431-SPEC-000012
Revision D
Effective Date: August 10, 2007
Expiration Date: August 10, 2012

Lunar Reconnaissance Orbiter Project

LRO Mechanical Systems Specification

LRO GSFC CMO

August 10, 2007

RELEASED

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and
Space Administration

CM FOREWORD

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

Questions or comments concerning this document should be addressed to:

LRO Configuration Management Office
Mail Stop 451
Goddard Space Flight Center
Greenbelt, Maryland 20771

Signature Page

Prepared by:

Electronic Signature on NGIN___ _5/25/2007
Craig Stevens Date
LRO Lead Structural Analyst
GSFC/NASA, Code 542

Reviewed by:

Electronic Signature on NGIN___ _5/25/2007
Leslie Hartz Date
LRO Payload Systems Engineer
GSFC/NASA, Code 599

Electronic Signature on NGIN___ _5/25/2007
Giulio Rosanova Date
LRO Mechanical Systems Lead
GSFC/NASA, Code 543

Electronic Signature on NGIN___ _5/25/2007
Martin Houghton Date
LRO Mission Systems Engineer
GSFC/NASA, Code 543

Approved by:

Electronic Signature on NGIN___ _5/25/2007
Craig Tooley Date
LRO Project Manager
GSFC/NASA, Code 431

LUNAR RECONNAISSANCE ORBITER PROJECT

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

REV LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED
Rev-	Released per 431-CCR-000002	C. Tooley	7/14/2005
Rev-A	Released per 431-CCR-000130	C. Tooley	4/06/2006
Rev-B	Released per 451-CCR-000363	C. Tooley	3/01/2007
Rev C	Released per 451-CCR-000514	C. Tooley	5/25/2007
Rev D	Released per 451-CCR-000613	C. Tooley	8/10/2007

List of TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table Page

1.0 INTRODUCTION

The Lunar Reconnaissance Orbiter (LRO) mission objective is to conduct investigations that will be specifically targeted to characterize future lunar landing sites and identify potential resources in support of the National Aeronautics and Space Administration’s (NASA) Exploration Initiative.

This document defines the limit loads, mechanical environments, and mechanical verification requirements of the LRO spacecraft (SC), and its instruments, components and ground support equipment (GSE).

1.1 LUNAR RECONNAISSANCE ORBITER OVERVIEW

The LRO mission will be launched from the Kennedy Space Center (KSC) on an Atlas V class Evolved Expendable Launch Vehicle (EELV) into a low altitude parking orbit and then injected into a lunar trajectory by the EELV’s second stage. After a trans-lunar trajectory phase of approximately 100 hours the SC will be inserted into lunar orbit using the on-board propulsion system. The primary mission will be conducted in a circular polar mapping orbit with an altitude of 30-50 kilometers (km) for one earth year. The 3-axis stabilized SC will fly a nadir-pointing attitude with off-nadir maneuvers if required by the observing instruments.

1.2 DEFINITIONS

Qualification Test: A test performed on non-flight hardware. The purpose of the test is to prove that a new design meets one or more of its design requirements. Qualification testing is performed at maximum expected flight levels plus a margin. Test durations are typically longer than for acceptance tests.

Protoflight Test: A test performed on flight hardware. The purpose of the test is to prove that a new design meets one or more of its design requirements. Protoflight testing is performed at maximum expected flight levels plus a margin. Test durations are typically the same as for acceptance tests.

Acceptance Test: A test performed on flight hardware. The purpose of this test is to prove that a particular flight unit has been manufactured properly. The design has already been proven during a qualification or protoflight test program. Acceptance testing is performed at maximum expected flight levels.

Instrument: A SC subsystem consisting of sensors and/or optical hardware used for making measurements or observations. For the purpose of this document instruments are distinguished from components.

Component: A component is a self-contained combination of items performing a function. Examples are electronic box, transmitter, gyro package, motor, and battery. For the purposes of this document, the term component is used generically to represent an analyzable or testable level of assembly below the Orbiter level.

Subsystem: A functional subdivision consisting of two or more components. Science instruments and experiments are considered subsystems.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

431-SPEC-000091	Lunar Reconnaissance Orbiter General Thermal Subsystem Specification
GSFC-STD-7000	General Environmental Verification Standards (GEVS) for Flight Programs and Projects
CLSB-0409-1109	Atlas Launch System Mission Planner’s Guide
NSI 15-010422	Spreader Bar Lift Stability

2.2 REFERENCE DOCUMENTS

NASA-HDBK-7005	Dynamic Environmental Criteria
NASA-STD-5001	Structural Design and Test Factors of Safety for Spacecraft Hardware
NASA-STD-7001	Payload Vibroacoustic Test Criteria
NASA-STD-7003	Pyroshock Test Criteria
RP-1403	Force Limited Vibroacoustic Testing Monograph, NASA Reference Publication

3.0 REQUIREMENTS

In this document, a requirement is identified by “shall,” a good practice by “should”, permission by “may”, or “can”, expectation by “will”, and descriptive material by “is.”

3.1 ENVIRONMENTAL REQUIREMENTS

The following section contains information for all steady-state and dynamic handling, launch, and on-orbit environments. This document assumes that the LRO will launch on an Atlas V 401. All other configurations may differ and need to be evaluated.

The LRO hardware structures shall demonstrate the ability to “survive” the ground, launch, and operational environments. The survival criteria are listed below.

Survival criteria for analysis:

1. Positive margins of safety under limit loading with the appropriate factor of safety.
2. No interference under limit loading with the appropriate factor of safety.

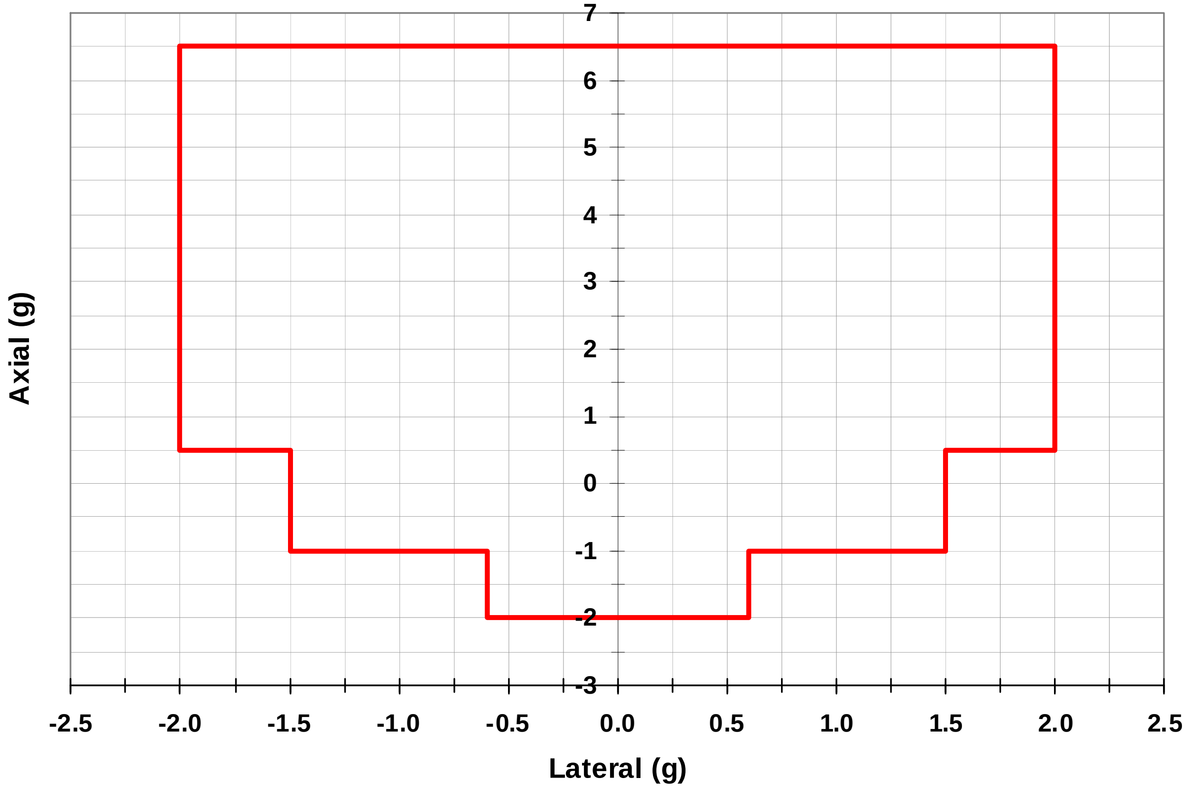
Survival criteria for test:

1. Complete testing to limit levels with the appropriate test factor.
2. No structural degradation after test
   a. No unexplainable frequency shifts more than 5% between pre- and post-test.
   b. No visible damage that is a result of the test environment.
   c. Meet instrument and spacecraft alignment requirements.
3. Pass all functional performance testing performed during and upon completion of test.

