Proton Launch System Mission Planner's Guide

SECTION 3

Spacecraft Environments

3. SPACECRAFT ENVIRONMENTS

This section provides the expected ground and flight environments that a SC may encounter during a Proton launch campaign and flight.

3.1 THERMAL/HUMIDITY

In this section, the thermal and humidity environment for the SC is defined for transportation from the Yubileiny Airfield through launch base processing, launch and separation. SC component temperatures, to be used for assessing ground and flight thermal compatibility, will be determined by analysis using a Customer-supplied SC thermal model.

3.1.1 SC Ground Thermal and Humidity Environment

Ambient temperatures at the Baikonur Cosmodrome are provided in Table 3.1.1-1. Facility and transportation temperatures and relative humidity are provided in Table 3.1.1-2. During transport, the SC is air-conditioned either by Customer-provided air conditioning equipment or by a railcar-mounted thermal control unit. While on the pad, thermal control is provided by the Air Thermal Mode Control System (ATMCS) and/or the Liquid Thermal Mode Control System (LTMCS).

Table 3.1.1-1: Ambient Temperatures at the Baikonur Cosmodrome

Month	Maximum (°C)	Minimum (°C)
January	3	-40
February	0	-37
March	10	-27
April	22	-12
May	33	0
June	41	8
July	44	9
August	41	8
September	35	2
October	27	-12
November	20	-31
December	12	-38

Table 3.1.1-2: SC Thermal and Humidity Environment

#	Location/Event	Item	Temperature (°C)		Relative Humidity** (%)		Temperature Control
			Min.	Max.	Min.	Max.	
1	SC Container	Inlet air to container	15	30	30	60	Thermal control railcar supplied by KhSC provides flow rate of 2000 to 8000 m^3/hr. Monitoring of the temperature environment in SC container is the SCC's responsibility.
2	Container cleaning and storage area, Building 92A-50 (Hall 102)	SC ambient air	13	25	35	60	Building air conditioning
3	Fueling Hall, 92A-50 (Hall 103A)	SC ambient air	15	25	35	60	Building air conditioning
4	AU Integration Area, Building 92A-50 (Hall 101)	SC ambient air	17	27	35	60	Building air conditioning
5	Transportation of Integrated AU to LV Integration Area (Hall 101 to Hall 111)	SC ambient air	13	27	0.5	60	Thermal control railcar supplied by KhSC. Flow rate ≤ 8000 m^3/hr.*
6	AU/LV Integration Area, Hall 111, Building 92A-50	SC ambient air	17	27	30	60	Building air conditioning. If needed, the external air conditioning unit provided by KhSC is used. Flow rate 2000 to 8000 m^3/hr.*
7	Transportation of Integrated Launch Vehicle (ILV) to the US fueling area	SC ambient air	10	25	0.5	60	Thermal control railcar unit provided by KhSC. Flow rate ≤ 8000 m^3/hr.*
8	Breeze M fueling station	SC ambient air	10	22	0.5	60	Thermal control railcar supplied by KhSC. Flow rate ≤ 8000 m^3/hr.*
9	Integrated ILV rollout to the pad	SC ambient air	13	25	0.5	60	Thermal control railcar supplied by KhSC. Flow rate ≤ 8000 m^3/hr.*
10	Erection	SC ambient air	10	30	0.5	60	No active temperature control is provided for 3 hours before LTMCS activation.
11	On-pad with air-conditioning by ATMCS	SC ambient air	13	25	0.5	60	Air-conditioning by launch pad ATMCS. Flow rate 5000 to 13000 m^3/hr.*
12	On-pad with thermal conditioning by LTMCS	SC ambient air	10	30	0.5	60	LTMCS temperature control panels in fairing.
13	Launch abort	SC ambient air	10	30	0.5	60	No active temperature control is provided prior to LTMCS activation.

*The temperature is to be preset jointly by KhSC and the SCC taking into account the SC and LV thermal environment in specific weather conditions and maintained accurate to ± 2°C.

**If relative humidity becomes <35%, operations in the vicinity of the SC (and under PLF after SC encapsulation) are permitted only after coordination with the SCC.

3.1.1.1 Thermal Control During SC Preparation

SC thermal control occurs during the following phases of launch operations:

- SC arrival. If needed, an external air conditioning unit can be used to supply conditioned air for the SC in the SC container from arrival at Yubileiny Airfield through transport by rail to Building 92A-50, Payload Processing Facility (PPF).
- SC operations. SC preparations, SC fueling and integration with the Ascent Unit (AU) rely upon the building air conditioning system in Building 92A-50.
- Mating of the AU to Proton. Transportation of the AU to Hall 111 for mating to the lower three stages relies upon an external air conditioning unit.
- AU thermal pre-conditioning before transportation to the fueling station. (Pre-conditioning is conducted based on the weather forecast for the transportation day and begins approximately 12 hours prior to transportation. The AU is protected by a thermal cover.)
- Transportation of the LV with the integrated AU to the Breeze M fueling station.
- Breeze M fueling. KhSC's external air conditioning system is used and it operates in a closed-cycle mode.
- Thermal pre-conditioning before Integrated LV transportation to the pad.
- Integrated LV transportation to the pad.

3.1.1.2 Thermal Control at Launch Pad

An external thermal insulation shroud is placed around the fairing prior to pad rollout to provide additional insulation during the erection of the LV on the pad when there is no active air conditioning. During transportation to the pad, conditioned air is provided to the SC from the thermal control railcar. At the pad, the air conditioning is disconnected and the LV is erected.

Installation of the Integrated LV on the pad takes up to five hours before rollup of the Mobile Service Tower (MST) and reconnection of the air conditioning. For the first 2.5 to 3 hours of this process, there is no active temperature control provided, and the internal AU thermal environment is maintained by the PLF thermal cover and insulation. If thermal control is needed during the remaining 2 to 2.5 hours before MST rollup, the LTMCS can be connected and used.

After the MST is brought up to the LV, the pad ATMCS is connected and the thermal cover is removed. A thermal analysis is performed to verify that under worst-case ambient conditions, the SC temperature will not exceed allowable temperature limits during the erection process.

The on-pad air conditioning system remains active 24 hours a day until approximately 1 hour 50 minutes prior to launch, when preparations are begun for MST rollback. To provide thermal conditioning of the PLF after MST rollback, a liquid thermal control system is provided in the PLF. This system is the LTMCS, mentioned previously, and consists of radiators mounted on the PLF inside wall and connected to the thermal control system in the launch pad complex. The LTMCS is activated 3 hours 50 minutes prior to launch. The ATMCS and LTMCS operate in parallel from L-3h 50m to L-1h 50m, at which point the ATMCS is deactivated. From L-1h 50m to L-10 minutes, the LTMCS operates. Ten minutes prior to lift-off, the LTMCS is deactivated. Antifreeze fluid is drained from all lines and the lines are purged by dry nitrogen to ensure that the lines are free of liquid prior to lift-off. During this time, the AU thermal environment is maintained by the thermal properties of the AU.

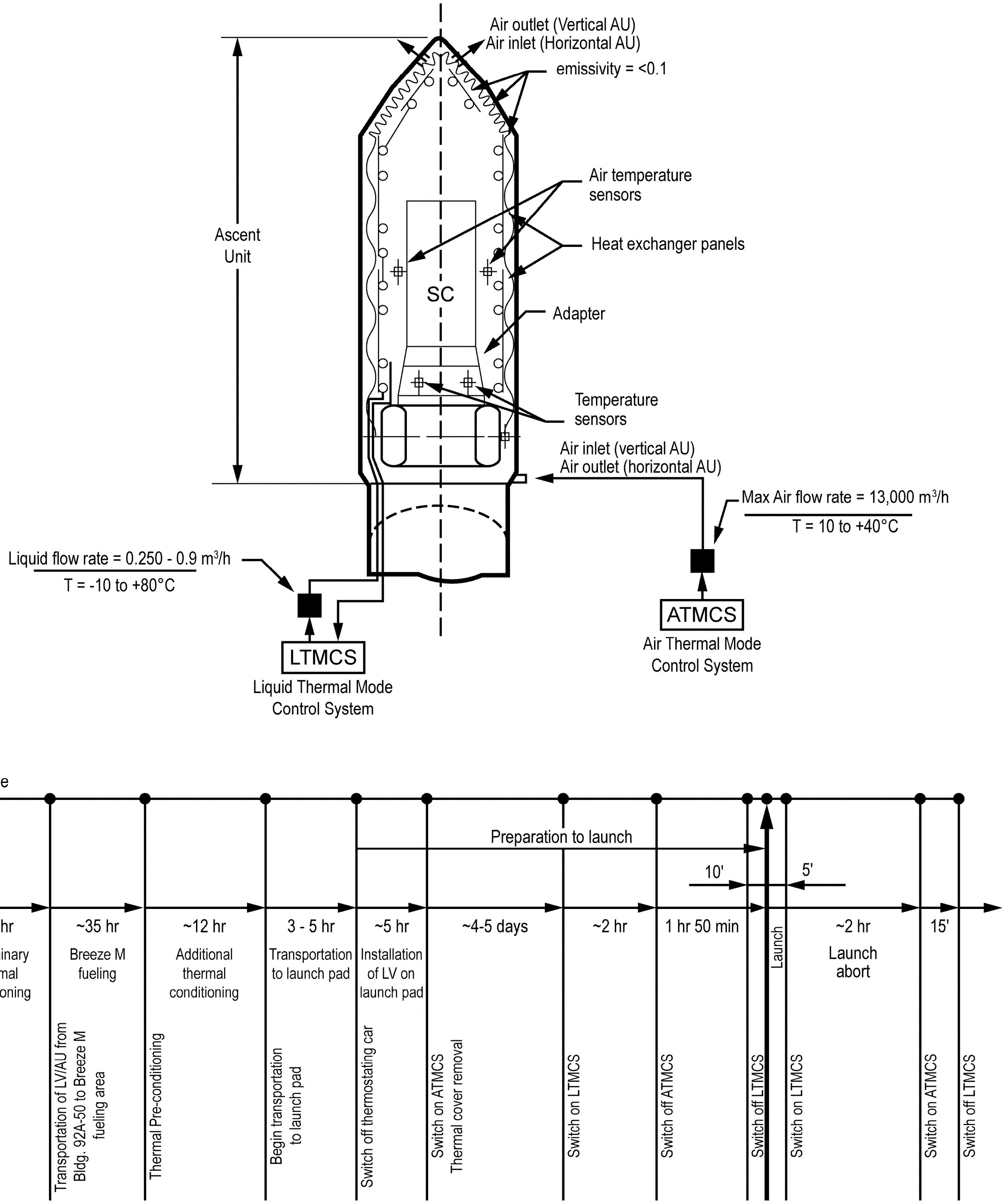
In the event that the launch must be aborted, the liquid system is reactivated in five minutes and the MST rolled up to the LV to renew air conditioning within 2 hours. Two hours after a launch abort, the MST completes roll-up to the LV and the connectors to the ATMCS are remated. The ATMCS and the LTMCS operate together for 15 minutes, and then the LTMCS is deactivated. All further pad operations up to relaunch are conducted in accordance with the previously described timeline.

Table 3.1.1.2-1 summarizes this timeline for the LV from pre-conditioning prior to transport to the Breeze M fueling station through all pad operations. Figure 3.1.1.2-1 shows the AU on-pad thermal control diagram and provides a schematic of the thermal conditioning timeline.

Table 3.1.1.2-1: AU Operations Timeline at Processing Facility and Launch Pad

#	Phase	Duration (hours/minutes)
1	AU thermal pre-conditioning before LV transportation to the fueling station	12 h/00 m
2	LV/AU assembly transportation to the Breeze M fueling station. Breeze M fueling. AU thermal pre-conditioning before LV/AU assembly transportation to the pad. LV/AU assembly transportation to the pad.	~ 50 h/00 m
3	Erection	5 h/00 m
4	LV on the pad; ATMCS and LTMCS ON	0 h/15 m
5	LV on the pad; ATMCS ON	96 h to 120 h
6	LV on the pad; ATMCS and LTMCS ON	2 h/00 m
7	LV on the pad; ATMCS OFF, LTMCS ON	1 h/40 m
8	LV on the pad until launch; LTMCS OFF	0 h/10 m
9	Launch abort; LTMCS OFF	0 h/05 m
10	Launch abort; LTMCS ON	2 h/00 m
11	Launch abort; ATMCS and LTMCS ON	0 h/15 m
12	LV on the pad until relaunch; ATMCS and LTMCS operating in accordance with standard timeline	variable

Figure 3.1.1.2-1: Fairing Air and Liquid Thermal Mode Control Systems Schematic and Operations Timeline



3.1.1.3 Supplemental Air Conditioning for SC Battery Charging

Supplemental SC air conditioning can be provided on the pad during SC battery charging operations as a Customer requested option. Up to 500 m^3/hr can be provided through several access doors in the fairing at a temperature selectable between 10 and 16°C up until the time of MST rollback, 1 hour, 50 minutes prior to launch. The air inlets can be provided in the mission-specific access doors (see Figure 3.1.1.3-1 and Figure 3.1.1.3-2), and are described in more detail in Section 4.

