEST AGENCY	PASS/ FAIL	COMMENTS

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JPL

ENVIRONMENTAL ANALYSIS COMPLETION STATEMENT

(NON-RADIATION ANALYSIS)

		LOG NO.
		DATE ISSUED
PROJECT	SUBSYSTEM / ASSEMBLY TITLE	ITEM NUMBER
REFERENCE DESIGNATION NUMBER	PART / DRAWING NUMBER	ENVIRONMENT ANALYZED

ANALYSIS APPROACH

ANALYSIS CONCLUSIONS

LIST OF PERTINENT DOCUMENTS (IOMs, Reports, etc. Attach as appropriate)

PREPARED BY - COGNIZANT ENGINEER/CONTRACT TECHNICAL MANAGER	PHONE NO.	DATE

COGNIZANT MANAGEMENT APPROVAL	PROJECT APPROVAL
TECHNICAL MANAGER / INSTRUMENT MANAGER / PI REPRESENTATIVE	ENVIRONMENTAL REQUIREMENTS ENGINEER

After Cognizant Management Approval, send statement and supporting documentation to the Environmental Requirements Engineer.

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MTO RADIATION ANALYSIS COMPLETION STATEMENT

Assembly ________________________________ Reference Designation Number _____________________

Cognizant Engineer _________________________ Date __________________

1) Total Ionizing Dose (TID)

TID level requirement* for this assembly: ________ krad(Si)
*(See MTO Project Environmental Requirements Document, JPL D-TBD)

Has the assembly/subsystem passed a Worst Case Circuit Analysis at or above the required TID level?

Yes No

WCA Document Number ______________________________________

If not, has a waiver to this project requirement been processed?
Yes No

Waiver Number(s) ____

Comments/Explanation____ _________________

2) Displacement Damage (DD)

Does the assembly contain parts susceptible to less than or equal to 10^{12} n/cm^2 equivalent 1 MeV neutron fluence* ? *(Ref: MTO Project Parts Program Requirements, JPL D-TBD)
Yes No

If yes, what is the DD requirement* for this assembly? _____________ equivalent 1 MeV neutrons/cm^2
*(See MTO Project Environmental Requirements Document, JPL D-TBD)

If yes, has the assembly/subsystem passed a Worst Case Circuit Analysis at the required DD level or higher?

Yes No

WCA Document Number ____

If not, has a waiver to this project requirement been processed?
Yes No

Waiver Number(s) ____

Comments/Explanation____
____

3) Materials TID/DD Capability

Do all materials meet the requirements in the MTO Project Materials & Processes Control Plan (JPL D-TBD) after exposure to the expected total ionizing dose and displacement damage levels?

Yes No

If not, has a waiver to this project requirement been processed?
Yes No

Waiver Number(s) ____

Comments/Explanation____
____

4) Single Event Effects (SEE)

Are all parts compliant with the MTO Single Event Latchup (SEL) requirements specified in the MTO Project Parts Program Requirements? (Ref: JPL D-TBD)

Yes No

If not, has a waiver to this project requirement been processed?

Yes No

Waiver Number(s) ____

b) Do all parts exhibit no upsets during Single Event Upset (SEU) testing at a LET of 75 MeV/mg/cm^2 at a fluence of 10^6 ions/cm^2? (Ref: MTO Project Parts Program Requirements, JPL D-TBDx)

Yes No

If not, have the parts upset rates been documented for use in a Single Event Effects Analysis (SEEA)?

Yes No

Has the assembly/subsystem passed SEEA using the appropriate parts upset rates?
Yes No

SEEA Document Number ____

If not, has a waiver to this project requirement been processed?
Yes No

Waiver Number(s) ____

c) Does the Parts Stress Analysis (PSA) show that all parts applications are compliant with MTO derating criteria for Single Event Burnout (SEB) and Single Event Gate Rupture (SEGR)? Yes No

PSA Document Number ____

If not, has a waiver to this project requirement been processed?
Yes No

Waiver Number(s) ____

Comments/Explanation____

NOTES: (1) In some instance, the same waiver may cover more than one of the above-listed items. The waiver must be listed under each applicable item.
(2) Waivers, ECRs, memorandums, reports, and other supporting documentation applicable to this radiation assessment shall be attached to this form.

Concurrence Signatures:

_____________________________ Date______________________
Assembly Cognizant Engineer

_____________________________ Date______________________
Assembly/Subsystem PEM

_____________________________ Date______________________
MTO Reliability Engineer

_____________________________ Date______________________
MTO Environmental Requirements Engineer