3.1.1 Launch Limit Loads

3.1.1.1 Primary Structure

MSS-19 The LRO primary structure shall demonstrate its ability to meet its performance requirements after being subjected to the net Center of Gravity (CG) limit load factors shown in the figure below. These loads are derived from the Atlas Launch System Mission Planner's Guide (CLSB-0409-1109) and coupled loads analysis (CLA) trade studies. These loads will be updated further as coupled loads analysis results become available.



Positive axial load denotes compression
Lateral loads may act in any direction

Figure 3-1. CG Limit Loads for the LRO Primary Structure

3.1.1.2 Instruments

MSS-20 The LRO instruments shall demonstrate their ability to meet their performance requirements after being subjected to the net CG limit loads shown in the tables below. The instrument limit loads shown in Table 3-1 have been tailored based on instrument location. Table 3-2 is a mass-acceleration curve for all instruments not listed in Table 3-1. Note that these design limit loads are intended to only cover the low frequency launch environment and must be used in conjunction with the random vibration environments to assess structural margins.

The instruments listed in Table 3-1 may design to their specified limit loads. Any instrument (or instrument subcomponent) not defined in the table below must use the limit loads in Table 3-2.

Table 3-1. Tailored Instrument Limit Loads

Instrument	**Limit Load (g, any direction)**
CRaTER	8.0
Diviner Instrument	8.0
Diviner DREB	12.0
LAMP	9.0
LEND	8.0
LOLA OTA	8.0
LOLA MEB	9.0
LROC NAC	8.0
LROC WAC	9.0
LROC SCS	8.5
Mini-RF Antenna	12.0
Mini-RF Electronics Boxes	12.0

Table 3-2. Generic Instrument Limit Loads

3.1.1.3 Components

MSS-21 The LRO components shall demonstrate their ability to meet their performance requirements after being subjected to the net CG limit loads shown in the tables below. Components mounted on the Isothermal Panel (ITP) shall use Table 3-2. All other components shall use Table 3-3. For Table 3-3 linear interpolation should be used between breakpoints to determine the appropriate limit load as a function of component weight. Note that these design limit loads are intended to only cover the low frequency launch environment and must be used in conjunction with the random vibration environments to assess structural margins.

Table 3-3. ITP Component Limit Loads

Component	Limit Load (g, any direction)
ITP Component	12.0

Table 3-4. Component Limit Loads

Component Mass (kg)	Limit Load (g, any direction)
0.5 or less	35.9
2	33.6
5	30.1
10	26.8
15	24.5
20	22.8
30	19.9
50	17
60	16
70	15
80	14.4
100.0 or Greater	13.4

3.1.2 On-Orbit Limit Loads

3.1.2.1 Guidance Navigation and Control System Loads

MSS-22 The LRO in its on-orbit configurations shall meet its performance requirements while being subjected to loads induced on it by the Guidance Navigation and Control (GN&C) System.

3.1.2.1.1 Instruments

MSS-36 The instruments in their on-orbit configurations shall meet their performance requirements while being subjected to 0.1 g loads induced on it by the GN&C System. These loads may act in any direction.

3.1.2.1.2 Components

MSS-37 The components in their on-orbit configurations shall meet their performance requirements while being subjected to 0.1 g loads induced on it by the GN&C System. These loads may act in any direction.

3.1.2.1.3 High Gain Antenna System

MSS-38 The high gain antenna system (HGAS) in its on-orbit configurations shall meet its performance requirements while being subjected to the loads induced on it by the GN&C System. These loads are shown in the table below. They are presented in the LRO coordinate system and are should be applied at the LRO center of mass. These environments occur simultaneously for each mission phase.

Table 3-4 HGAS On-Orbit GN&C Environment

Acc X (m/s^2)	**Acc Y (m/s^2)**	**Acc Z (m/s^2)**	**α_X (rad/s^2)**	**α_Y (rad/s^2)**	**α_Z (rad/s^2)**
0.5	0.05	0.05	0.05	0.1	0.1

3.1.2.1.4 Solar Array System

MSS-39 The solar array system (SAS) in its on-orbit index (90 degrees, -45 degrees) configuration shall meet its performance requirements while being subjected to the loads induced on it by the GN&C System. These loads are shown in the table below. They are presented in the LRO coordinate system and are should be applied at the LRO center of mass. These environments occur simultaneously for each mission phase.

Table 3-4 SAS On-Orbit GN&C Environment

.

Acc X (m/s^2)	**Acc Y (m/s^2)**	**Acc Z (m/s^2)**	**α_X (rad/s^2)**	**α_Y (rad/s^2)**	**α_Z (rad/s^2)**
0.5	0.05	0.05	0.05	0.1	0.1

3.1.2.2 Thermal Loads

MSS-23 The LRO structure in its on-orbit configuration shall meet its performance requirements while being subjected to the thermal environments defined in Lunar Reconnaissance Orbiter General Thermal Subsystem Specification (431-SPEC-000091).

3.1.3 Mechanical Ground Support Equipment Limit Loads

3.1.3.1 Strength

MSS-24 The LRO and its Mechanical Ground Support Equipment (MGSE) shall demonstrate their ability to meet their performance requirements after being subjected to the MGSE limit load factors listed in the following table. The load factors are assumed to act simultaneously in all three directions unless otherwise noted.

Table 3-5. MGSE Design Limit Load Factors

Type of MGSE	Load Factor in g's		
	Vertical	Lateral	Longitudinal
Slings	-1.6	N/A	N/A
Dollies	+/-1.6	+/-0.5*	+/-0.5*
Shipping Container	-4.5/+2.0	+/-1.5	+/-3.0
Work Platform	-1.6	+/-0.5	N/A

* Applied separately
Vertical loads act in the gravity gradient, Lateral loads act perpendicular to the direction of travel, and Longitudinal loads act in the direction of travel.
For stationary MGSE, lateral loads act in any horizontal direction
Positive loads impart a tension load at the MGSE/Spacecraft interface

3.1.3.2 Stability

MSS-25 In addition to the above load factors, MGSE shall be analyzed for stability using a 1 g vertical load and a 0.5 g lateral load.

MSS-26 Lifting device stability analysis shall follow the procedures in Analysis Procedure for Spreader Bar Lift Stability (NSI 15-010422).

3.1.4 Sinusoidal Vibration

3.1.4.1 Lunar Reconnaissance Orbiter

MSS-27 The LRO shall demonstrate its ability to meet its performance requirements after being subjected to the following sine vibration environment. These input levels are to be applied at the LRO/Payload Adapter (PLA) interface.

Table 3-6. Orbiter Sine Vibration Environment

Axis	**Atlas V (401)**	
	Frequency (Hz)	**Limit Level**
Lateral	5 - 10	0.4 g
	10 - 15	0.55 g
	15 - 65	0.4 g
	65 - 80	0.5 g
	80 - 85	0.55 g
	85 - 100	0.6 g
Thrust	5 - 10	0.6 g
	10 - 20	1.1 g
	20 - 30	1.0 g
	30 - 75	0.6 g
	75 - 80	0.7 g
	80 - 100	0.9 g

These levels will be updated as coupled loads analysis (CLA) data becomes available. The above environments are derived from the Atlas Launch System Mission Planner's Guide (CLSB-0409-1109). The LRO will be tested and analyzed for this environment up to 50 Hz per GSFC-STD-7000 guidelines. The above input levels may be notched to not exceed 1.25 times the Orbiter net CG loads specified in Section 3.1.1.1.

3.1.4.2 Instruments

MSS-28 The LRO instruments shall demonstrate their ability to meet their performance requirements after being subjected to the sine vibration environments shown below. Table 3-6 is the generic instrument sine vibration environment. The instrument sine vibration environments in Table 3-8 through Table 3-34 have been tailored based on their location. Any instrument (or instrument subcomponent) without specifically tailored sine vibration environments must use the levels defined in Table 3-7. These levels are to be applied at the LRO/instrument interface. Please note that these input levels may be notched to limit the Net CG response to 1.25 times the instrument design limit load (defined in Section 3.1.1.2).

The generic sine vibration environment is shown below.

Table 3-7. Generic Instrument Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 17.7	1.27 cm D.A.	5 - 15.8	1.27 cm D.A.
17.7 - 50	8 g's	15.8 - 50	6.4 g's

The CRaTER instrument sine vibration environments are shown below. The input is defined in the LRO coordinate system.