3.1.2 SC Flight Thermal Environment

3.1.2.1 Launch to Parking Orbit Injection

During ascent, the LV will be exposed to aerodynamic heat flux. Following PLF jettison, the SC will be exposed to solar radiation and Free Molecular Heat Flux (FMHF). A thermal analysis will be performed using the Customer-supplied SC thermal model to predict SC temperatures during this phase of the mission. The heat flux density radiated upon the SC by the internal surfaces of the PLF does not exceed 500 W/m^2 from the time of launch until PLF jettison. The PLF is jettisoned at approximately 340 to 350 seconds into flight (at an altitude of 121 to 125 km or more), and the maximum FMHF does not exceed 1135 W/m^2 at any time following PLF jettison.

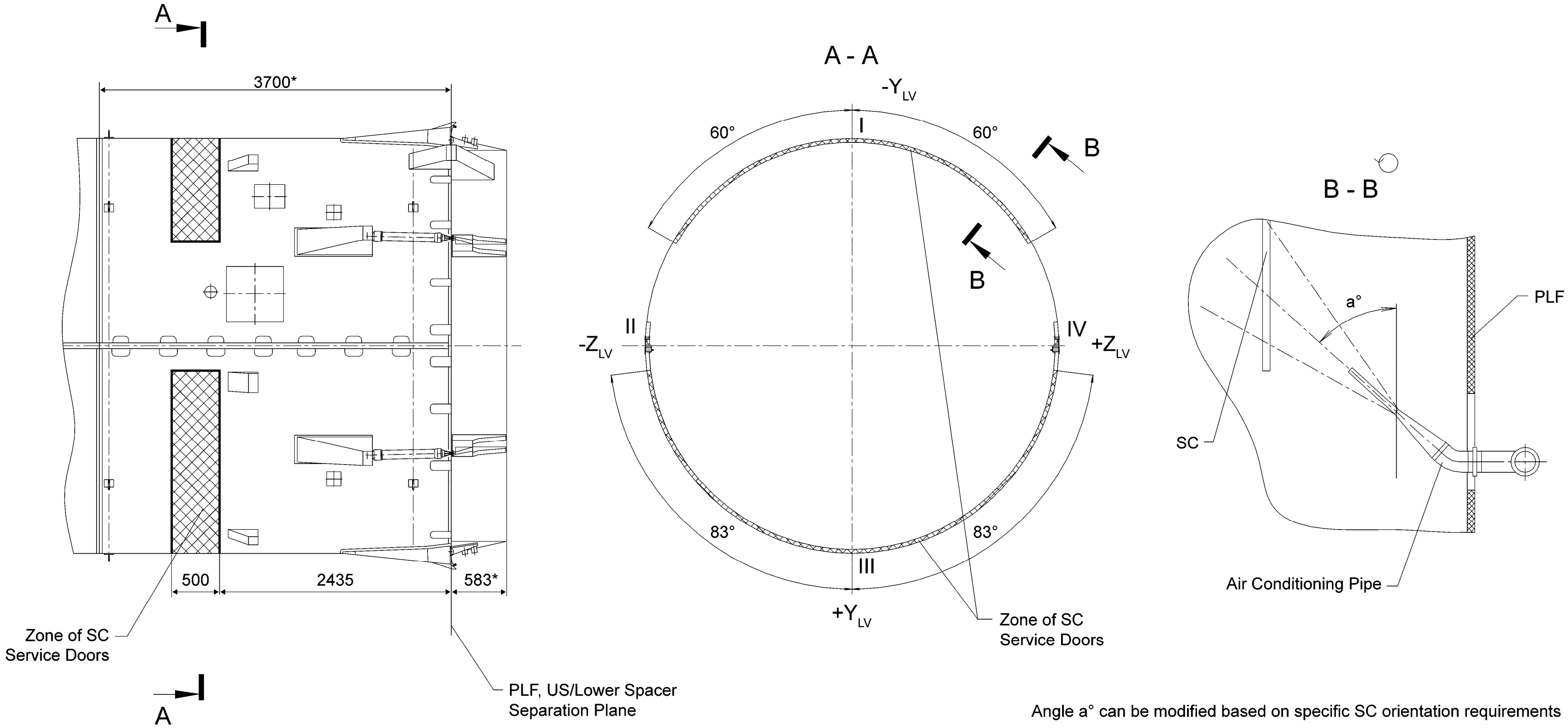
3.1.2.2 Orbit

Following injection into parking orbit, the SC thermal environment is determined mainly by solar radiation, albedo and infrared earth radiation, and FMHF. Attitude maneuvers of the Breeze M can be programmed to provide desired sun angles for maintaining SC battery power and thermal control. An integrated thermal analysis is performed by KhSC using the SCC-supplied thermal mathematical model to determine SC temperatures as a function of time throughout the flight up to SC separation.

3.1.3 Air Impingement Velocity

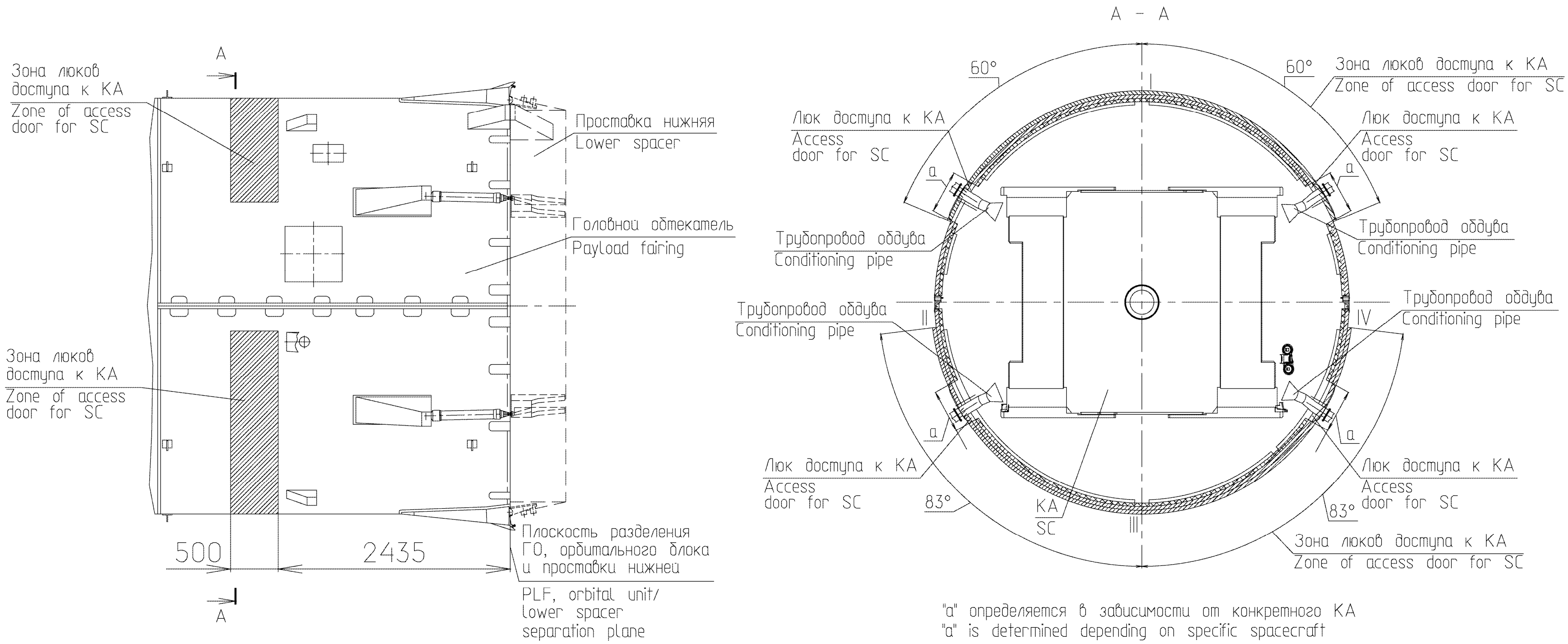
The air impingement velocity on the SC surfaces within the PLF does not exceed five m/s during ground operations following encapsulation through launch. The actual value of the velocity will be determined based on mission-specific analysis.

Figure 3.1.1.3-1: SC Battery Air Conditioning System (Option 1)



* Dimensions for reference

Figure 3.1.1.3-2: SC Battery Air Conditioning System (Option 2)



3.2 CONTAMINATION ENVIRONMENT

3.2.1 Ground Contamination Control

The contamination environment around the SC is controlled by use of ISO Class 8 cleanroom facilities and strict control of material cleanliness of flight hardware in proximity to the SC. During transportation using KhSC-provided air conditioning systems and while on the pad, air is filtered to provide at least ISO Class 8 particle content. Air cleanliness is monitored regularly in all areas where the SC is present to ensure particle count levels are maintained within specification. In addition, witness plates can be mounted inside the fairing following encapsulation to monitor particle fallout inside the fairing up to L-1 day. The ground contamination environment around the SC meets the cleanliness levels specified in Table 3.2.1-1.

Table 3.2.1-1: Ground Contamination Environment

Location/Event	Cleanliness Level Required*	Comments
SC container	ISO Class 8	ILS/KhSC-supplied conditioned air
SC processing facilities (Building 92A-50)	ISO Class 8	Facility air conditioning
Encapsulated in PLF during transportation, Breeze M fueling and battery charging	ISO Class 8	Payload encapsulated, filtered air provided
Erection	ISO Class 8	Payload compartment sealed
On-pad with air conditioning through umbilical	ISO Class 8	Filtered air provided
On-pad following removal of air conditioning umbilical	ISO Class 8	Payload compartment sealed

* Per ISO 14644-1

3.2.2 In-Flight Contamination Control

The LV systems are designed to preclude in-flight contamination of the SC. The LV pyrotechnic devices near the SC used for PLF jettison and SC separation have sealed gas chambers and do not release significant contamination to the outside environment. The PLF liquid thermal control system pipes are sealed by automatic valves, which close at PLF jettison. The third stage retrorocket plume does not result in any significant particle contact with the SC due to its position on the aft end of the third stage and the orientation of the retrorocket axis 15 degrees away from the LV longitudinal axis. The Breeze M attitude control thrusters are located on the aft section of the central unit and oriented perpendicular to the Breeze M longitudinal axis (worst case), such that the plume does not contact the SC while the SC is attached to the Breeze M.

Following SC separation, the Breeze M maintains the attitude specified at spacecraft separation until the SC is a safe distance away. After an appropriate amount of time, the Breeze M performs a Collision and Contamination Avoidance Maneuver (CCAM).

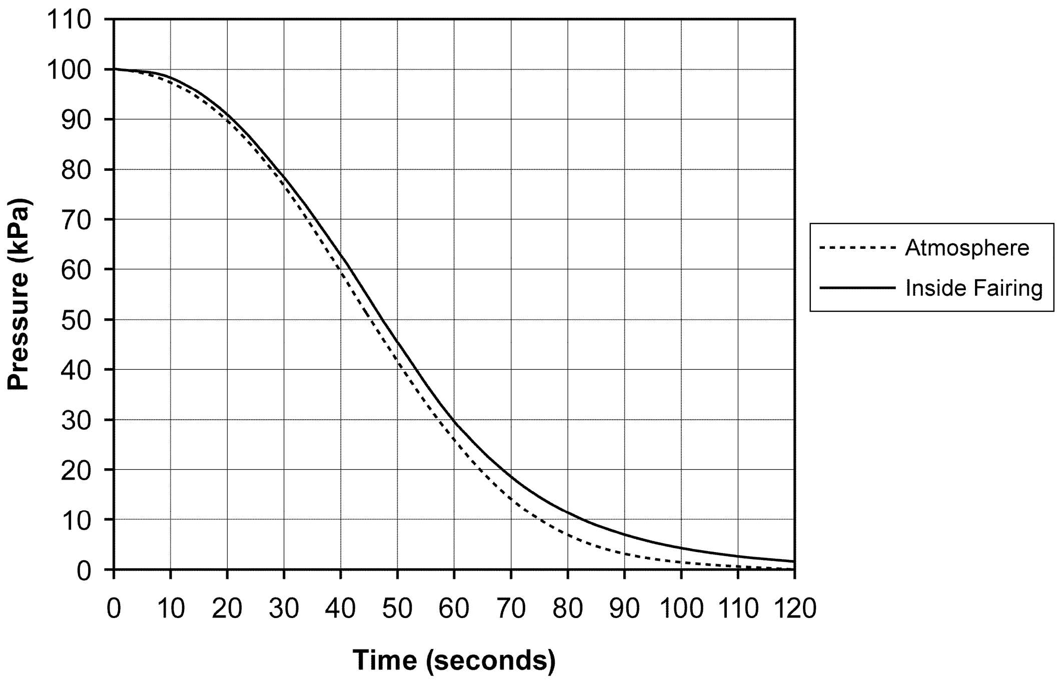
3.3 PRESSURE

3.3.1 Payload Compartment Venting

During ascent, the payload compartment is vented through four to six venting orifices distributed equally about the cylindrical portion of the fairing. Maximum rate of pressure drop in the fairing will not exceed 3.5 kPa/s. A representative pressure drop profile inside the fairing during flight is shown in Figure 3.3.1-1.

