APPENDIX G

Preliminary Structural Design and Test Requirements

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1.0 Introduction

The purpose of this document is to define preliminary structural design and test requirements for the Solar Terrestrial Relations Observatory (STEREO) and its components. The baselined launch vehicle for the STEREO program is the Athena II, however, since Shuttle is being carried as an alternative, this document addresses those requirements as well.

2.0 References

The following documents are referred to within this document and were used as guidance in the development of design load factors and environmental test requirements.

(1) *LMLV Mission Planner's Guide,* Lockheed Martin Astronautics, Denver Colorado, Initial Release, September 1997.

(2) *Athena Environments Update to the Athena Mission Planner's Guide* (as of 9/98), Lockheed Martin Astronautics, Denver Colorado.

(3) *Flight Support System (FSS) User 's Guide for Space Shuttle*, STE-35, Baseline Issue, July 17, 1992, United Space Alliance.

(4) *Shuttle Orbiter/Cargo Standard Interfaces (CORE)* ICD-2-19001, Revision L, CPN-68, United Space Alliance, January 15, 1998.

(5) *Payload Verification Requirements, Space Shuttle Program,* NASA Space Transportation System (NSTS) 14046 Revision C, NASA, April 1994.

(6) GEVS-SE REV A, *General Environmental Verification Specification for STS & ELV Payloads, Subsystems, and Components*, NASA Goddard Space Flight Center, Greenbelt, Maryland, June 1996.

(7) *Trans-Lunar Injection Timer*, Lockheed Martin document Number P402S002, 20 May 1996.

3.0 General Approach

The design and test requirements are based on the assumption that the STEREO Spacecraft will be launched on either a Lockheed Martin Athena II or a Space Shuttle with Flight Support System (FSS) cradles. The Athena II is currently being carried as the baseline launch vehicle. The Athena II configuration consists of a Model 92 payload fairing, a Model 47 payload adapter, and Thiokol STAR-37FM motor injection system. The Space Shuttle configuration uses a Thiokol STAR 48V motor injection system. An attempt has been made to envelop the Athena and Shuttle load cases without being overly conservative. The testing philosophy is based on the proto-flight approach, where hardware is tested to design qualification levels for flight acceptance durations.

4.0 Spacecraft Requirements

This section addresses design loads and environments for the spacecraft.

4.1 Design Load Factors

The primary structure shall be designed to the following limit loads (maximum expected loads) multiplied by the appropriate factor of safety. Limit load factors for the Athena II are provided in References 1 and 2. Limit load factors for the Shuttle are provided in Reference 3.

PRELIMINARY

Preliminary Athena II Spacecraft Center of Gravity (Cg) Load Factors

Lockheed-Martin Proprietary Data

Preliminary Shuttle Spacecraft Center of Gravity (Cg) Load Factors

	Load Factors (g)		
Shuttle Flight Event	**Nx (thrust)**	**Ny (lateral)**	**Nz (lateral)**
Liftoff	+6.4	+2.0	+5.0
Landing	–3.6	+4.0	–8.4

Note:
(1) Load factors are considered to be “yield” load factors.
(2) Axial and lateral load factors should be applied simultaneously for each load case.
(3) Load factors are to be applied at the center of gravity of the payload.
(4) Payload is defined as the STEREO spacecraft with the STAR 48V motor assembly.
(5) Load factors contain a spacecraft dynamic uncertainty factor of 2.0.

4.2 Factors and Margins of Safety

The following factors of safety shall be used for design of the spacecraft primary and secondary structures:

FST = Factor of Safety for Test = 1.25
FSY= Factor of Safety for Yield Strength Design = 1.25
FSU = Factor of Safety for Ultimate Strength Design = 1.4

Margins of Safety:

$$\text{MSY} = \text{Margin of Safety on Yield Strength} = \frac{\text{Material Yield Strength}}{\text{FSY x Applied Stress}} - 1.0 \geqq 0.10$$

$$\text{MSU} = \text{Margin of Safety on Ultimate Strength} = \frac{\text{Material Ultimate Strength}}{\text{FSY x Applied Stress}} - 1.0 \geqq 0.10$$

4.3 Stiffness Requirements

4.3.1 Athena II Requirements

Lockheed-Martin Proprietary Data

4.3.2 Shuttle Requirements

To avoid dynamic coupling of spacecraft and Shuttle Flight Support Structure modes, the primary spacecraft structure should be designed to have fundamental frequencies above 10 Hz. (Reference 3).