Table 3-8. CRaTER Instrument X-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 9.9	1.27 cm D.A.	5 - 8.8	1.27 cm D.A.
9.9 - 50	2.5 g's	8.8 - 50	2.0 g's

Table 3-9. CRaTER Instrument Y-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 15.6	1.27 cm D.A.	5 - 14.0	1.27 cm D.A.
15.6 - 25	6.25 g's	14.0 - 25	5.0 g's
25 - 50	3.125 g's	25 - 50	2.5 g's

Table 3-10. CRaTER Instrument Z-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 17.1	1.27 cm D.A.	5 - 15.3	1.27 cm D.A.
17.1 - 25	7.5 g's	15.3 - 25	6.0 g's
25 - 50	3.125 g's	25 - 50	2.5 g's

The Diviner instrument sine vibration environments are shown below. The input is defined in the LRO coordinate system.

Table 3-11. Diviner Instrument X-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 9.9	1.27 cm D.A.	5 - 8.8	1.27 cm D.A.
9.9 - 50	2.5 g’s	8.8 - 50	2.0 g’s

Table 3-12. Diviner Instrument Y-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 14.0	1.27 cm D.A.	5 - 12.5	1.27 cm D.A.
14.0 - 25	5.0 g’s	12.5 - 25	4.0 g’s
25 - 50	2.5 g’s	25 - 50	2.0 g’s

Table 3-13. Diviner Instrument Z-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 14.8	1.27 cm D.A.	5 - 13.3	1.27 cm D.A.
14.8 - 25	5.625 g’s	13.3 - 25	4.5 g’s
25 - 50	2.5 g’s	25 - 50	2.0 g’s

The LAMP instrument sine vibration environments are shown below. The input is defined in the LRO coordinate system.

Table 3-14. LAMP Instrument X-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 15.6	1.27 cm D.A.	5 - 14.0	1.27 cm D.A.
15.6 - 38	6.25 g’s	14.0 - 38	5.0 g’s
38 - 50	9.375 g’s	38 - 50	7.5 g’s

Table 3-15. LAMP Instrument Y-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 12.1	1.27 cm D.A.	5 - 10.8	1.27 cm D.A.
12.1 - 38	3.75 g’s	10.8 - 38	3.0 g’s
38 - 50	6.0 g’s	38 - 50	4.8 g’s

Table 3-16. LAMP Instrument Z-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 14.8	1.27 cm D.A.	5 - 13.3	1.27 cm D.A.
14.8 - 28	5.625 g’s	13.3 - 28	4.5 g’s
28 - 40	8.0 g’s	28 - 40	6.4 g’s
40 - 50	5.625 g’s	40 - 50	4.5 g’s

The LEND instrument sine vibration environments are shown below. The input is defined in the LRO coordinate system.

Table 3-17. LEND Instrument X-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 14.0	1.27 cm D.A.	5 - 12.5	1.27 cm D.A.
14.0 - 25	5.0 g’s	12.5 - 25	4.0 g’s
25-30	8.25 g’s	25-30	6.6 g’s
30-35	10.0 g’s	30-35	8.0 g’s
35-40	8.25 g’s	35-40	6.6 g’s
40 - 50	8.0 g’s	40 - 50	6.4 g’s

Table 3-18. LEND Instrument Y-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 9.9	1.27 cm D.A.	5 - 8.8	1.27 cm D.A.
9.9 - 25	2.5 g’s	8.8 - 25	2.0 g’s
25-30	8.0 g’s	25-30	6.4 g’s
30-35	10.0 g’s	30-35	8.0 g’s
35 - 50	8.0 g’s	35 - 50	6.4 g’s

Table 3-19. LEND Instrument Z-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 9.9	1.27 cm D.A.	5 - 8.8	1.27 cm D.A.
9.9 - 25	2.5 g’s	8.8 - 25	2.0 g’s
25-30	8.25 g’s	25-30	6.6 g’s
30-35	10.0 g’s	30-35	8.0 g’s
35-40	8.25 g’s	35-40	6.6 g’s
40 - 50	8.0 g’s	40 - 50	6.4 g’s

The LOLA OTA instrument sine vibration environments are shown below. The input is defined in the LRO coordinate system.

Table 3-20. LOLA OTA Instrument X-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 14.0	1.27 cm D.A.	5 - 12.5	1.27 cm D.A.
14.0 - 38	5.0 g’s	12.5 - 38	4.0 g’s
38 - 50	8.5 g’s	38 - 50	6.8 g’s

Table 3-21. LOLA OTA Instrument Y-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 13.1	1.27 cm D.A.	5 - 11.7	1.27 cm D.A.
13.1 - 28	4.375 g’s	11.7 - 28	3.5 g’s
28 - 40	5.625 g’s	28 - 40	4.5 g’s
40 - 50	3.125 g’s	40 - 50	2.5 g’s

Table 3-22. LOLA OTA Instrument Z-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 13.5	1.27 cm D.A.	5 - 12.1	1.27 cm D.A.
13.5 - 50	4.688 g’s	12.1 - 50	3.75 g’s

The LOLA MEB instrument sine vibration environments are shown below. The input is defined in the LRO coordinate system.

Table 3-23. LOLA MEB Instrument X-Axis Sine Vibration Environment

Protoflight/Qualification		Acceptance	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 15.6	1.27 cm D.A.	5 - 14.0	1.27 cm D.A.
15.6 - 38	6.25 g’s	14.0 - 38	5.0 g’s
38 - 50	9.375 g’s	38 - 50	7.5 g’s

Table 3-24. LOLA MEB Instrument Y-Axis Sine Vibration Environment

Protoflight/Qualification		Acceptance	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 13.5	1.27 cm D.A.	5 - 12.1	1.27 cm D.A.
13.5 - 50	4.688 g’s	12.1 - 50	3.75 g’s

Table 3-25. LOLA MEB Instrument Z-Axis Sine Vibration Environment

Protoflight/Qualification		Acceptance	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 17.1	1.27 cm D.A.	5 - 15.3	1.27 cm D.A.
17.1- 50	7.5 g’s	15.3 - 50	6.0 g’s

The LROC NAC instrument sine vibration environments are shown below. The input is defined in the LRO coordinate system.

Table 3-26. LROC NAC Instrument X-Axis Sine Vibration Environment

Protoflight/Qualification		Acceptance	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 13.1	1.27 cm D.A.	5 - 11.7	1.27 cm D.A.
13.1 - 38	4.375 g’s	11.7 - 38	3.5 g’s
38 - 50	8.5 g’s	38 - 50	6.8 g’s

Table 3-27. LROC NAC Instrument Y-Axis Sine Vibration Environment

Protoflight/Qualification		Acceptance	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 12.1	1.27 cm D.A.	5 - 10.8	1.27 cm D.A.
12.1 - 38	3.75 g’s	10.8 - 38	3.0 g’s
38 - 50	8.5 g’s	38 - 50	6.8 g’s

Table 3-28. LROC NAC Instrument Z-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 14.0	1.27 cm D.A.	5 - 12.5	1.27 cm D.A.
14.0 - 50	5.0 g’s	12.5 - 50	4.0 g’s

The LROC WAC instrument sine vibration environments are shown below. The input is defined in the LRO coordinate system.

Table 3-29. LROC WAC Instrument X-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 14.0	1.27 cm D.A.	5 - 12.5	1.27 cm D.A.
14.0 - 38	5.0 g’s	12.5 - 38	4.0 g’s
38 - 50	9.125 g’s	38 - 50	7.3 g’s

Table 3-30. LROC WAC Instrument Y-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 14.8	1.27 cm D.A.	5 - 13.3	1.27 cm D.A.
14.8 - 38	5.625 g’s	13.3 - 38	4.5 g’s
38 - 50	6.875 g’s	38 - 50	5.5 g’s

Table 3-31. LROC WAC Instrument Z-Axis Sine Vibration Environment

Protoflight/Qualification		**Acceptance**	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 15.6	1.27 cm D.A.	5 - 14.0	1.27 cm D.A.
15.6 - 50	6.25 g’s	14.0 - 38	5.0 g’s

The LROC SCS sine vibration environments are shown below. The input is defined in the local LROC SCS coordinate system.

Table 3-32. LROC SCS X-Axis Sine Vibration Environment (Local CS)

Protoflight/Qualification		Acceptance	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 14.0	1.27 cm D.A.	5 - 12.5	1.27 cm D.A.
14.0 - 38	5.0 g’s	12.5 - 38	4.0 g’s
38 - 50	9.125 g’s	38 - 50	7.3 g’s

Table 3-33. LROC SCS Y-Axis Sine Vibration Environment (Local CS)

Protoflight/Qualification		Acceptance	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 14.0	1.27 cm D.A.	5 - 12.5	1.27 cm D.A.
14.0 - 22	5.0 g’s	12.5 - 22	4.0 g’s
22 - 40	7.5 g’s	22 - 40	6.0 g’s
40 - 50	5.0 g’s	40 - 50	4.0 g’s

Table 3-34. LROC SCS Z-Axis Sine Vibration Environment (Local CS)

Protoflight/Qualification		Acceptance	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 12.1	1.27 cm D.A.	5 - 10.8	1.27 cm D.A.
12.1 - 50	3.75 g’s	10.8 - 50	3.0 g’s

3.1.4.3 Components

MSS-29 The LRO components shall demonstrate their ability to meet their performance requirements after being subjected to the following sine vibration environment. These levels are to be applied at the LRO/component interface. Please note that these input levels may be notched to limit the Net CG response to 1.25 times the instrument design limit load (defined in Section 3.1.1.3).