The archimedes volume of the SC to be taken into account for the venting analysis will be provided by the Customer.

Figure 3.3.1-1: Nominal Payload Compartment Internal Pressure Change During Ascent



Time (s)	Pressure (kPa)	
	Atmosphere	Inside Fairing
0	100.11	100.11
10	97.64	98.37
20	89.63	90.92
30	76.32	78.38
40	59.42	62.92
50	41.54	45.47
60	25.76	29.56
70	14	18.51
80	6.9	11.35
90	3.12	6.95
100	1.31	4.25
110	0.53	2.6
120	0.21	1.59

3.4 MECHANICAL LOADS

The SC is subject to various types of mechanical loads due to transportation and handling during the launch campaign, as well as due to the various flight events following lift-off. These mechanical loads are maximum expected environments at the SC interface. Mission peculiar updates to these environments may be further specified in the SC/LV Interface Control Document (ICD). In this case, the ICD levels supersede the PMPG values and are applicable only to the specific mission defined.

The PMPG environments are divided into separate loading types: quasi-static loads, sine and random vibration loads, acoustic loads, and shock loads. Operating (maximum expected) environments for SC ground processing and flight are presented in the sections below. These maximum expected environments do not include safety factors typically employed to determine actual environmental requirements, such as qualification or proto-flight levels during static or dynamic tests. Requirements for various kinds of testing are presented in Section 3.4.5.

3.4.1 Quasi-Static Loads at the SC Separation Plane

The operating loads at the SC separation plane are specified using quasi-static accelerations and are determined using the following relations:

$$N_{axial} = m_{SC} \times a_{axial}$$
$$Q_{shear} = m_{SC} \times a_{lateral}$$
$$M_{bend} = m_{SC} \times a_{lateral} \times L_{CG}$$

where:

N_{axial} is the axial force,
Q_{shear} is the lateral shear force,
M_{bend} is the bending moment,
m_{SC} is the maximum possible SC mass for a given operation,
L_{CG} is the distance from the separation plane to the SC CG for a suitable SC position,
a_{axial} is the axial quasi - static acceleration,
$a_{lateral}$ is the lateral quasi - static acceleration.

For the SC primary structure, the equivalent linear loads along the LV interface serve as the LV compatibility criterion. These loads consider the combined action of longitudinal force and bending moment. The equivalent linear load is calculated using the following relation:

$$q = \frac{N_{axial} \pm 4M_{bend}}{\pi \cdot D}$$

where:

q is the equivalent linear load,
N_{axial} is the axial force,
M_{bend} is the bending moment,
D is the diameter of the interface ring.

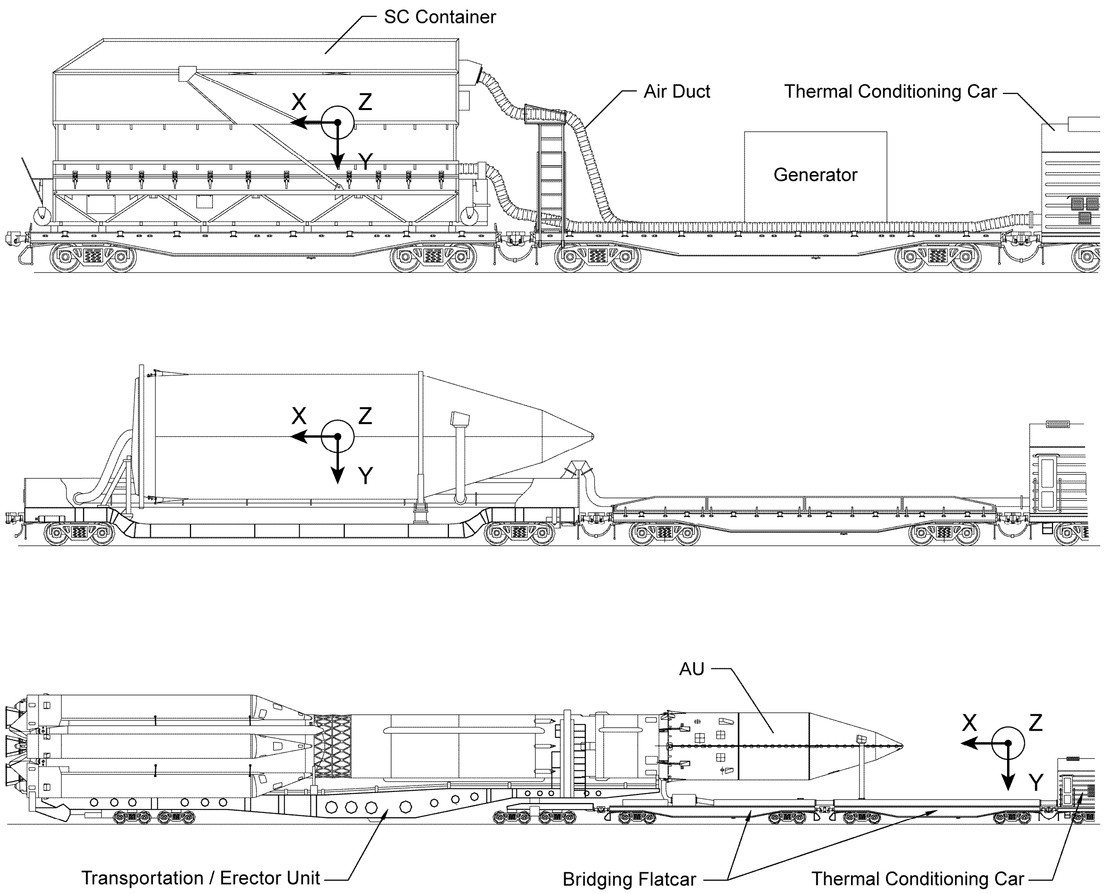
The interface between the SC and LV shall withstand an equivalent linear load that corresponds to all combinations of quasi-static accelerations, with an appropriate safety factor.

In compiling a test program for a SC/LV interface static environment, the non-uniformity of linear load distribution along the circumference of the interface ring must be considered. If the SC/LV interface is modeled by one six-degree node in the SC dynamic model, then the developer of the SC dynamic mode shall calculate the non-uniformity factor with due regard for the flexibility of the LV adapter system. When the interface is modeled with several nodes (i.e., the interface is statically indeterminate), the non-uniformity factor is calculated on the basis of coupled dynamic models of the SC and LV (or LV adapter system).

3.4.1.1 Ground Operations Environment

SC ground operations include handling operations and operations related to SC transportation, both locally in a container and as part of the AU and integrated launch vehicle as shown in Figure 3.4.1.1-1.

Figure 3.4.1.1-1: SC Transportation in the Manufacturer's SC Container or in a KhSC Container, AU Transportation, and Proton-M LV Transportation



Quasi-static accelerations in the transport unit reference frame, which are used to determine the operating environment in the SC separation plane during ground operations, are shown in Table 3.4.1.1-1.

Quasi-static accelerations act simultaneously along the X, Y, and Z axes. Quasi-static accelerations along the Y axis include the acceleration of gravity (1g) in all cases.

Table 3.4.1.1-1: Quasi-Static SC Accelerations During Transportation and Handling Operations

Operations	Quasi-Static Accelerations (g)		
	X-axis	Y-axis	Z-axis
Standalone SC transport in its transport container (a, b, d)	± 1.00	1.00 ± 1.00	± 0.40
SC transportation as part of the AU (a, d)	± 0.50	1.00 ± 0.50	± 0.40
SC transportation as part of the integrated LV (a, d)	± 0.40	1.00 ± 0.30	± 0.15
Handling operations with the SC and with the container containing the SC (c, e)	0.15	1.00 ± 0.50	-

Notes:

a) During transportation, the employed reference frame is linked to the axes of the transportation unit (Fig. 3.4.1.1-1). Specifically:

- The X axis coincides with the direction of motion
- The Y axis coincides with the direction of the force of gravity
- The Z axis completes a right-handed coordinate system

b) The SC is not loaded with propellant. The container is mounted in such a way that its principal dimension is directed along the direction of motion.

c) The following reference frame is used for handling operations

-The Y axis coincides with the direction of the force of gravity

-The X axis is directed in any transverse direction

d) $a_{axial} = a_x ; a_{lateral} = \sqrt{a_y^2 + a_z^2}$

e) $a_{axiall} = a_x$; $a_{lateral} = a_y$

3.4.1.2 Flight Environments

Loads act on a SC in flight, attaining maximum values in the lateral direction during LV lift-off and in the axial direction during first stage separation.

Quasi-static accelerations for determining the operating environment along the SC separation plane during flight are shown in graphical and tabular form in Figure 3.4.1.2-1 and Table 3.4.1.2-1.

In a conservative assessment of the environment, it is assumed that quasi-static accelerations in the longitudinal and lateral directions act simultaneously (i.e., in the worst case).

The environment shown is the most probable and is refined on the basis of a Coupled Loads Analysis (CLA) using a combined dynamic model of the SC and LV.

The maximum limit equivalent linear load obtained from the CLA should not exceed the maximum equivalent linear load corresponding to all combinations of quasi-static accelerations (Fig. 3.4.1.2-1).

Figure 3.4.1.2-1: Limit Quasi-Static Accelerations on the SC During Flight

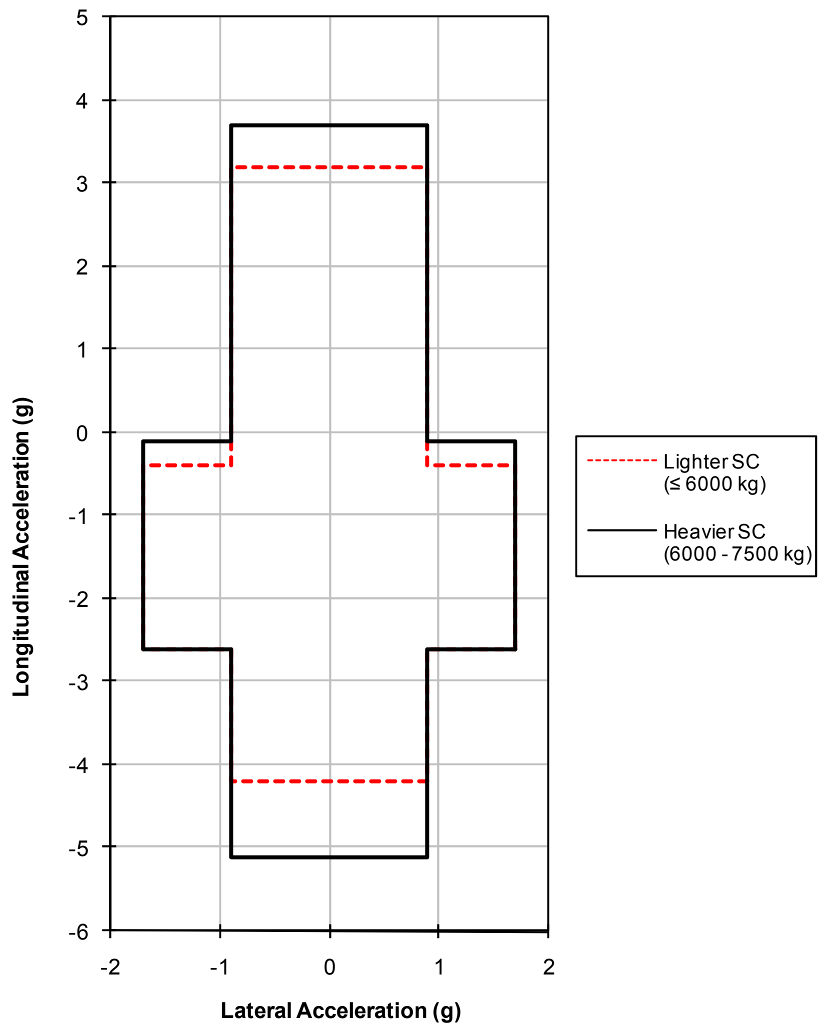


Table 3.4.1.2-1: Limit Quasi-Static Accelerations on the SC During Flight

Design Case	**Quasi-Static Accelerations (g)**				
	a_{axial}*				$a_{lateral}$
	m_{SC} **≤ 6000 kg**		**6000 kg ≤** m_{SC} **≤ 7500 kg**		
	max	min	max	min	
Lift-off	-0.4	-2.60	-0.10	-2.60	± 1.70
Maximum dynamic pressure, ($\bar{q}_{max}$)	-2.20				± 1.30
Stage 1/2 separation	3.2	-4.2	3.70	-5.10	± 0.90
Stage 2/3 separation	-0.30	-3.00	-0.30	-3.00	± 0.30
Stage 3/4 separation	-0.30	-2.80	-0.30	-2.80	± 0.30