4.4 Sine Vibration Testing

A spacecraft level sine burst or sinusoidal vibration test will be designed to cover both the structural strength test and the simulated flight environment. The final vibration levels will depend on results of the STEREO/launch vehicle dynamic coupling analysis, but preliminary levels are presented below:

Preliminary Athena II Sine Vibration Levels
Sweep rate = 4 octaves/min

Lockheed-Martin Proprietary Data

4.5 Acoustic Testing – Athena II and Shuttle

To verify the ability of the spacecraft to survive the launch acoustic environment, a spacecraft level acoustic test shall be performed in a reverberant sound pressure field. The spacecraft shall be tested to the following proto-flight (maximum expected levels +3 dB) acoustic levels:

4.6 Shock Testing

The primary source of shock for the STEREO spacecraft is the separation nut ordnance used to separate the STEREO Injection Stage from the STEREO Spacecraft. Actual ordnance shall be fired to test the separation of the spacecraft from the STEREO Injection Stage. To account for the scatter associated with the actuation of the same device, this test shall be performed twice (Reference 6). The separation system is assumed to be similar to that for the Lunar Prospector Mission. The expected shock environment is shown below (Reference 7).

PRELIMINARY

Athena I & II Internal Acoustical Levels (Reference 1)
1/3 OCTAVE SPL, dB

Lockheed-Martin Proprietary Data

Shuttle Orbiter Cargo Bay Internal Acoustic Environment (Reference 4)

1/3 Oct. Band Center Frequency (Hz)	Sound Pressure Level (dB) Ref. 2×10^{-5} N/m2		Sound Power Level (dB) Ref. 10^{-12} Watts	
	MEI/Lift-off	Max Q/Transonic	Payload Bay Vents **	
	5 Seconds per Mission* Payload Diameter < 160 Inches	10 Seconds per Mission* Payload Diameter ≤ 180 Inches	Lift-off 5 Seconds per Mission	Max Q/Transonic 35 Seconds per Mission
31.5	122.0	112.0	119.0	110.0
40	124.0	114.0	121.0	114.0
50	125.5	116.0	122.0	114.0
63	127.0	118.0	126.0	115.0
80	128.0	120.0	128.0	118.0
100	128.5	121.0	130.0	120.0
125	129.0	122.5	126.0	125.0
160	129.0	123.5	130.0	130.0
200	128.5	124.5	129.0	125.0
250	127.0	125.0	132.0	121.0
315	126.0	125.0	130.0	124.0
400	125.0	124.0	127.0	118.0
500	123.0	121.5	130.0	119.0
630	121.5	119.5	122.0	117.0
800	120.0	117.5	123.0	115.0
1000	117.5	116.0	122.0	114.0
1250	116.0	114.0	121.0	115.0
1600	114.0	112.5	118.0	109.0
2000	112.0	110.5	121.0	108.0
2500	110.0	108.5	123.0	110.0
OASPL	138.0	133.5	140.0	134.0

* Time per mission does not include a scatter factor
** The payload bay vents act as individual noise sources for the payload bay
The noise radiated from any one vent is described below

The pyrotechnic devices used to release booms, solar arrays, protective covers, etc. produce a local source of shock. Shock testing shall be conducted at the spacecraft level by firing the ordnance and allowing the release of the boom, solar array, cover, etc. These tests shall be performed twice.

4.7 Mass Properties

Spacecraft mass properties shall be determined by analysis and measured to the following accuracy:

Lunar Prospector Separation Shock Environment

Frequency (Hz)	Shock Level (g's)
100	35.2
315	59.3
1250	1125
2500	3741
3150	4942
8000	5983
10000	5420

STEREO Spacecraft Mass Property and Spin Balance Accuracy

	Launch Configuration	Orbital Configuration
Weight	±TBD%	±TBD%
Center of Gravity	±TBD% inches w/respect to separation plane at geometric center.	Derived analytically from launch configuration.
Moment of Inertia	Measured in three mutually perpendicular axes within ±TBD%. have a goal of TBD times lateral (y, z) moment of inertia.	Derived analytically from launch configuration. Thrust (x) moment of inertia shall
Spin Balance	Angle between spacecraft geometric thrust (x) axis and spacecraft principal thrust axis must not exceed TBD.	Derived analytically from launch configuration.