Table 3-35. Component Sine Vibration Environment

Protoflight/Qualification		Acceptance	
Frequency (Hz)	**Level**	**Frequency** (Hz)	**Level**
5 - 17.7	1.27 cm D.A.	5 - 15.8	1.27 cm D.A.
17.7 - 50	8 g’s	15.8 - 50	6.4 g’s

3.1.5 Acoustics

MSS-30 The LRO and its instruments and components shall demonstrate their ability to meet their performance requirements after being subjected to the maximum expected flight (limit) level acoustic environment listed in the table below.

Table 3-36. Limit Level Acoustic Environments

Center Frequency (Hz)	Atlas V 401 Sound Pressure Level (dB)
25	114.0
31.5	118.0
40	125.2
50	122.5
63	124.0
80	124.5
100	126.0
125	126.0
160	127.2
200	127.0
250	126.5
315	126.0
400	125.9
500	124.4
630	122.0
800	119.5
1000	116.5
1250	114.0
1600	112.0
2000	114.2
2500	111.0
3150	110.0
4000	109.0
5000	108.5
6300	108.1
8000	109.7
10000	110.5
OASPL	136.9

The reference point is 20 μPa.

3.1.6 Random Vibration

3.1.6.1 Instruments

MSS-31 The LRO instruments shall demonstrate their ability to meet their performance requirements after being subjected to the random vibration environments shown below. Table 3-37 is the generic instrument random vibration environment. Diviner Remote Electronics Box, LEND, LOLA, LROC WAC, LROC NAC, Mini-RF electronics and Mini-RF antenna random environments, shown in the tables below the generic environment, have been tailored based on their location. These levels are to be applied at the LRO/instrument interface. Force limited random vibration testing is recommended (see RP-1403).

The general instrument random vibration environment is shown below.

Table 3-37. Generic Instrument Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.026 g^2/Hz	0.013 g^2/Hz
20 - 50	+6dB/Octave	+6dB/Octave
50 - 800	0.160 g^2/Hz	0.080 g^2/Hz
800 - 2000	-6dB/Octave	-6dB/Octave
2000	0.026 g^2/Hz	0.013 g^2/Hz
Over All	14.1 grms	10.0 grms

The above random environment is appropriate for instruments weighing 22.7 kg (50 pounds (lbs)) or less. For instruments weighing more than 22.7 kg (50 lbs), the random vibration levels may be mass attenuated following the procedure found in the General Environmental Verification Standards (GEVS) for Flight Programs and Projects (GSFC-STD-7000, Section 2.4.2.5). For very large instruments, the random vibration test levels may have to be supplemented or replaced by an acoustic test if the vibration levels are insufficient to excite internal hardware. This environment will be updated based on random vibration and statistical energy analysis. Note for lightweight instruments, the highest design loads may be from this random vibration environment. Each instrument shall perform random vibration analysis along with static loads analysis. Please see NASA-HDBK-7005 and NASA-STD-7001 for more information.

The Diviner Remote Electronics Box (DREB) random vibration environments are shown below.

Table 3-38. DREB In-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.013 g^2/Hz	0.010 g^2/Hz
20 - 31	+6 dB/Octave	+3 dB/Octave
31	0.031 g^2/Hz	0.016g^2/Hz
31- 50	+6 dB/Octave	+6 dB/Octave
50 - 600	0.08 g^2/Hz	0.040 g^2/Hz
600 - 770	-5 dB/Octave	-5 dB/Octave
770	0.052 g^2/Hz	0.026 g^2/Hz
770 - 2000	-5 dB/Octave	-3 dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	9.2 grms	6.9 grms

Table 3-39. DREB Out-of-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.026 g^2/Hz	0.013 g^2/Hz
20 - 50	+6 dB/Octave	+6 dB/Octave
50-600	0.16 g^2/Hz	0.08 g^2/Hz
600-2000	-5 dB/Octave	-5 dB/Octave
2000	0.020 g^2/Hz	0.010 g^2/Hz
Over All	12.9 grms	9.2 grms

The LEND instrument random vibration environments are shown below.

Table 3-39. LEND In-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.010 g^2/Hz	0.010 g^2/Hz
20 - 32	+8dB/Octave	+3dB/Octave
32	0.033 g^2/Hz	0.016 g^2/Hz
32 - 50	+8dB/Octave	+8dB/Octave
50 - 800	0.100 g^2/Hz	0.050 g^2/Hz
800 - 1250	-8dB/Octave	-8dB/Octave
1250	0.033 g^2/Hz	0.016 g^2/Hz
1250 - 2000	-8dB/Octave	-3dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	10.8 grms	7.8 grms

Table 3-40. LEND Out-of-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.010 g^2/Hz	0.010 g^2/Hz
20 - 32	+8dB/Octave	+3dB/Octave
32	0.033 g^2/Hz	0.016 g^2/Hz
32 - 50	+8dB/Octave	+8dB/Octave
50 - 800	0.100 g^2/Hz	0.050 g^2/Hz
800 - 1250	-8dB/Octave	-8dB/Octave
1250	0.033 g^2/Hz	0.016 g^2/Hz
1250 - 2000	-8dB/Octave	-3dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	10.8 grms	7.8 grms

The LOLA instrument random vibration environments are shown below.

Table 3-41. LOLA In-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.010 g^2/Hz	0.010 g^2/Hz
20 - 32	+8dB/Octave	+3dB/Octave
32	0.033 g^2/Hz	0.016 g^2/Hz
32 - 50	+8dB/Octave	+8dB/Octave
50 - 700	0.100 g^2/Hz	0.050 g^2/Hz
700 - 1119	-7dB/Octave	-7dB/Octave
1119	0.036 g^2/Hz	0.018 g^2/Hz
1119 - 2000	-7dB/Octave	-3dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	10.4 grms	7.6 grms

Table 3-42. LOLA Out-of-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.010 g^2/Hz	0.010 g^2/Hz
20 - 32	+8dB/Octave	+3dB/Octave
32	0.033 g^2/Hz	0.016 g^2/Hz
32 - 50	+8dB/Octave	+8dB/Octave
50 - 700	0.100 g^2/Hz	0.050 g^2/Hz
700 - 1119	-7dB/Octave	-7dB/Octave
1119	0.036 g^2/Hz	0.018 g^2/Hz
1119 - 2000	-7dB/Octave	-3dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	10.4 grms	7.6 grms

The LROC WAC instrument random vibration environments are shown below.

Table 3-43. LROC WAC In-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.010 g^2/Hz	0.010 g^2/Hz
20 - 40	+6dB/Octave	+3dB/Octave
40	0.040 g^2/Hz	0.020 g^2/Hz
40 - 80	+6dB/Octave	+6dB/Octave
80 - 200	0.160 g^2/Hz	0.080 g^2/Hz
200 - 250	+9dB/Octave	+9dB/Octave
250 - 400	0.320 g^2/Hz	0.160 g^2/Hz
400 - 500	-9dB/Octave	-9dB/Octave
500 - 700	0.160 g^2/Hz	0.080 g^2/Hz
700 - 1311	-8dB/Octave	-8dB/Octave
1311	0.031 g^2/Hz	0.015 g^2/Hz
1311 - 2000	-8dB/Octave	-3dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	13.9 grms	10.0 grms

Table 3-44. LROC WAC Out-of-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.013 g^2/Hz	0.010 g^2/Hz
20 - 31	+6dB/Octave	+3dB/Octave
31	0.031 g^2/Hz	0.016 g^2/Hz
31 - 50	+6dB/Octave	+6dB/Octave
50 - 800	0.080 g^2/Hz	0.040 g^2/Hz
800 - 1290	-6dB/Octave	-6dB/Octave
1290	0.031 g^2/Hz	0.016 g^2/Hz
1290 - 2000	-6dB/Octave	-3dB/Octave
2000	0.013 g^2/Hz	0.010 g^2/Hz
Over All	10.0 grms	7.2 grms

The LROC NAC instrument random vibration environments are shown below.