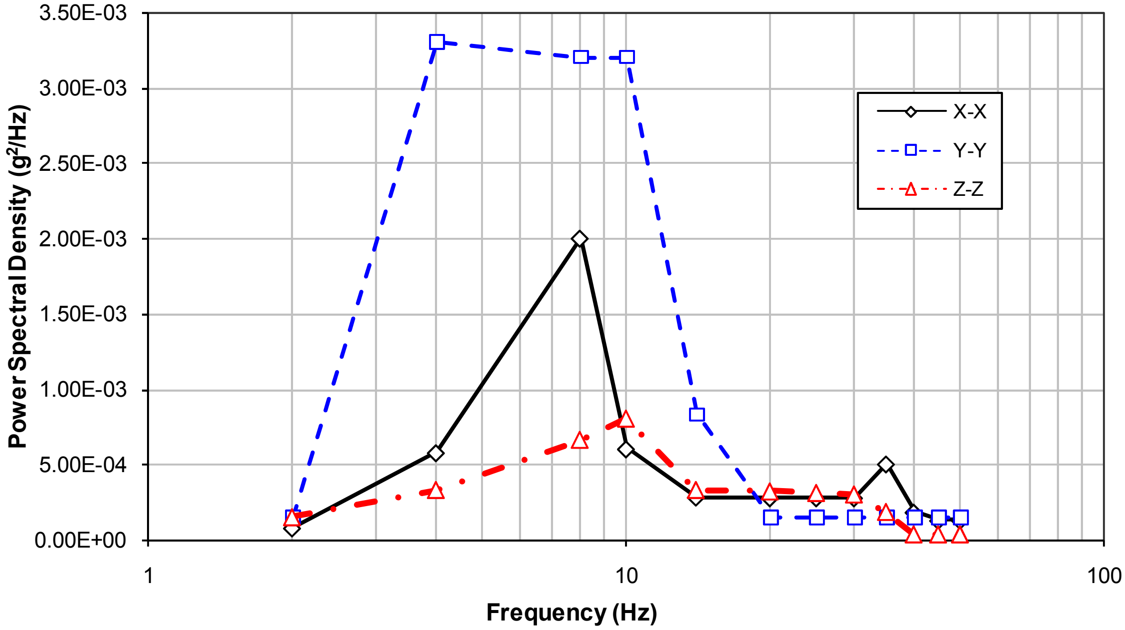
* "+" denotes tension; "-" denotes compression

3.4.2 Sine and Random Vibration Loads

3.4.2.1 Random Vibrations During Ground Operations

During ground transportation rail transport, the SC is exposed to random vibrations. The random vibration levels for different transport configurations are shown in Figures 3.4.2.1-1 and 3.4.2.1-2. These levels may be considered maximum limit load environments, based on a statistical limit of 99% probability. The duration that is specified is not the actual time of transport, but is an equivalent duration of exposure to maximum load, to which all existing transportation vibration levels are reduced given a log–normal distribution.

Figure 3.4.2.1-1: Random Vibration Levels-Ground Transportation by Rail, SC in Container and SC Attached to AU



Frequency (Hz)	PSD (g^2/Hz)		
	X-X	Y-Y	Z-Z
2	0.000075	0.000150	0.000150
4	0.000575	0.003300	0.000330
8	0.002000	0.003200	0.000660
10	0.000600	0.003200	0.000800
14	0.000280	0.000833	0.000330
20	0.000275	0.000150	0.000320
25	0.000275	0.000150	0.000310
30	0.000275	0.000150	0.000300
35	0.000500	0.000150	0.000185
40	0.000180	0.000150	0.000037
45	0.000125	0.000150	0.000037
50	0.000125	0.000150	0.000037
Duration (minutes)	*	*	*

Notes:

The X-axis is oriented in the direction of movement.

The Y-axis is directed vertically, parallel to the gravity field.

The Z-axis completes a right-handed coordinate system.

- The transportation velocity is less than or equal to 15 km/hr (SC in container) or 5 km/hr (as part of AU from Building 92A-50)

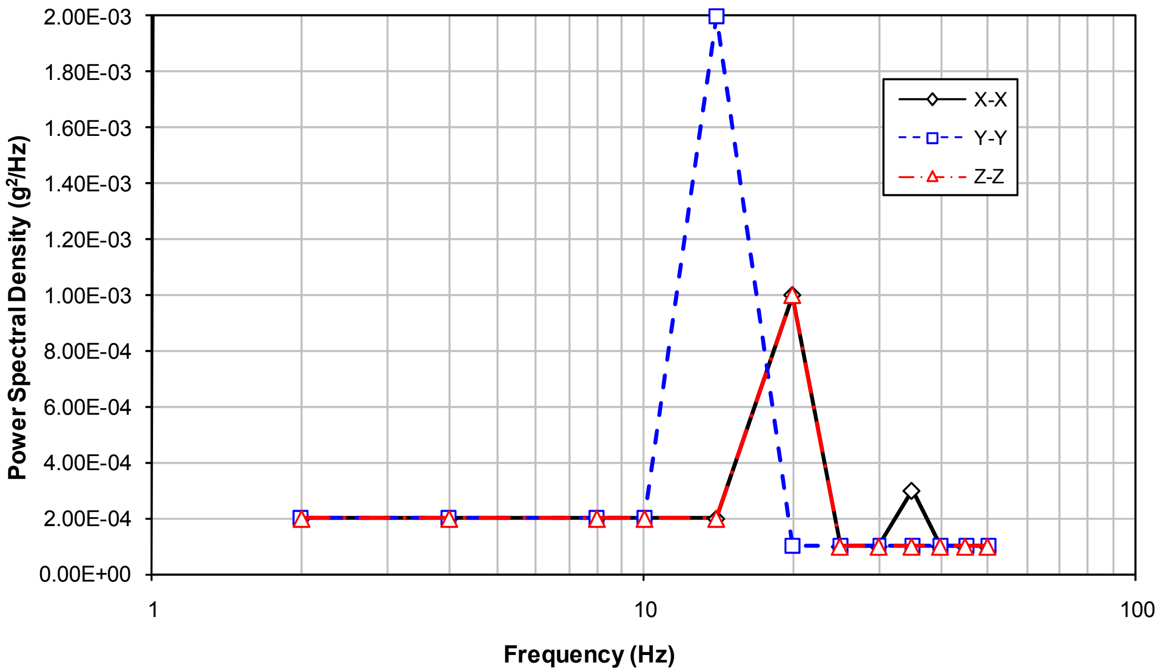
- The random vibration values shown are those at the base of the container when the SC is transported by itself, and those at the SC/adapter interface for transportation as part of the AU.

* Durations are as follows:

SC and container transport from Yubileiny to Building 92A-50 in 60 minutes.

AU transport from Hall 101 to Hall 111 of Building 92A-50 in 5 minutes.

Figure 3.4.2.1-2: Random Vibration Levels - ILV Ground Transportation by Rail



Frequency (Hz)	PSD (g^2/Hz)		
	X-X	Y-Y	Z-Z
2	0.0002	0.0002	0.0002
4	0.0002	0.0002	0.0002
8	0.0002	0.0002	0.0002
10	0.0002	0.0002	0.0002
14	0.0002	0.0020	0.0002
20	0.0010	0.0001	0.0010
25	0.0001	0.0001	0.0001
30	0.0001	0.0001	0.0001
35	0.0003	0.0001	0.0001
40	0.0001	0.0001	0.0001
45	0.0001	0.0001	0.0001
50	0.0001	0.0001	0.0001
Duration (minutes)	10	10	10

Notes:
The X-axis is oriented in the direction of movement.
The Y-axis is directed vertically, parallel to the gravity field.
The Z-axis completes a right-handed coordinate system.
Transportation velocity < 5 km/hr.
The random vibration values shown are those at the SC/PLA interface.

3.4.2.2 Equivalent Sinusoidal Environments During Flight

At launch, when the propellant valves of the first stage engines are opened, reactive forces act on the liquid propellant in the tanks (for approximately 0.1 sec) causing LV longitudinal oscillations on the elastic pad supports. Prevailing oscillation frequencies are approximately 4 Hz with amplitudes of 0.3 g.

The engines operate at a preliminary thrust level that remains constant for approximately 1.6 sec. During this period, the LV experiences flexible bending oscillations brought about by uneven thrust among the six engines and unequal off-loading of the pad supports. The prevailing frequencies are 5 to 7 Hz.

Longitudinal flexible body oscillations appear simultaneously with frequencies ranging from 5 to 15 Hz. They are magnified as the engines are throttled up to full thrust within 0.5 sec as the LV leaves the pad.

During first stage flight, lateral dynamic loads are generated by wind gusts superimposed on steady-state wind loads generated by the jet stream. LV longitudinal flexible oscillations are produced at 10 to 12 Hz by the natural random pulsation of the engine thrust. There is no pogo phenomenon. The maximum value of these oscillations based on telemetry measurements is $\pm$ 0.35 g.

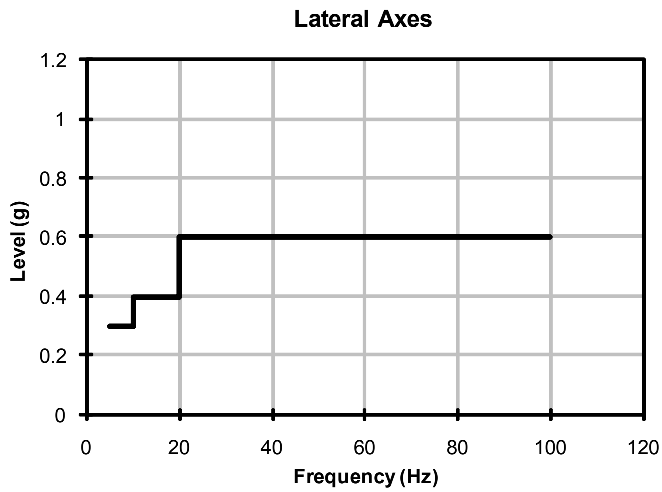
From 0.5 to 0.6 seconds before first stage cutoff, the four second stage engines start up and gain preliminary thrust. Because of the uneven thrust of the four engines, lateral reaction forces are generated, causing lateral flexible oscillations of the LV body. These oscillations are influenced additionally by the first stage engines reacting to control system commands. The first stage cutoff is characterized by an abrupt decay from 90% to 20% within 0.03 sec, which causes significant flexible longitudinal oscillations of the LV second stage, driven by the preliminary thrust of its own engines. The oscillations are additionally magnified due to the increase in thrust to 100%. These oscillations damp out within about 3 seconds.

Dynamic loads occurring during the propulsive events following first/second stage separation are enveloped by the preceding events.