5.0 Component, Subsystem and Instruments Requirements

5.1 Design Load Factors

The following design load factors, multiplied by the appropriate factor of safety, shall be applied to components, subsystems, and instruments. Thrust and lateral load factors are to be applied simultaneously for each load case.

5.2 Factors and Margins of Safety

The following factors and margins of safety will be used for the development of component, subsystem and instrument structures:

Instrument and Component Design Load Factors for Athena II

Load Case	Thrust (x) Load Factor (g's)	Lateral (y, z) Load Factor (g's)
1 (Due to 2nd Stage Castor Ignition)	±20	±2.5
2 (Due to 2nd Stage Motor Resonance and Gust)	±14.5	±4

Instrument and Component Design Load Factors for Shuttle

Load Case	Thrust (x) Load Factor (g's)	Lateral (y) Load Factor (g's)	Lateral (z) Load Factor (g's)
1 (Due to lift-off)	±9.5	±3.0	±7.5
2 (Due to landing)	±5.4	±6.0	±12.6

Factors of Safety:

FST = Factor of Safety for Test = 1.25
FSY= Factor of Safety for Yield Strength Design = 1.25
FSU = Factor of Safety for Ultimate Strength Design = 1.4

Margins of Safety:

$$MSY = \text{Margin of Safety on Yield Strength} = \frac{\text{Material Yield Strength}}{\text{FSY x Applied Stress}} - 1.0 \geqq 0.10$$

$$MSU = \text{Margin of Safety on Ultimate Strength} = \frac{\text{Material Ultimate Strength}}{\text{FSY x Applied Stress}} - 1.0 \geqq 0.10$$

5.3 Stiffness Requirements

Components, subsystems, and instruments shall be designed to have primary structural vibration modes above 100 Hz in the thrust axis and 50 Hz in the lateral axes.

5.4 Pressure Requirements

Components, subsystems, and instruments shall be designed to withstand a maximum pressure rate change of TBD psi/sec. Pressure profile testing is considered optional.

5.5 Shock Requirements

Separation shock must be considered in the design of components, subsystems, and instruments located near the spacecraft/STEREO injection system separation plane. Expected shock levels shall be addressed on a case by case basis.

Self-induced shock shall be considered in the design of components, subsystems, or instruments and shall be tested at the component level. Self-induced shock can result from the actuation of pyrotechnic or pneumatic devices to release booms, solar arrays, protective covers, etc. "End of travel" impact of deployable devices can also produce a self-induced shock. Self-induced shock shall be tested by actuation of the device, allowing release of the boom, cover, etc. This test shall be performed twice.

5.6 Sine Vibration Testing

Components, subsystems, and instruments shall be subjected to sinusoidal vibration along each of the three orthogonal axes. Proto-flight levels are shown in the following tables.

Preliminary Athena II Component Sine Vibration Levels Sweep rate = 4 octaves/min

Axial		Lateral	
Frequency (Hz)	Acceleration (g's, zero to peak)	Frequency (Hz)	Acceleration (g's, zero to peak)
5 to 30	0.4	5 to 30	0.3
30 to 35	20.0	30 to 35	12.0
35 to 70	0.6	35 to 60	0.3
70 to 100	0.45	60 to 75	0.7
		75 to 100	0.85

Preliminary Shuttle Component Sine Vibration Levels Sweep rate = 4 octaves/min

Axial		Lateral	
Frequency (Hz)	Acceleration (g's, zero to peak)	Frequency (Hz)	Acceleration (g's, zero to peak)
5 to 30	0.5	5 to 30	0.5
30 to 35	23.0	30 to 35	19.0
35 to 100	0.5	35 to 100	0.5

5.7 Random Vibration Testing

Components, subsystems, and instruments shall be subjected to random vibration along each of the three orthogonal axes, one of which is parallel to the thrust axis. The proto-flight levels, obtained from Reference 6, are as follows:

Preliminary Component Random Vibration Levels
Duration = 60 seconds

Frequency (Hz)	PSD Level
20	0.026 g^2/Hz
20–50	+6 dB/Oct
50–800	0.16 g^2/Hz
800–2000	−6 DB/Oct
2000	0.026 g^2/Hz
Overall	**14.1 G rms**

5.8 Mass Properties

Each component, subsystem, and instrument shall be weighed to an accuracy of 1% or 1 pound, whichever is less. The accuracy of the center of gravity and moment of inertia calculations shall have an accuracy goal of 10%.