Table 3-45. LROC NAC In-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.010 g^2/Hz	0.010 g^2/Hz
20 – 28	+9dB/Octave	+3dB/Octave
28	0.028 g^2/Hz	0.014 g^2/Hz
28 – 50	+9dB/Octave	+9dB/Octave
50 – 70	0.160 g^2/Hz	0.080 g^2/Hz
70 – 75	-13dB/Octave	-13dB/Octave
75 – 150	0.120 g^2/Hz	0.060 g^2/Hz
150 – 200	+3dB/Octave	+3dB/Octave
200 – 700	0.160 g^2/Hz	0.080 g^2/Hz
700 – 1300	-8dB/Octave	-8dB/Octave
1300	0.032 g^2/Hz	0.016 g^2/Hz
1300 – 2000	-8dB/Octave	-3dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	12.6 grms	9.1 grms

Table 3-46. LROC NAC Out-of-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.010 g^2/Hz	0.010 g^2/Hz
20 – 35	+7dB/Octave	+3dB/Octave
35	0.035 g^2/Hz	0.018 g^2/Hz
35 – 50	+7dB/Octave	+7dB/Octave
50 – 100	0.080 g^2/Hz	0.040 g^2/Hz
100 – 150	+5dB/Octave	+5dB/Octave
150 – 700	0.160 g^2/Hz	0.080 g^2/Hz
700 – 1300	-8dB/Octave	-8dB/Octave
1300	0.032 g^2/Hz	0.016 g^2/Hz
1300 – 2000	-8dB/Octave	-3dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	12.5 grms	9.0 grms

A force limit may be applied during analysis and testing of the LROC NAC random vibration environment. The net interface force limit was calculated using a semi-empirical force limit approach. The corresponding random vibration force specifications are shown in the tables below. The levels are presented as net interface force spectral densities (FSD). Note that the specifications are in the units of pound force (lbf) to be consistent with vibration test equipment.

Table 3-47. LROC NAC In-Plane Random Vibration Net Interface Force Specification

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	11.6 lbf^2/Hz	11.6 lbf^2/Hz
20 – 28	+9dB/Octave	+3dB/Octave
28	32.4 lbf^2/Hz	16.2 lbf^2/Hz
28 – 50	+9dB/Octave	+9dB/Octave
50 – 70	185.0 lbf^2/Hz	92.5 lbf^2/Hz
70 – 75	-13dB/Octave	-13dB/Octave
75 – 150	138.8 lbf^2/Hz	69.4 lbf^2/Hz
150 – 200	+3dB/Octave	+3dB/Octave
200 – 485	185.0 lbf^2/Hz	92.5 lbf^2/Hz
485 – 700	-6dB/Octave	-6dB/Octave
700	76.5 lbf^2/Hz	38.2 lbf^2/Hz
700 – 1300	-14dB/Octave	-14dB/Octave
1300	4.4 lbf^2/Hz	2.2 lbf^2/Hz
1300 – 2000	-14dB/Octave	-9dB/Octave
2000	0.6 lbf^2/Hz	0.6 lbf^2/Hz

Table 3-48. LROC NAC Out-of-Plane Random Vibration Net Interface Force Specification

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	11.6 lbf^2/Hz	11.6 lbf^2/Hz
20 – 35	+7dB/Octave	+3dB/Octave
35	40.5 lbf^2/Hz	20.8 lbf^2/Hz
35 – 50	+7dB/Octave	+7dB/Octave
50 – 100	92.5 lbf^2/Hz	46.3 lbf^2/Hz
100 – 150	+5dB/Octave	+5dB/Octave
150 – 210	185.0 lbf^2/Hz	92.5 lbf^2/Hz
210 – 700	-6dB/Octave	-6dB/Octave
700	16.7 lbf^2/Hz	8.3 lbf^2/Hz
700 – 1300	-14dB/Octave	-14dB/Octave
1300	1.0 lbf^2/Hz	0.5 lbf^2/Hz
1300 – 2000	-14dB/Octave	-9dB/Octave
2000	0.1 lbf^2/Hz	0.1 lbf^2/Hz

An additional force limit may be applied to each of the LROC NAC three fastener out-of-plane forces. These are the only connections that react the out-of-plane loads. The out-of-plane FSDs at these three locations may be limited across the entire frequency spectrum based on the Orbiter level acoustic analysis predictions. The random vibration force specification is shown in the table below.

Table 3-49. LROC NAC Out-of-Plane Random Vibration Fastener Force Specification

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20 – 2000	80.0 lbf^2/Hz	40.0 lbf^2/Hz

A total of four force limits may be applied to each LROC NAC random vibration axis. The acceleration spectral density input may be notched to allow no exceedences of these limits at any frequency.

The Mini-RF electronics random vibration environments are shown below.

Table 3-50. Mini-RF Electonics In-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.013 g^2/Hz	0.010 g^2/Hz
20 - 31	+6 dB/Octave	+3 dB/Octave
31	0.031 g^2/Hz	0.016g^2/Hz
31- 50	+6 dB/Octave	+6 dB/Octave
50 - 600	0.08 g^2/Hz	0.040 g^2/Hz
600 - 770	-5 dB/Octave	-5 dB/Octave
770	0.052 g^2/Hz	0.026 g^2/Hz
770 - 2000	-5 dB/Octave	-3dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	9.2 grms	6.9 grms

Table 3-51. Mini-RF Electronics Out-of-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.026 g^2/Hz	0.013 g^2/Hz
20 - 50	+6 dB/Octave	+6 dB/Octave
50-600	0.16 g^2/Hz	0.08 g^2/Hz
600-2000	-5 dB/Octave	-5 dB/Octave
2000	0.020 g^2/Hz	0.010 g^2/Hz
Over All	12.9 grms	9.2 grms

The Mini-RF Antenna random vibration environments are shown below.

Table 3-52. Mini-RF Antenna In-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.013 g^2/Hz	0.010 g^2/Hz
20 - 31	+6 dB/Octave	+3 dB/Octave
31	0.031 g^2/Hz	0.016g^2/Hz
31- 50	+6 dB/Octave	+6 dB/Octave
50 - 700	0.08 g^2/Hz	0.040 g^2/Hz
700 - 985	-6 dB/Octave	-6 dB/Octave
985	0.041 g^2/Hz	0.021 g^2/Hz
985 - 2000	-6 dB/Octave	-3 dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	9.5 grms	7.0 grms

Table 3-53. Mini-RF Antenna Out-of-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.026 g^2/Hz	0.013 g^2/Hz
20 - 50	+6 dB/Octave	+6 dB/Octave
50-700	0.16 g^2/Hz	0.08 g^2/Hz
700-1311	-8 dB/Octave	-8 dB/Octave
1311	0.031 g^2/Hz	0.016 g^2/Hz
1311-2000	-8 dB/Octave	-3 dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	12.8 grms	9.2 grms

Components

MSS-32 The LRO components shall demonstrate their ability to meet their performance requirements after being subjected to the following random vibration environments. Components located on the Isothermal Panel (ITP) shall use the environments shown in tables 3-55 and 3-56. All other components shall use the generic component random vibration environment shown in Table 3-54. These levels are to be applied at the LRO/component interface.

Table 3-54. Generic Component Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.026 g^2/Hz	0.013 g^2/Hz
20 - 50	+6dB/Octave	+6dB/Octave
50 - 800	0.160 g^2/Hz	0.080 g^2/Hz
800 - 2000	-6dB/Octave	-6dB/Octave
2000	0.026 g^2/Hz	0.013 g^2/Hz
Over All	14.1 grms	10.0 grms

The above random environment is appropriate for components weighing 22.7 kg (50 lbs) or less. For components weighing more than 22.7 kg (50 lbs), the random vibration levels may be mass attenuated following the procedure found in the General Environmental Verification Standards (GEVS) for Flight Programs and Projects (GSFC-STD-7000, Section 2.4.2.5). This environment will be updated with random vibration analysis. Note for lightweight components, the highest design loads may be from this random vibration environment. Each component shall perform random vibration analysis along with static loads analysis. Please see NASA-HDBK-7005 and NASA-STD-7001 for more information.

The ITP component random vibration environments are shown below.

Table 3-55. ITP Components In-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.013 g^2/Hz	0.010 g^2/Hz
20 - 31	+6 dB/Octave	+3 dB/Octave
31	0.031 g^2/Hz	0.016g^2/Hz
31- 50	+6 dB/Octave	+6 dB/Octave
50 - 600	0.08 g^2/Hz	0.040 g^2/Hz
600 - 770	-5 dB/Octave	-5 dB/Octave
770	0.052 g^2/Hz	0.026 g^2/Hz
770 - 2000	-5 dB/Octave	-3 dB/Octave
2000	0.010 g^2/Hz	0.010 g^2/Hz
Over All	9.2 grms	6.9 grms

Table 3-56. ITP Components Out-of-Plane Random Vibration Environment

Frequency (Hz)	Protoflight/Qual Level	Acceptance Level
20	0.026 g^2/Hz	0.013 g^2/Hz
20 - 50	+6 dB/Octave	+6 dB/Octave
50-600	0.16 g^2/Hz	0.08 g^2/Hz
600-2000	-5 dB/Octave	-5 dB/Octave
2000	0.020 g^2/Hz	0.010 g^2/Hz
Over All	12.9 grms	9.2 grms

3.1.7 Shock Environment

3.1.7.1 Lunar Reconnaissance Orbiter/Payload Adapter Interface

The maximum expected (limit level) shock environment at the LRO/PLA interface is defined in the table below. LRO/PLA interface shock testing will be performed on the LRO.