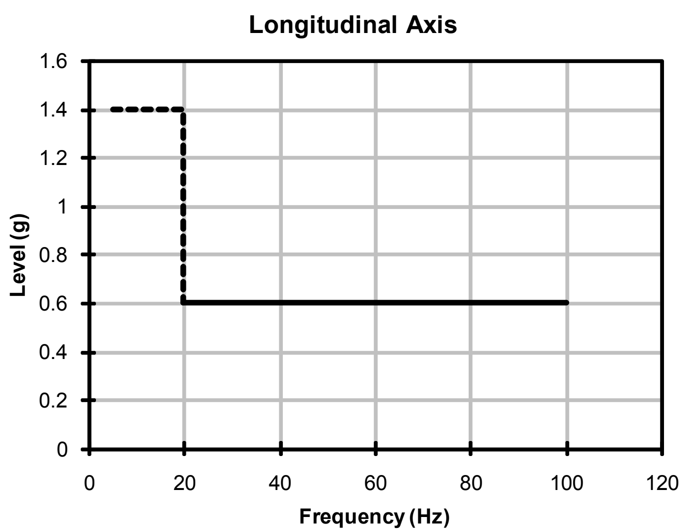
The above dynamic load environment can be represented by the quasi-sinusoidal vibration environment applied at the SC/LV interface plane shown in Figure 3.4.2.2-1. This can be considered a flight limit load environment.

It must be noted that response of SC primary structure at frequencies significantly lower than the frequency of the fundamental longitudinal mode of the SC will be equivalent to the static load applied. Since the minimum frequency of the SC longitudinal mode is required to be at least 25 Hz (see Section 3.4.1.1), the response of primary structure to longitudinal (i.e., thrust axis) excitations below 15 Hz shall be considered to be quasi-static in nature. Such loading will then be qualified from static testing results. The user should consider the worst-case combination of QSL in accordance with Figure 3.4.1.2-1.

Figure 3.4.2.2-1: Equivalent Sine Levels at SC Interface - Flight Environment



Frequency (Hz)		Level (g)
5	10	0.3
10	20	0.4
20	100	0.6



Frequency (Hz)		Level (g)
5	20	1.4*
20	100	0.6

*If it can be demonstrated, by test or test configuration analysis, that there are NO secondary structure resonances below 20 Hz and that peak responses of primary and secondary structure can be attained at frequencies greater than 20 Hz, then testing below 20 Hz can be eliminated (thrust axis only). However, it is recommended that testing from 5 Hz to 20 Hz, at a level of at least 1.0 g, be performed to provide workmanship quality demonstration.

3.4.3 Acoustic Loads

The launch acoustic loads arise from acoustic sound waves generated by the supersonic jets from the first stage engine nozzles being diverted by the launch pad and flame deflectors. At transonic velocity and maximum aerodynamic drag, acoustic loads are caused by aerodynamic pressure pulsation effects on the PLF surface. The peak acoustic loads occur for a period no longer than 5 seconds at lift-off. Peak acoustic load characteristics normalized to the threshold pressure of 20 μPa are shown in Figure 3.4.3-1. These levels should be taken as the 95/50 statistical levels, taking into account Proton Breeze M launch history to date.

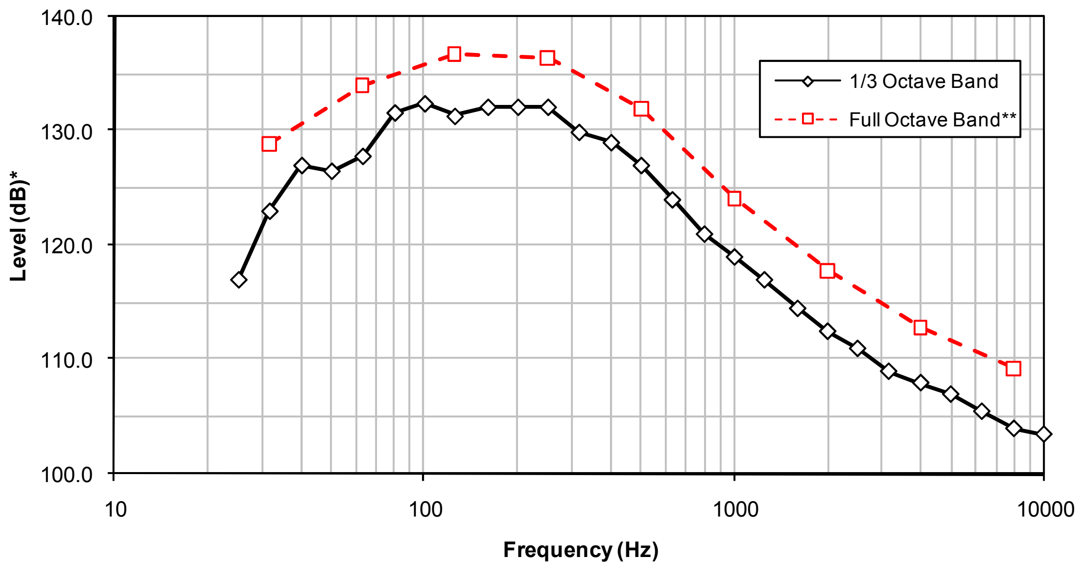
3.4.4 Shock Loads

Shock loads act on the SC during firing of pyro charges during fairing jettison, Proton LV staging, jettisoning of the Breeze M auxiliary propellant tanks, SC separation from the Proton integrated launch vehicle, etc. The maximum shock load levels occur during SC separation from the adapter, and depend on the type of separation system, as well as the tension of the clampband or the bolts for a 4 hard-point interface.

Figure 3.4.4-1 and Table 3.4.4-1 present the shock spectrum values in the 100 to 10,000 Hz frequency range for an adapter system with 937 mm, 1194 mm, and 1666 mm diameter interfaces, equipped with a clampband separation system, as well as for an adapter system with a 1664 mm diameter, 4 hard point interface. A description of various adapter/clampband systems is given in Section 4.1.5. The clampband tension for different types of clampbands varies between 30 kN and 56 kN. The shock loads in Figure 3.4.4-1 are specified for a plane located 25 mm to 120 mm from the SC separation plane, on the SC side.

The specified loads shown are based on local tests by the adapter system manufacturers (specifically, RUAG, CASA, and KhSC), and have been confirmed by shock load measurements during fitchecks of standard SC.

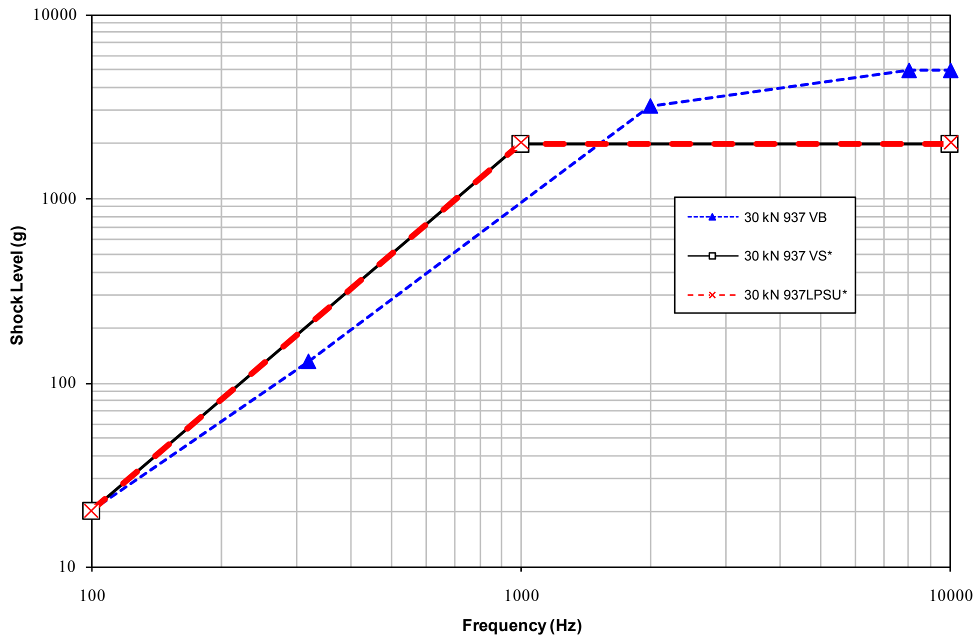
Figure 3.4.3-1: Limit Acoustic Environment



*Acoustic environments are defined with respect to a reference level of 20 mPa.
**Testing is recommended to 1/3 octave; full octave data are provided for information purposes.

Center Frequency (Hz)	Acoustic Levels on Spacecraft (dB)*	
	1/3 Octave Band	Full Octave Band**
25	117.0	128.8
31.5	123.0	
40	127.0	
50	126.5	134.0
63	127.8	
80	131.6	
100	132.4	136.7
125	131.3	
160	132.1	
200	132.1	136.3
250	132.1	
315	129.9	
400	129.0	131.9
500	127.0	
630	124.0	
800	121.0	124.1
1000	119.0	
1250	117.0	
1600	114.5	117.7
2000	112.5	
2500	111.0	
3150	109.0	112.8
4000	108.0	
5000	107.0	
6300	105.5	109.2
8000	104.0	
10000	103.5	
OASPL	**141.5**	**141.5**

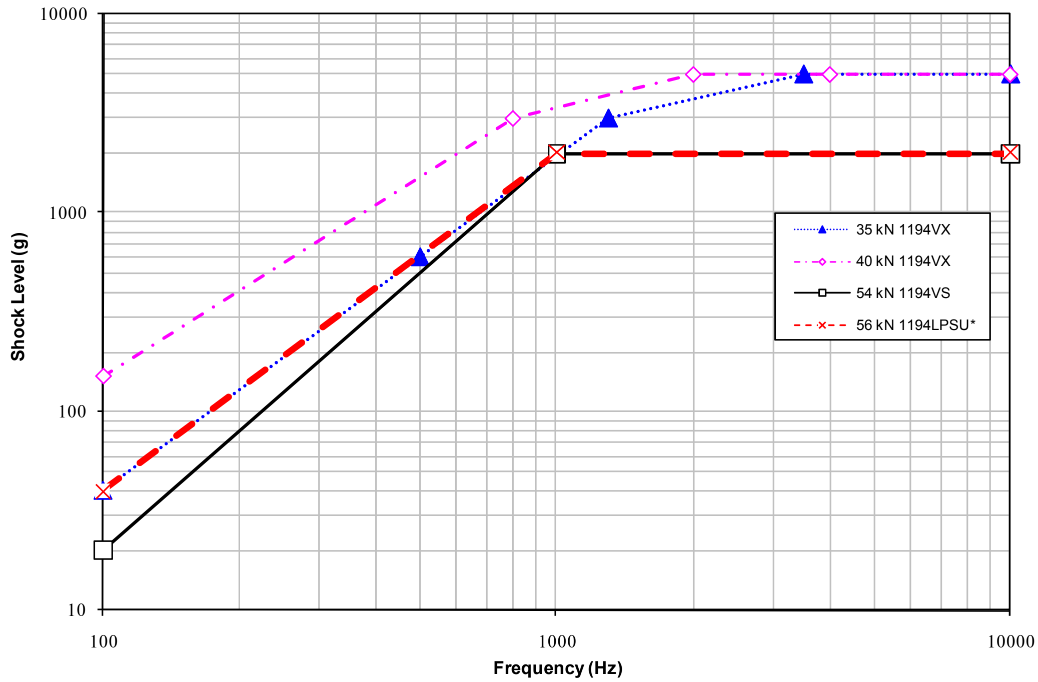
Figure 3.4.4-1a: Shock Load Spectra During SC Separation



* These data are preliminary and will be updated after testing.

Frequency (Hz)	Separation System Shock Level (g)		
	30 kN 937 VB	30 kN 937 VS*	30 kN 937LPSU*
100	20	20	20
320	130	-	-
500	-	-	-
600	-	-	-
800	-	-	-
900	-	-	-
1000	-	2000	2000
1300	-	-	-
1330	-	-	-
1500	-	-	-
2000	3200	-	-
2200	-	-	-
3000	-	-	-
3500	-	-	-
4000	-	-	-
6000	-	-	-
8000	5000	-	-
9000	-	-	-
10000	-	2000	2000

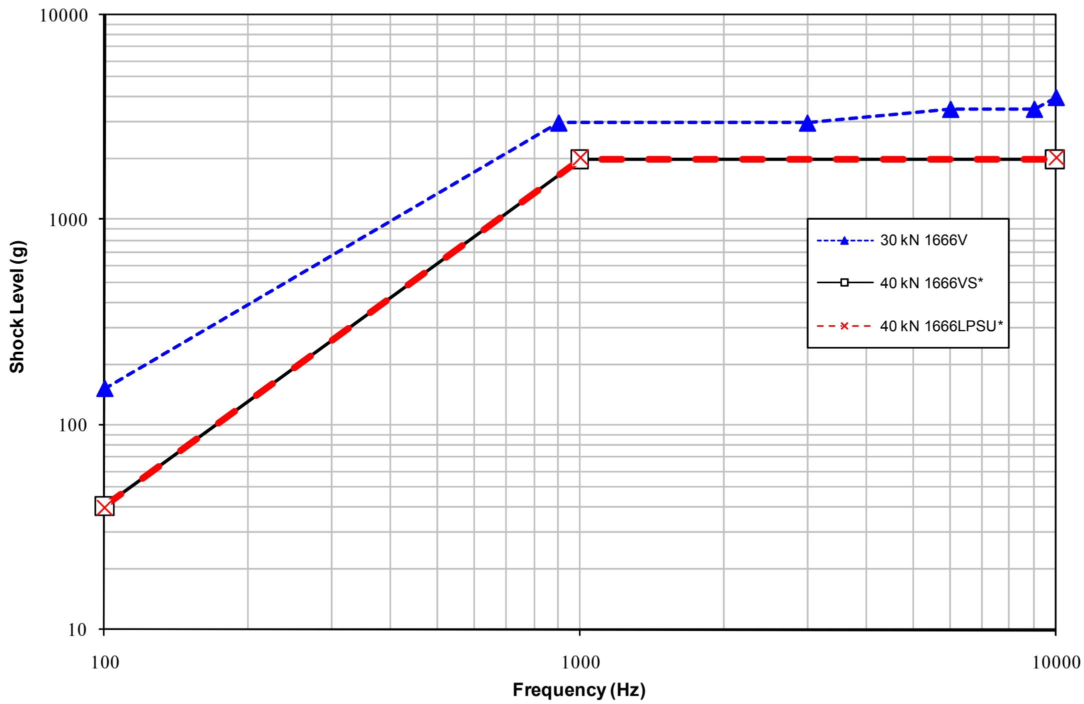
Figure 3.4.4-1b: Shock Load Spectra During SC Separation



*These data are preliminary and will be updated after testing.

Frequency (Hz)	Separation System Shock Level (g)			
	35 kN 1194VX	40 kN 1194VX	54 kN 1194VS	56 kN 1194LPSU*
100	40	150	20	40
320	-	-	-	-
500	600	-	-	-
600	-	-	-	-
800	-	3000	-	-
900	-	-	-	-
1000	-	-	2000	2000
1300	3000	-	-	-
1330	-	-	-	-
1500	-	-	-	-
2000	-	5000	-	-
2200	-	-	-	-
3000	-	-	-	-
3500	5000	-	-	-
4000	-	5000	-	-
6000	-	-	-	-
8000	-	-	-	-
9000	-	-	-	-
10000	5000	5000	2000	2000

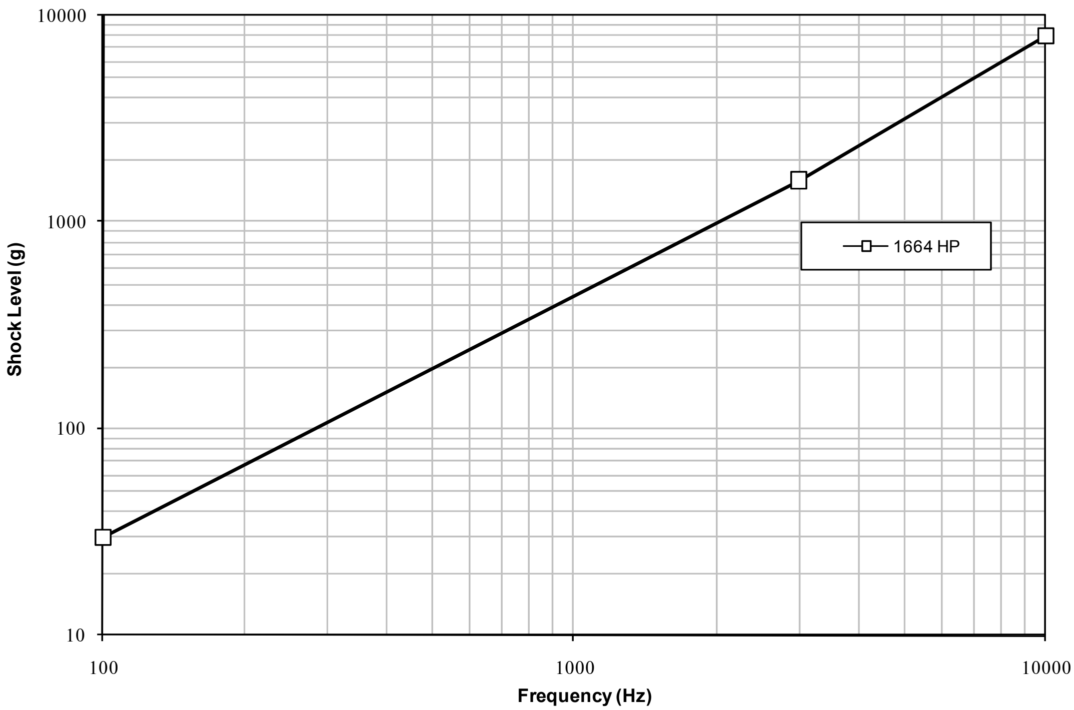
Figure 3.4.4-1c: Shock Load Spectra During SC Separation



* These data are preliminary and will be updated after testing.

Frequency (Hz)	Separation System Shock Level (g)		
	30 kN 1666V	40 kN 1666VS*	40 kN 1666LPSU*
100	150	40	40
320	-	-	-
500	-	-	-
600	-	-	-
800	-	-	-
900	3000	-	-
1000	-	2000	2000
1300	-	-	-
1330	-	-	-
1500	-	-	-
2000	-	-	-
2200	-	-	-
3000	3000	-	-
3500	-	-	-
4000	-	-	-
6000	3500	-	-
8000	-	-	-
9000	3500	-	-
10000	4000	2000	2000

Figure 3.4.4-1d: Shock Load Spectra During SC Separation



Frequency (Hz)	Separation System Shock Level (g)
	160 kN 1664 HP
100	30
320	-
500	-
600	-
800	-
900	-
1000	-
1300	-
1330	-
1500	-
2000	-
2200	-
3000	1600
3500	-
4000	-
6000	-
8000	-
9000	-
10000	8000

Table 3.4.4-1: Shock Load Spectra During SC Separation

Frequency (Hz)	Accelerations Above the SC Separation Plane (g)										
	937 VB Band tension 30 kN	**937 VS*** Band tension 30 kN	**937LPSU*** Band tension 30 kN	**1194VX** Band tension 35 kN	**1194VX** Band tension 40 kN	**1194VS** Band tension 54 kN	**1194LPSU*** Band tension 56 kN	**1666V** Band tension 30 kN	**1666VS*** Band tension 40 kN	**1666LPSU*** Band tension 40 kN	**813MDTB10** Bolt tension 160 kN
100	20	20	20	40	150	20	40	150	40	40	30
320	130	-	-			-	-	-	-	-	-
500	-	-	-	600		-	-	-	-	-	-
600	-	-	-			-	-	-	-	-	-
800	-	-	-		3000	-	-	-	-	-	-
900	-	-	-			-	-	3000	-	-	-
1000	-	2000	2000			2000	2000	-	2000	2000	-
1300	-	-	-	3000		-	-	-	-	-	-
1330	-	-	-			-	-	-	-	-	-
1500	-	-	-			-	-	-	-	-	-
2000	3200	-	-		5000	-	-	-	-	-	-
2200	-	-	-			-	-	-	-	-	-
3000	-	-	-			-	-	3000	-	-	1600
3500	-	-	-	5000		-	-	-	-	-	-
4000	-	-	-		5000	-	-	-	-	-	-
6000	-	-	-			-	-	3500	-	-	-
8000	5000	-	-			-	-	-	-	-	-
9000	-	-	-			-	-	3500	-	-	-
10000	-	2000	2000	5000	5000	2000	2000	4000	2000	2000	8000

Note: * These data are preliminary and will be updated after testing.

3.4.5 Environmental Test Requirements

The SC environmental test program is intended to verify that the SC is capable of withstanding the maximum expected environments defined in Section 3.4, with due regard to applied safety factors.

Static testing of the primary structure is required as a qualification of the structure for flight for first-of-a-kind SC. Demonstration of the SC secondary structures ability to withstand dynamic loads induced by flight events and ground transportation is required for qualification and acceptance of the SC design. Testing is required for hardware that does not have a design margin of safety greater than 2.0 with respect to the maximum expected environment.

Test levels are defined as follows:

- Qualification Level Test - Qualification level test is performed on structural test articles that will not be used for flight. This test is used to support early development or verification of preliminary design of new SC hardware.

- Proto-Qualification Level Test - Proto-qualification level test is performed on flight hardware for verification of final design and is generally used for first-of-a-kind SC.

- Acceptance Level Test - Acceptance level test is performed as workmanship verification for flight hardware and is generally used for follow-on SC that have already been qualified.

The test level is determined by the SC classification: follow-on or first-of-a-kind. The definitions of these SC classifications are as follows:

- First-Of-A-Kind SC - First-of-a-kind SC include all SC bus platforms that have not been qualified to Proton ground and flight environments. SC that have flown on the Proton with a bus structure that has been modified in such a manner as to affect critical SC modal responses are considered first-of-a-kind.

- Follow-On SC - Previously qualified SC configurations that have demonstrated margins consistent with the levels defined in this document are classified as follow-on missions. SC configurations that have identical primary bus structures to missions previously flown on Proton are also considered as follow-on. These SC configurations shall have no hardware modifications that affect the response of (1) SC primary modes (primary structure, bus components, tanks), and (2) major subsystem assemblies (i.e., antenna feeds/reflectors, solar arrays, bus panels). Secondary hardware that has changed from previous SC configurations may be tested at the component level provided that the interface boundary and associated inputs are representative of the system response.

In order to classify a mission as follow-on, a list of previous qualification test experience and a description of all major subassemblies shall be provided by the SC manufacturer outlining what components are new/modified. In addition, a comparison of new/old system level frequencies shall be provided to determine the extent of the hardware updates. The determination of follow-on versus first-of-a-kind shall be determined jointly by ILS and the SC Customer.

Tests levels, durations, and margins are defined as they apply to first-of-a-kind and follow-on missions. Table 3.4.5-1 outlines test requirements for both qualification and acceptance level tests for each of the loading environments.

The following paragraphs define the specific loading environment and associated test requirements in more detail.

Table 3.4.5-1: Test Requirements Summary

	Quasi-Static Loads	Sine Vibe	Random Vibe[1]	Acoustic	Shock[2]
Qualification/Protoflight (First-of-a-Kind)	X	X	X	X	X
Acceptance (Follow-on)		X		X	

1. May be demonstrated by a fatigue analysis and/or test.
2. Consistent with shock test description in Section 3.4.5.5.

3.4.5.1 Acoustic Test Requirements

For newly designed hardware, system level acoustic testing is performed at protoflight or qualification levels to qualify the SC design. The test should use a SC adapter that represents the flight adapter stiffness to avoid over constraining the LV/SC interface. Follow-on SC are also tested at the system level to verify material properties and workmanship at maximum expected flight levels.

The SC test requirements are provided in Table 3.4.5.1-1.

Table 3.4.5.1-1: Acoustic Test Requirements

Type of Test	Levels	Test Duration (seconds)
Qualification	Limit levels + 3 dB	120
Proto-Qualification	Limit levels +3 dB	60
Acceptance	Not less than operational levels, in accordance with Figure 3.4.3-1 in each band	60

The SC test shall be configured such that the average of all control microphones represents a good average of the acoustic environment around the entire SC. Levels attained shall be such that the average of all control microphones shall be greater than or equal to the levels shown in Table 3.4.5.1-1 in each band and at each moment in time during the entire test duration. As a consequence, the SC manufacturer has to set the control levels such that with test tolerances, this minimum criteria is attained.

The SC manufacturer may decide to test to single octave equivalent of the levels shown in Figure 3.4.3-1. This is possible on a mission-specific basis with specific approval from ILS.

3.4.5.2 Static Test Requirements

The static test must demonstrate the capability of the structure to withstand the worst-case combination of quasi-static loads shown in Table 3.4.1.2-1 and Figure 3.4.1.3-1 or obtained from CLA. For structure static testing, 1.1 yield safety factor and 1.25 ultimate safety factor must be assumed. For ground handling lift points, ultimate safety factor shall be 1.5 minimum.

3.4.5.3 Equivalent Sine Test Requirements

Sine vibration testing is used in conjunction with mission-specific CLA in order to show that the SC is compatible with the Proton transient vibration environment. This environment covers a frequency range from 5 to 100 Hz.