Table 3-40. LRO/PLA Interface Shock Response Spectrum

Atlas V (Type B1194 PLA)	
Frequency (Hz)	**Level (Q=10)**
100	100 g
100 - 1400	+7.6 dB/Octave
1400 - 10000	2800 g

3.1.7.2 Deployables Interface

The maximum expected shock environment at the high gain antenna system (HGAS) and solar array system (SAS) separation mechanism interfaces are defined in the following table. The HGAS and SAS separation mechanism shock testing will be performed on the LRO.

Table 3-41. Deployables Interface Separation Mechanism Shock Response Spectrum

NEA	
Frequency (Hz)	**Level (Q=10)**
100	80 g
100 - 615	+6.1 dB/Octave
615 - 10000	500 g

3.1.7.3 Instruments and components

MSS-33 All instruments and components shall be assessed for damage due to shock based on shock sensitivity or proximity to shock sources. The maximum expected shock environment due to LRO/PLA separation and LRO/deployables separation at instrument and component interfaces are shown in the tables below. Note that the specifications are divided into zones aboard the orbiter. The first three tables are for assessment of general instruments and components. LEND, CRaTER, and DIVINER shock environments, shown in the last three tables, have been tailored based on their location. Instruments and components not considered susceptible to the shock environment may have shock testing deferred to the level of assembly that allows for actuation of the actual shock-producing device. Any instrument or component considered to be susceptible to the shock environment should perform a shock test to demonstrate that the item can survive the predicted shock environment. Instrument shock testing may be performed at the lowest level of assembly necessary to demonstrate compliance with the predicted shock environment (see NASA-STD-7003).

Instruments and components that have self-induced shock environments must be test qualified for the environment prior to delivery to the LRO.

Instruments and components aboard the LRO honeycomb side panels and isothermal panel should be assessed using the following table.

Table 3-42. Isothermal panel and side panels shock response spectrum

Frequency (Hz)	Level (Q=10)
100	100 g
100 - 796	+7.6 dB/Octave
796 - 10000	1372 g

Instruments and components aboard the instrument module and top deck should be assessed using the following table.

Table 3-43. Instrument module and top deck shock response spectrum

Frequency (Hz)	Level (Q=10)
100	100 g
100 - 600	+7.6 dB/Octave
600 - 10000	960 g

All other instruments and components should be assessed using the table below.

Table 3-44. General instrument and component shock response spectrum

Frequency (Hz)	Level (Q=10)
100	100 g
100 - 1056	+7.6 dB/Octave
1056 - 10000	1960 g

The LEND instrument should be assessed using the table below.

Table 3-45. LEND interface shock response spectrum

Frequency (Hz)	Level (Q=10)
100	60 g
100 - 815	+7.1 dB/Octave
815 - 10000	710 g

The CRaTER instrument should be assessed using the table below.

Table 3-46. CRaTER shock response spectrum

Frequency (Hz)	Level (Q=10)
100	15 g
100 - 1000	+9.3 dB/Octave
1000 - 10000	525 g

The DIVINER instrument should be assessed using the table below.

Table 3-47. DIVINER shock response spectrum

Frequency (Hz)	Level (Q=10)
100	15 g
100 - 990	+10.0 dB/Octave
990 - 10000	675 g

3.1.8 Venting

MSS-34 LRO components and instruments, not having a minimum of 0.25 square inches of vent area for each cubic foot volume, shall demonstrate the ability to survive the maximum expected flight pressure profiles described in the figures below. A qualification test is required if analysis does not indicate a positive margin at loads equal to twice those induced by the maximum expected pressure differential. Please see the Atlas Launch System Mission Planner's Guide (CLSB-0409-1109) and GEVS for Flight Programs and Projects (GSFC-STD-7000, Section 2.4.6) for more information.

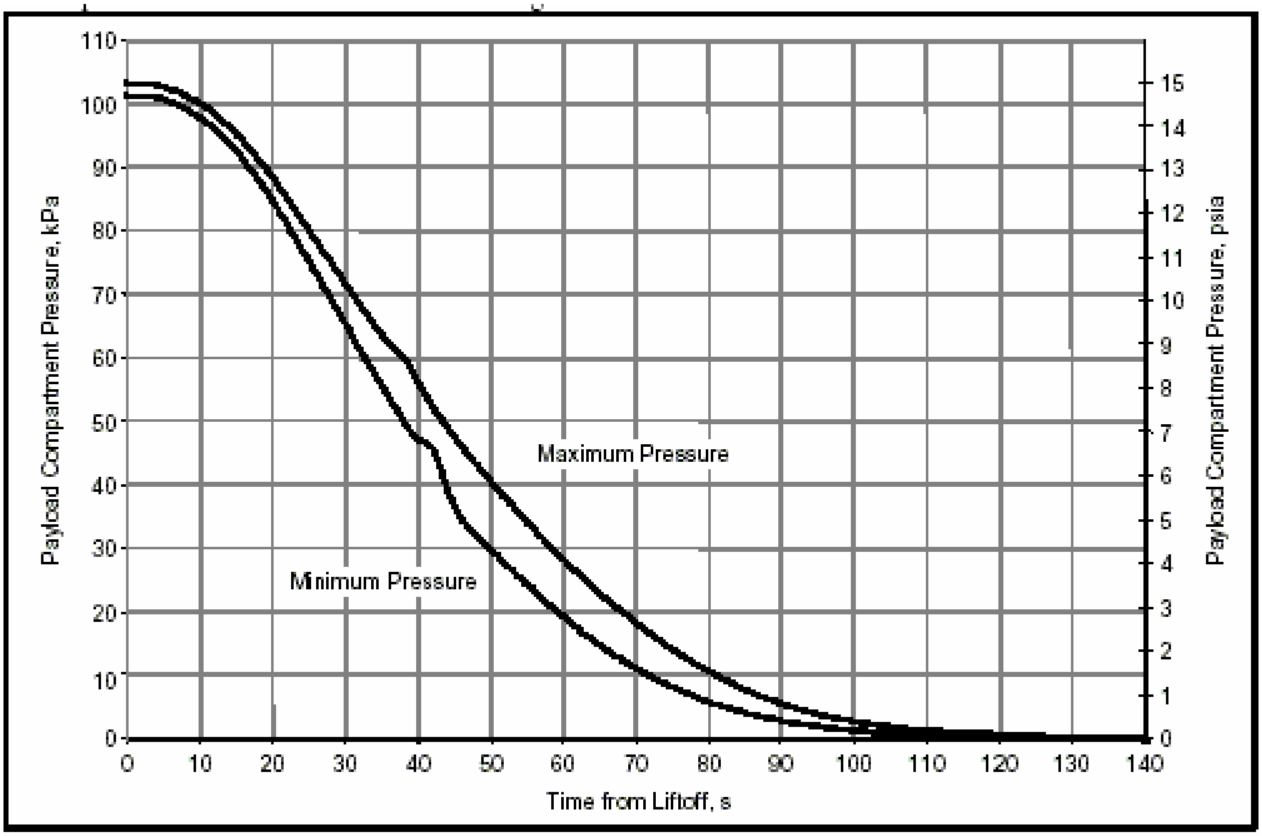


Figure 3-2. Atlas V Typical Static Pressure Profiles Inside the Payload Fairing

3.2 FREQUENCY REQUIREMENTS

3.2.1 Spacecraft Primary Structure

MSS-1 LRO shall have minimum fundamental frequencies greater than the values shown in the table below when hard mounted to its PLA interface.

Table 3-48. LRO Minimum Frequency Requirements

Axis	Atlas V 401 (Hz)
Lateral	8
Thrust	15

3.2.2 Instruments

3.2.2.1 Stowed Configuration

MSS-2 The LRO instruments in their stowed configuration shall have a fundamental frequency greater than 35 Hz when hard mounted at their SC interface with the appropriate attachment degrees of freedom (DOF) rigidly constrained. All instruments should have a minimum frequency goal of 50 Hz. This simplifies loads predictions and usually results in lower more stable structural loads. It also ensures that the hard requirement of 35 Hz is met.

3.2.2.2 Deployed Configuration

MSS-3 The LRO instruments in their deployed configuration shall have a deployed fundamental frequency greater than 3 Hz when hard mounted at their SC interface.

3.2.3 Components

3.2.3.1 Stowed Configuration

MSS-4 The LRO components in their stowed configuration shall have a fundamental frequency greater than 50 Hz when hard mounted at their SC interface.

3.2.3.2 Deployed Configuration

MSS-5 The LRO components in their deployed configuration shall have a deployed fundamental frequency greater than 3 Hz when hard mounted at their SC interface.