For all first-of-a-kind hardware, three-axis dynamic sine vibration testing shall be performed to qualify the SC design. Testing shall be performed at either qualification or protoflight levels. For follow-on SC, acceptance sine vibration testing shall be performed to verify workmanship at the system level. Secondary hardware, which has changed from previous SC configurations, may be tested at the component level provided that the interface boundary and associated inputs are representative of the system response.

Loading the SC primary structure with expected static environments is not a goal of the sine vibration testing. Testing of secondary structure to maximum dynamic acceleration without consideration of the quasi-static component must be demonstrated during sine vibration testing. If, during static testing, the SC primary structure has not been qualified for some expected static environment, then such a qualification may be performed during sine testing. Ground tests are considered to be capable of yielding conservative reactions (i.e., reactions with margin) as compared to flight environments. The maximum flight accelerations obtained from the CLA may be attained during sine testing underground conditions at frequencies that differ from loading frequencies in the flight configuration.

The sine test requirements are provided in Table 3.4.5.3-1.

Table 3.4.5.3-1: Sine Test Requirements

Type of Test	Levels	Test Frequency Sweep Rate (octaves/minute)
Sine sweep qualification	Sine levels in Figure 3.4.2-1 x 1.25	2
Sine sweep proto-qualification	Levels in Figure 3.4.2-1 x 1.25	4
Sine sweep acceptance	Levels in Figure 3.4.2-1	4

For thrust axis excitation between 5 and 20 Hz, if it can be demonstrated by test or test configuration analysis that there are NO secondary structure resonances and that peak responses of primary and secondary structure can be attained at frequencies greater than 20 Hz, then testing in this frequency range may be eliminated (for the thrust axis test only).

3.4.5.3.1 Notching Criteria

To prevent overloading of the hardware, sine vibration testing is performed with due regard for CLA. While an input sine vibration signal level to peak design CLA results is permitted, notching at some frequency is allowed only if there is a risk of exceeding design loads on some part of the SC structure. At those frequencies where notching of the excitation level is required, the SC finite element model must be test verified in order to assure conservative CLA predictions. The notched test level must normally ensure that the SC response is greater than the worst-case response predicted by the final CLA, multiplied by the appropriate factor of safety.

For SC secondary structure, where the load level does not attain the values predicted for the worst case, the capability of the structure to withstand these loads shall be proven in any suitable manner.

Table 3.4.5.3.1-1 shows the minimum allowable notching levels, without safety factors.

All input excitation notching levels shall be concurred by ILS and KhSC before each type of sine vibration testing.

Table 3.4.5.3.1-1: Minimum Input Signal Notching Levels (Without Safety Factor)

Test Axis	Frequency Range	
	5 Hz to 60 Hz	**60 Hz to 100 Hz**
Longitudinal axis excitation (along the thrust axis)	Sine equivalent CLA levels, except for cases where loads at low frequencies may be qualified as a quasi-static load	0.35 g
Lateral axis excitation	Sine equivalent CLA levels	0.2 g

Should it not be possible to meet the above requirement for some components due to risk of overloading the SC during test, the two following criteria shall be satisfied:

1. The component that does not attain required levels shall have demonstrated compatibility with these levels either by component test or analysis.
2. Test responses should be equal to or greater than the CLA peak (x 1.25 for qualification) for at least 70% of all measured locations.

3.4.5.3.2 Three Axis Sine Testing

The baseline sine vibration test for SC qualification for the Proton is the three-axis test. For all first-of-a-kind hardware, a three-axis dynamic sine vibration testing shall be performed to qualify the SC design. Testing performed shall be either qualification or protoflight.

For follow-on SC, sine vibration testing shall be performed to verify workmanship at the system or component level. The baseline for follow-on SC is a three-axis dynamic sine vibration test at acceptance test levels and durations.

3.4.5.3.3 Single Axis Sine Testing

For a SC bus that has been three-axes tested previously, it is sometimes preferable for SC manufacturers to utilize a single axis sine vibration test. In lieu of a three-axis dynamic sine vibration test, a single axis test (thrust axis) may be used for acceptance testing if the SC manufacturer submits a waiver to ILS. This waiver must demonstrate that the SC meets certain criteria. The SC manufacturer shall request a waiver for a single axis test to ILS no less than three weeks before testing. This waiver shall include the following:

1. **Verification of the SC Finite Element Model (FEM) by test**. The FEM shall have been test-correlated during product line modal or sine testing. FEMs of secondary hardware not included in first-of-a-kind testing shall be verified at the component level. The SC manufacturer shall provide a matrix in the format provided in Section 3.4.6 that substantiates the SC FEM is validated based on test.

2. **Demonstration of adequate coupling between the thrust and lateral axes**. At least 70% of the peak lateral responses must be realized during the single axis testing to demonstrate adequate coupling between the thrust and lateral axes. This criterion must be verified by analysis based on a CLA simulation of single and three-axis testing. Components that are not exposed to acceptance levels shall be tested for workmanship at the component level. The SC manufacturer shall provide a matrix, as specified in Section 3.4.6, to verify that minimum peak lateral responses are realized.

3. **Verification of new or changed hardware.** System or component level testing shall verify any hardware not included in first-of-a-kind testing and not tested to protoflight levels during single axis testing. The SCC shall identify all hardware that is new or changed from previous three-axis testing. The new and changed hardware shall be tabulated and the method of verification documented according to the format specified in Section 3.4.6.

The SCC shall review the single axis test results and confirm that the analysis and test criteria provided have been met. If the test criteria are not met, the SCC may be required to revert to a three-axis sine vibration test or submit a waiver.

3.4.5.4 Random Vibration

The Proton random environment is based upon ground transportation loads, which the SC will be exposed to during transport from the payload processing facility to the launch site. This environment is defined as an equivalent random environment from a frequency range of 2 to 50 Hz. A fatigue analysis and/or some combination of a system level test and component level test may be used to demonstrate compatibility with this environment.

3.4.5.5 Shock Test Requirements

A shock test using the adapter clamp system with the flight adapter and SC is required at the SCC's facility in conjunction with a mechanical/electrical fitcheck for first-of-a-kind SC and the first follow-on SC in a series. For this test, the flight band will be tensioned, as per the manufacturer's separation system test procedure. Shock levels will be measured at a location 30 to 120 mm above the SC separation plane by the SCC in a minimum of two locations: 1) in proximity to the clampband firing device, and 2) approximately 90° from this location. SC measurements shall be provided to ILS by the SCC following the test to validate conformance with the shock level specification provided in this PMPG.

For subsequent SC, a shock test is not required, providing that there are no significant differences in the SC equipment configuration in proximity to the separation clampband interface.

3.4.6 SC Environmental Test Plan and Report

A SC environmental test plan will be provided to ILS prior to the start of the test program. This test plan will outline the test philosophy as it applies to both new and previously qualified SC hardware. The test plan shall include the following: rationale for acceptance versus protoflight test approach, identification of component versus system level tests, test level durations and acceptable test tolerances.

An environmental test report shall be provided to ILS no later than one month following the completion of the SC environmental test program. This report summarizes the static, sine vibration, acoustics, random vibration and shock testing performed and documents the adequacy of the SC for the Proton environmental loads. This report shall include for each environment: 1) a description of the test setup, 2) as-tested input levels and test durations and 3) a description of any anomalies that may have occurred during the test. Input test levels shall be compared to the environmental levels defined in Section 3.4. For the sine test, test levels shall also be compared to the final CLA results.

Table 3.4.6-1 provides an example of the report format required to verify that coupled loads results have been enveloped by the combination of sine, static and component level testing. Notching inputs should also be summarized as shown in Table 3.4.6-2. The test report shall also include a comparison of the SC FEM predictions and test responses, as shown in the example in Table 3.4.6-3. Frequency response comparisons should also be provided for primary SC modes and major subsystem assemblies (i.e., antenna feeds/reflectors, solar arrays, bus panels).

Table 3.4.6-1: Typical Format For Post-Test Report And CLA Summary Matrix

NASTRAN Grid ID	Accel No/Axis	Description of Accelerometer	Max Predicted CLA (g)	Allowable Design (g)	X-Axis Test		Y-Axis Test		Z-Axis Test		Overall Max Response (g)	Design Allow/ Max Response	Max Response/CLA	CLA Value Covered By				Unit Qual Level (g)	Unit Qual Freq (Hz)
					Max Response (g)	Max Response Freq (Hz)	Max Response (g)	Max Response Freq (Hz)	Max Response (g)	Max Response Freq (Hz)				Sine Test	Static Test	Unit Test	Design		
10001	100-X	N Solar Array	18	30	25	38	10	42	4	42	25	1.20	1.39	1				25	5-100
10002	101-Y	N Solar Array	17	25	5	38	16	38	5	38	16	1.56	0.94			1		20	5-100
10003	102-Z	N Solar Array	6	10	3	42	3	42	3.5	42	3.5	2.86	0.58		1			10	5-100
10004	103-X	S Solar Array	18	30	25	38	11	42	4	42	25	1.20	1.39	1				25	5-100
10005	104-Y	S Solar Array	17	25	5	38	16	38	5	38	16	1.56	0.94			1		20	5-100
10006	105-Z	S Solar Array	6	10	3	42	3	42	3.5	42	3.5	2.86	0.58		1			10	5-100
													Total	2	2	2	0		
													%	0.33	0.33	0.33	0.00		

Table 3.4.6-2: Typical Post-Test Report Sine Vibration Notching Summary

X-Axis Test Notch				Y-Axis Test Notch				Z-Axis Test Notch			
Freq (Hz)	Accel No.	Description/Comp	Peak (g)	Freq (Hz)	Accel No.	Description/ Comp	Peak (g)	Freq (Hz)	Accel No.	Description/ Comp	Peak (g)
12-14	201-X	Base Bending Input	0.2	12-14	301-Y	Base Bending Input	0.2	37-39	501-Z	Tank Strut	5.5
36-40	100-X	Solar Array	25	35-39	75-Y	East Reflector	17				

Table 3.4.6-3: Typical Summary Verification of SC FEM Based on Sine Vibration Test

System Description	System Mode Description	Test Freq (Hz)	Analysis Freq (Hz)	Ratio Test to Analysis	Test Reference	New Hardware
Primary Structure	1st Bending-X/Y	14.10	14.30	0.99	System level sine testing	no
Primary Structure	2nd Bending-X/Y	25.70	25.90	0.99	System level sine testing	no
Primary Structure	1st Axial	40.00	42.00	0.95	System level sine testing	no
Subsystem	Antenna Feed	42.70	44.10	0.97	Component	yes
Component	Reaction Wheel	38.00	40.00	0.95	System level sine testing	no
Component	SADM	39.00	37.00	1.05	System level sine testing	no
Subsystem	Reflectors	38.50	38.00	1.01	System level sine testing	no
Subsystem	Solar Arrays	40.10	44.10	0.91	System level sine testing	no
Component	Batteries	42.80	40.10	1.07	Component	yes

3.5 ELECTROMAGNETIC COMPATIBILITY (EMC)

Electromagnetic Interference (EMI) emissions and susceptibility of the SC and the LV shall be tested separately (individually) to the extent necessary to ensure EMC of the fully integrated system.

3.5.1 EMI Safety Factor (EMISF) and Reserve Margin (EMIRM)

The integrated SC/LV system shall be designed to provide EMC with a minimum of 20 dB EMIRM (versus dc no-fire threshold) for ordnance circuits, and 6 dB EMIRM for the entire system.

3.5.2 Radiated Emissions

The LV intentional emissions are described in Table 3.5.2-1. The SC needs to be compatible with these emissions.

The LV generated and launch base spurious EMI sources shall not exceed the levels of Figure 3.5.2-1 in a plane 1 meter below and parallel to the SC/LV interface plane.

3.5.3 Radiated Susceptibility

LV and launch pad susceptibility limits for Proton M/Breeze M are provided in Figure 3.5.3-1. The antenna locations for the Breeze M are shown in Figure 3.5.3-2.

The LV/Breeze M susceptibility limits have been defined at 1 meter from the SC outer surface for the adapter/SC interface plane.

SC-generated and spurious EMI sources should not exceed the levels of Figure 3.5.3-1 in a plane 1 meter below and parallel to the SC/LV interface plane. Intentional radiation above these values must be verified by an EMC analysis performed by ILS (see Section 3.5.4).

3.5.4 EMC of RF Transmitters and Receivers

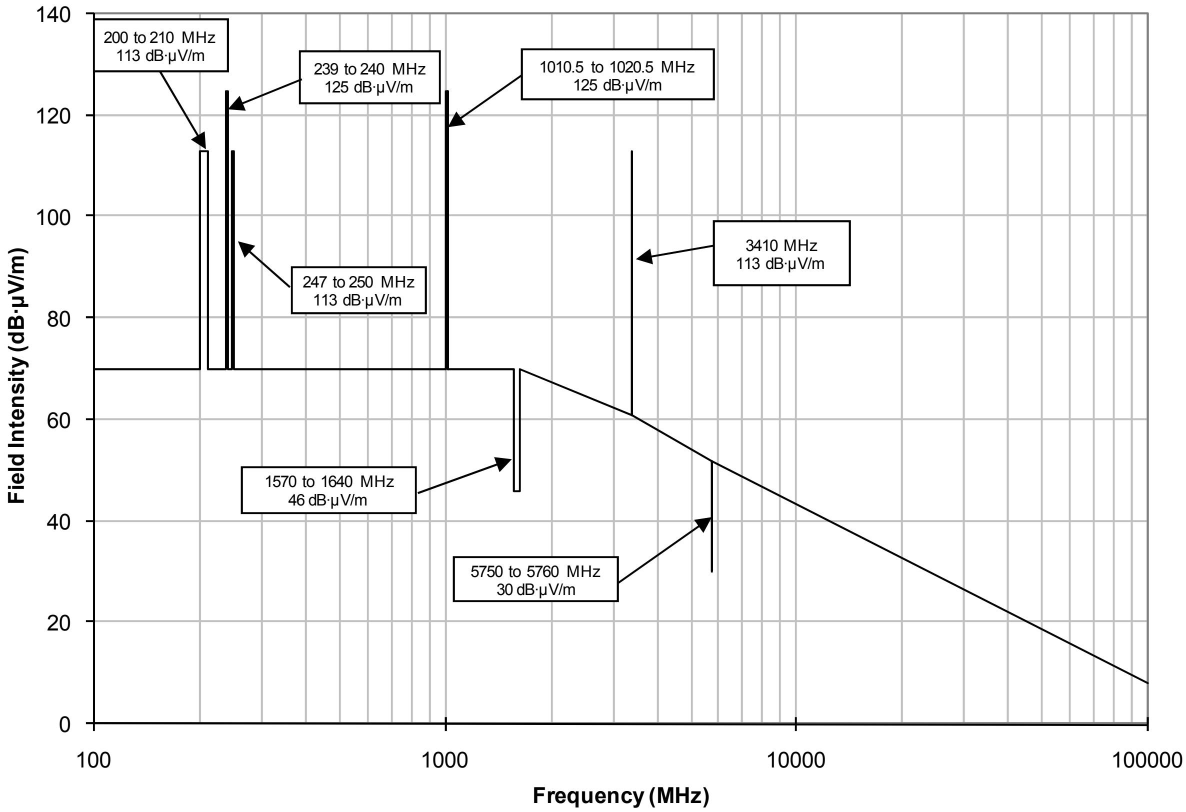
The RF characteristics of all SC transmitters and receivers shall be provided by the Customer according to the data requirements of Appendix C. ILS will perform an EMC analysis for each mission to verify the compatibility of SC, LV and launch pad transmitters and receivers.

Table 3.5.2-1: Proton M/Breeze M RF Equipment Characteristics

Description	Transmitters						Receivers	
	TLM Stage 1	TLM Stage 1	TLM Stage 2	TLM Stage 3	TLM Breeze M	Trajectory Control	Glonass/ GPS	Trajectory Control
1. Carrier frequency (MHz)	200.74; 203.3	247.3 - 249.86	239.3	1010.5; 1013.06	1018.5; 1020.5	3410	1570 - 1640	5754.9
2. 3 dB bandwidth (MHz)	0.6	0.6	0.6	0.6	0.563 0.340	0.066	50	40
3. Modulation type and characteristics	APM-FM	APM-FM	APM-FM	APM-FM	PCM-FM	PCM/PhM/ PSK	PCM/NPSK/PhM	PCM/PhM/ PSK
4. Transmitter output power at carrier frequency (dBW)	12.3	12.3	12.3	12.3	9.5	6		
5. Receiver sensitivity at carrier frequency (dBW)							-160	-133
6. Antenna gain coefficient (dB)	-10	-10	-10	-10	3 dB (0°), -10 dB (±75°)	2.3 dB (0°), -10 dB (±70°)	3	0 dB (0°), -12 dB (±70°)
7. Antenna type, polarization	Omni, linear				Semi-directional, linear	Semi-directional, circular	Semi-directional, circular	Semi-directional, circular
8. Operating on launch pad?	Yes	Yes	Yes	Yes	Yes	No	Yes	No
9. Operating in flight?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

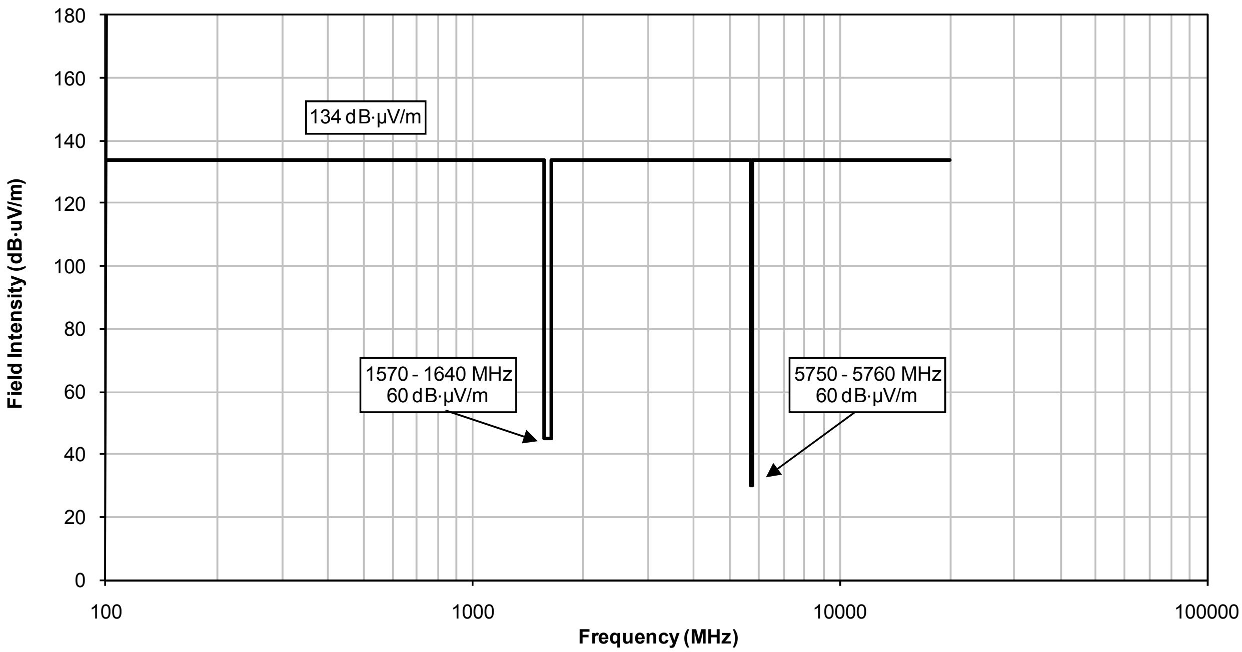
APM/FM - Amplitude Pulse Modulation/Frequency Modulation
PCM/FM - Pulse Code Modulation/Frequency Modulation
PM - Pulse Modulation
PCM/PhM/PSK - Pulse Code Modulation/Phase Modulation/Phase Shift Keying
PCM/NPSK/PhM - Pulse Code Modulation/Noise-Like Phase Shift Keying/Phase Modulation

Figure 3.5.2-1: Electric Field Intensity Levels Generated by Proton M/Breeze M Launch Equipment



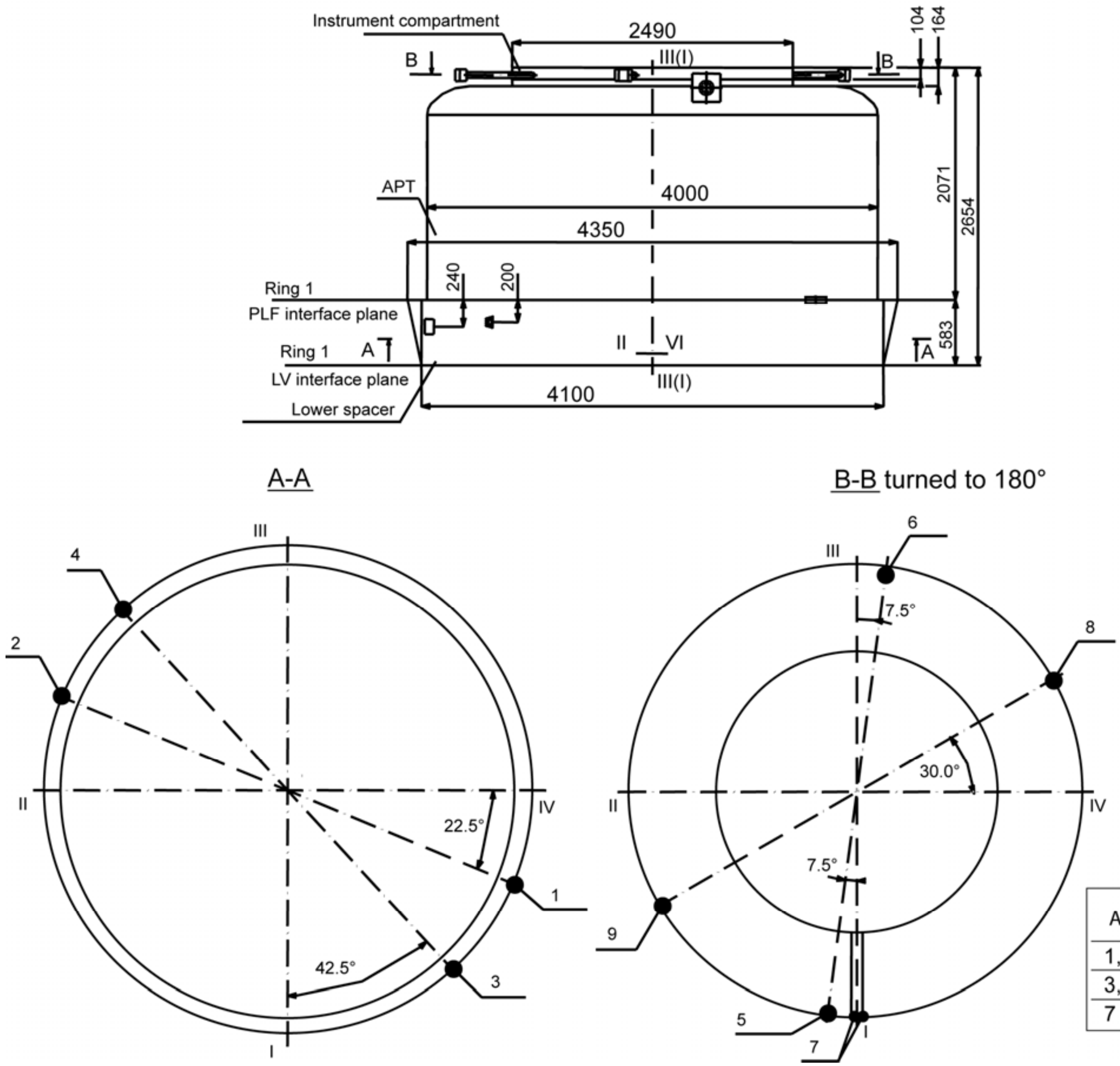
Frequency (MHz)	Field Intensity (dB·µV/m)	Bandwidth at 3 dB·µV/m
200 to 210	113	0.6
239 to 240	125	0.6
247 to 250	113	0.6
1010 to 1013	125	0.6
1018 to 1020	125	0.34
1570 to 1640	46	50
3410	113	0.066
5750 to 5760	30	40
100000	8	N/A

Figure 3.5.3-1: Proton M/Breeze M and Launch Pad Radiated Susceptibility



Frequency (MHz)	Field Intensity (dB·µV/m)
100 to 1570	134
1570 to 1640	45
1640 to 5700	134
5700 to 5800	30
5800 to 20000	134

Figure 3.5.3-2: Breeze M Antennae Locations



Antenna	System	Qty.	Frequency (MHz)
1, 2, 8, 9	GPS/Glonass	4	1570 to 1640
3, 4, 5, 6	Telemetry	4	1018.5; 1020.5
7	Tracking	1	3410.3; 5754.9

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