3.2.4 Solar Array System

The SAS frequency requirements will be handled on a case-by-case basis. Please contact the LRO lead analyst if the following frequency goals are not satisfied.

3.2.4.1 Stowed Configuration

The SAS in its stowed configuration should have a fundamental frequency greater than 35 Hz when hard mounted at its SC interface.

3.2.4.2 Deployed Configuration

The SAS in its deployed configuration should have a fundamental frequency greater than 1 Hz when hard mounted at its SC interface.

3.2.5 High Gain Antenna System

The HGAS frequency requirements will be handled on a case-by-case basis. Please contact the LRO lead analyst if the following frequency goals are not satisfied.

3.2.5.1 Stowed Configuration

The HGAS in its stowed configuration should have a fundamental frequency greater than 35 Hz when hard mounted at its SC interface.

3.2.5.2 Deployed Configuration

The HGAS in its deployed configuration should have a fundamental frequency greater than 1 Hz when hard mounted at its SC interface.

3.3 VERIFICATION REQUIREMENTS

3.3.1 Factors of Safety

MSS-6 The LRO structure, instruments, and components as well as MGSE shall demonstrate positive Margins of Safety for all yield and ultimate failures using the Factors of Safety (FS) defined in the table below (see NASA-STD-5001 for more information on other materials (e.g. glass)).

Table 3-49. Factors of Safety

Type of Hardware	Design Factor of Safety	
	Yield	Ultimate
Tested Flight Structure - metallic	1.25	1.4
Tested Flight Structure - beryllium	1.4	1.6
Tested Flight Structure - composite*	N/A	1.5
Pressure Loaded Structure	1.25	1.5
Pressure Lines and Fittings	1.25	4.0
Untested Flight Structure - metallic only	2.0	2.6
Ground Support Equipment	3.0	5.0
Transportation Dolly/Shipping Container	2.0	3.0

*All composite structures must be tested to 1.25 x limit loads

Margin of Safety (MS) is defined as follows:

MS = (Allowable Stress(or Load)/(Applied Stress(or Load) x FS)) -1

3.3.2 Test Factors

MSS-7 The following test factors and durations, shown in the following table, shall be used for prototype, protoflight, and flight hardware. The hardware definitions are included in GEVS (GSFC-STD-7000).

Table 3-50. Test Factors and Durations

Test	**Qualification**	**Protoflight**	**Acceptance**
Structural Loads			
Level	1.25 X Limit Load	1.25 X Limit Load	Limit Load$^{(2)}$
Duration			
Centrifuge	1 Minute	30 Seconds	30 Seconds
Sine Burst$^{(1)}$	5 Cycles Full Level	5 Cycles Full Level	5 Cycles Full Level
Acoustic			
Level	Limit Level +3dB	Limit Level +3dB	Limit Level
Duration	2 Minutes	1 Minute	1 Minute

Test	Qualification	Protoflight	Acceptance
Random Vibration			
Level	Limit Level +3dB	Limit Level +3dB	Limit Level
Duration	2 Minutes/Axis	1 Minute/Axis	1 Minute/Axis
Sine Vibration			
Level	1.25 X Limit Level	1.25 X Limit Level	Limit Level
Sweep Rate(3)	2 Octaves/Minute/Axis	4 Octaves/Minute/Axis	4 Octaves/Minute/Axis
Shock			
Actual Device	2 Actuations	2 Actuations	1 Actuation
Simulated	1.4 X Limit Level 2 Actuations/Axis	1.4 X Limit Level 1 Actuation/Axis	Limit Level 1 Actuation/Axis

(1) Sine burst testing shall be done a frequency sufficiently below primary resonance as to ensure rigid body motion.
(2) All composite structures must be tested to 1.25 x limit loads. All beryllium structures must be tested to 1.4 x limit loads.
(3) Unless otherwise specified these sine sweep rates shall apply

3.3.3 Frequency Verification Requirements

3.3.3.1 Primary Structure

MSS-8 A modal test shall be performed on the LRO primary structure. The LRO finite element model will be correlated up to 50 Hz to the results of this modal test. Modes containing more than 5% modal effective mass will be correlated to within 5% on frequency.

MSS-9 The test to analysis cross orthogonality matrix shall have at least 0.9's on the diagonal and no greater than 0.1's on the off diagonals for modes with more than 5% modal effective mass.

3.3.3.2 Instruments and Components above 50 Hertz

MSS-10 Instruments and components with fundamental frequencies above 50 Hz shall perform a frequency verification test, such as a low level sine sweep.

MSS-11 Frequencies shall be verified and reported up to 200 Hz.

3.3.3.3 Instruments and Components below 50 Hertz

MSS-12 Instruments and components with fundamental frequencies below 50 Hz shall perform a modal test.

MSS-13 Instrument and component finite element models shall be correlated to the results of this modal test. Modes containing more than 5% modal effective mass will be correlated to within 5% on frequency.

MSS-14 The test to analysis cross orthogonality matrix shall have at least 0.9’s on the diagonal and no greater than 0.1’s on the off diagonals for modes with more than 5% modal effective mass.

MSS-15 Frequencies between 50 and 200 Hz shall be verified and reported.

3.4 FINITE ELEMENT MODEL REQUIREMENTS

MSS-16 Instruments and components with predicted first frequencies below 75 Hz shall provide Finite Element Models (FEMs) for LRO structural analysis. These FEMs have the following requirements.

3.4.1 Finite Element Model Documentation

MSS-17 Each formal finite element model submittal shall be submitted with documentation that describes the following:

1. The version of the model.
2. A list of element, node, property, and material identification (ID) numbers.
3. A description of the nonstructural mass represented on each property card.
4. A description of units.
5. A description of the local reference coordinate system.
6. The results of validity checks.
7. Mass Properties (CG location, Inertias, and total model mass).
8. Frequencies of the first ten modes while in a free-free boundary condition.

3.4.2 Finite Element Model Submittal

MSS-18 Formal finite element model submittals shall adhere to the following:

1. Model submitted as a MacNeal Schwendler Corporation (MSC)/ NASA Structural Analysis (NASTRAN) data deck.
2. Model file names include the date (YYMMDD) that they were made at the beginning of their name.
3. All model property and material cards have descriptive names.
4. Models submission is "full" model with no symmetry assumptions made to reduce model size.
5. Model includes no "Super Elements".
6. Model submission includes an explicit Single Point Constraint set.
7. Until actual hardware mass properties are verified and final, the finite element model is adjusted to the maximum allocated mass for each subsystem and component.
8. Model passes the following validity checks: unit enforced displacement and rotation,free-free dynamics with equilibrium check, and unit gravity loading.
9. Finite element models used for thermal analysis pass a unit increased temperature check.

4.0 QUALIFICATION ASSURANCE PROVISIONS

4.1 GENERAL

All requirements in this document shall be verified by one of the four methods defined below.

4.1.1 Analysis

The analysis method is used when:

- A rigorous, representative, and conclusive analysis is possible
- Test is not cost effective, and
- Inspection and demonstrations are not adequate
- Analyses may include, but are not limited to, engineering analysis (which includes models and simulations), review of record, and similarity analysis.

4.1.1.1 Engineering Analysis

Engineering analysis may be quantitative, qualitative, or a combination of the two. Quantitative analysis involves the study and modeling of the physical entity whose performance is to be verified. Examples of quantitative analyses include end-to-end link analysis, structural (static and dynamic) analysis, thermal models, pointing knowledge and stability. Qualitative analyses are non-numerical and related to qualitative measure of performance, such as failure modes and effects analyses (FMEA), maintainability, and redundancy.

4.1.1.2 Validation of Records and Other Documentation Analysis

This kind of analysis uses design and manufacturing documentation to show compliance of design features and manufacturing processes. Validation of design documentation, e.g., engineering drawings, verifies that the “as-designed” hardware complies with contractual design and construction requirements. Validation of manufacturing records at end-item acceptance verifies that the “as-built” hardware has been fabricated per the approved design and associated documentation. Review and analysis of other documentation such as acceptance data packages and other compliance documentation of lower levels of assembly are valid analysis techniques.

4.1.1.3 Similarity Analysis

Similarity is included as a valid verification/qualification method. Qualification by similarity is used in lieu of test when it can be shown that an item is similar to, or identical in design to another item that has been previously qualified to equivalent, or more stringent requirements. Formal qualification documentation of the previously qualified item must be available for assessment when planning to qualify by similarity. Furthermore, an item whose design has been qualified by similarity must undergo acceptance verification to assess workmanship.

4.1.2 Demonstration

Demonstration is a verification method that provides a qualitative determination, rather than direct quantitative measurement, of the properties or functional characteristics of an end-item. The qualitative determination is made through observation with, or without test equipment or instrumentation.

4.1.3 Inspection

Inspection is the verification method used to verify construction features, workmanship, dimension, physical characteristics, and spacecraft conditions such as configuration, cleanliness, and locking hardware. Inspection also includes simple measurements such as length, and it is performed without the use of special laboratory or precision equipment. In general, requirements specifying function or performance are not verified by inspection.

4.1.4 Test

Verification by test consists of direct measurement of performance parameters relative to functional, electrical, mechanical, and environmental requirements. These measurements are obtained, during or after controlled application of functional and environmental stimuli to the test article, e.g., payload or satellite, and using instrumentation or special test equipment that is not an integral part of the test article being verified. The test activities include reduction and analysis of the test data, as appropriate. The following paragraphs define different categories of tests including performance, functional, environmental, interface, and structural tests.

4.1.4.1 Performance Test

A performance test consists of an individual test or series of electrical and/or mechanical tests conducted on flight, or flight-configured hardware and software at conditions equal to, or less than design specifications. Its purpose is to verify compliance of the test article with the stated applicable specification requirements that are verifiable by test. Typically, a full performance test is conducted at ambient conditions at the beginning and the end of a test sequence during which the test article is subjected to applicable environmental conditions, e.g., vacuum, high/low temperature extremes, or acoustics/random mechanical excitation.

4.1.4.2 Functional Tests

A functional test is a suitably chosen subset of a performance test. Typically, functional tests are conducted at ambient conditions between environmental exposures during the qualification or acceptance test sequence. The objective is to verify that prior to application of the next environment, exposure to the environment has not adversely affected the test article. When appropriate, functional tests, or a portion thereof, are conducted while the test article is exposed to a particular thermal or vacuum environment. Functional test, or a portion thereof, may also be conducted to assess the state of health of the hardware after major operations, such as transportation of flight hardware from one location to another.

4.1.4.3 Environmental Tests

Environmental testing is an individual test or series of tests conducted on flight, or flight-configured hardware to assure that flight hardware will perform satisfactorily after it is subjected to the induced launch environments, as well as its flight environment. Examples are: vibration, acoustic, temperature cycling, thermal vacuum and vacuum outgassing certification, and Electromagnetic Interference/Compatibility. Depending on the severity of the chosen environmental conditions, the purpose of the environmental exposure is to sufficiently stress the hardware so as to verify the adequacy of the design (protoflight levels and durations) or workmanship during fabrication (acceptance levels and durations).

4.1.4.4 Special Tests

Special tests are individual tests, or a series of tests conducted on flight, or flight-configured hardware to assure satisfactory performance of a particular critical element of the system, e.g., optical alignment. The special test verification category includes structural, mechanism and communication tests. Special tests may, or may not be performed in conjunction with environmental exposure.

4.1.4.5 Interface Tests

Interface tests verify the mechanical, electrical, and/or hardware-software interface between units and elements integrated into a higher level of assembly such as a module, subsystem, element, or a system.

4.1.4.6 Structural Tests

These tests are performed on structural elements, components, or assembled subsystems before delivery of the assembled structure to the integration and test organization. Structural tests designed to verify requirements of this specification may include: (1) static structural proof tests (to verify the strength/stiffness adequacy of the primary load path), and (2) dynamic tests, such as a modal survey or acoustic response test.

4.2 VERIFICATION MATRIX TABLE

The following matrix table defines the method of verification for all requirements contain in this document:

Table 4-1. Verification Matrix Table

Verification Method:		**Level:**
Inspection	**(I)**	**1 System**
Analysis	**(A)**	**2 Segment**
Demonstration	**(D)**	**3 Subsystem**
Test	**(T)**	**4 Component**

Requirement Number		Heading	I	A	D	T	Responsible Org
MSS-19	3.1.1.1.0-1	Primary Structure		2		2	GSFC/NASA
MSS-20	3.1.1.2.0-1	Instruments		3		3	Instruments
MSS-21	3.1.1.3.0-1	Components		4		4	Components
MSS-22	3.1.2.1.0-1	Guidance Navigation and Control System Loads		2		2	All
MSS-36	3.1.2.1.1-1	Instruments		3		3	Instruments
MSS-37	3.1.2.1.2-1	Components		4		4	Components
MSS-38	3.1.2.1.3-1	High Gain Antenna System		3		3	GSFC/NASA
MSS-39	3.1.2.1.4-1	Solar Array System		3		3	GSFC/NASA
MSS-23	3.1.2.2.0-1	Thermal Loads		2		2	All
MSS-24	3.1.3.1.0-1	Strength		2		2	All
MSS-25	3.1.3.2.0-1	Stability		2		2	All
MSS-26	3.1.3.2.0-2	Stability					
MSS-27	3.1.4.1.0-1	Lunar Reconnaissance Orbiter		2		2	GSFC/NASA
MSS-28	3.1.4.2.0-1	Instruments		3		3	Instruments
MSS-29	3.1.4.3.0-1	Components		4		4	Components
MSS-30	3.1.5.0-1	Acoustics		2		2	All
MSS-31	3.1.6.1.0-1	Instruments		3		3	Instruments
MSS-32	3.1.6.2.0-1	Components		4		4	Components
MSS-33	3.1.7.3.0-1	Instruments and components		3		3	Instruments/

Requirement Number		Heading	I	A	D	T	Responsible Org
							Components
MSS-34	3.1.8.0-1	Venting		2		2	All
MSS-1	3.2.1.0-1	Spacecraft Primary Structure		2		2	GSFC/NASA
MSS-2	3.2.2.1.0-1	Stowed Configuration		3		3	Instruments
MSS-3	3.2.2.2.0-1	Deployed Configuration		3		3	Instruments
MSS-4	3.2.3.1.0-1	Stowed Configuration		4		4	Components
MSS-5	3.2.3.2.0-1	Deployed Configuration		4		4	Components
	3.2.4.0-1	Solar Array System					
	3.2.4.1-1	Solar Array System					
	3.2.4.2-1	Solar Array System					
	3.2.5.0-1	High Gain Antenna System					
	3.2.5.1-1	High Gain Antenna System					
	3.2.5.2-1	High Gain Antenna System					
MSS-6	3.3.1.0-1	Factors of Safety		2		2	All
MSS-7	3.3.2.0-1	Test Factors		2		2	All
MSS-8	3.3.3.1.0-1	Primary Structure		2		2	GSFC/NASA
MSS-9	3.3.3.1.0-2	Primary Structure		2		2	GSFC/NASA
MSS-10	3.3.3.2.0-1	Instruments and Components above 50 Hertz		4		4	Instruments/ Components
MSS-11	3.3.3.2.0-2	Instruments and Components above 50 Hertz		4		4	Instruments/ Components
MSS-12	3.3.3.3.0-1	Instruments and Components below 50 Hertz		4		4	Instruments/ Components
MSS-13	3.3.3.3.0-2	Instruments and Components below 50 Hertz		4		4	Instruments/ Components
MSS-14	3.3.3.3.0-3	Instruments and Components below 50 Hertz		4		4	Instruments/ Components
MSS-15	3.3.3.3.0-4	Instruments and Components below 50 Hertz		4		4	Instruments/ Components
MSS-16	3.4.0-1	Finite Element Model Requirements		4		4	Instruments/ Components
MSS-17	3.4.1.0-1	Finite Element Model Documentation		4			Instruments/ Components
MSS-18	3.4.2.0-1	Finite Element Model Submittal		4			Instruments/ Components

APPENDIX A. ABBREVIATIONS AND ACRONYMS

Abbreviation/ Acronym	DEFINITION
CCB	Configuration Control Board
CCR	Configuration Change Request
CG	Center of Gravity
CLA	Coupled Loads Analysis
CM	Configuration Management
CMO	Configuration Management Office
dB	decibel
DOF	Degree of Freedom
EELV	Evolved Expendable Launch Vehicle
FEM	Finite Element Model
FS	Factors of Safety
FSD	Force Spectral Density
g	Acceleration due to Gravity at Earth's Surface (e.g. 9.81 m/s^2)
GEVS	General Environmental Verification Specification
GN&C	Guidance Navigation and Control
Grms	Root-mean-square Response in g's
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HGAS	High Gain Antenna System
Hz	Hertz
ID	Identification
kg	kilogram
km	kilometer
KSC	Kennedy Space Center
lbf	pound force
lbs	pounds
LRO	Lunar Reconnaissance Orbiter
µPa	Micropascal
MECO	Main Engine Cutoff
MGSE	Mechanical Ground Support Equipment
MS	Margin of Safety
MSC	MacNeal Schwendler Corporation
N/A	Not applicable
NASA	National Aeronautics and Space Administration
NASTRAN	NASA Structural Analysis
NSI	Northrop Services Incorporated (now ManTech)

Abbreviation/ Acronym	DEFINITION
PLA	Payload Adapter
RP	Reference Publication
RQMT	Requirement
SAS	Solar Array System
SC	Spacecraft
SPC	Single Point Constraint
SPEC	Specification
STD	Standard