5 Spacecraft Environmental Conditions

This section describes the flight environment to which the spacecraft is exposed during its transport into orbit with the Rockot launcher. Accelerations occurring during ground transportation and handling are also defined in this section.

5.1 Mechanical Environment

5.1.1 General

During flight, the payload is subjected to static and dynamic loads induced by the launch vehicle. Such excitation may be of aerodynamic origin (wind, gusts, buffeting at transonic velocity), or may be due to loading induced by the propulsion systems (longitudinal acceleration, thrust build-up or tail-off transients, structure-propulsion coupling, attitude control operation, etc.).

The various types of mechanical environment experienced by the payload are described in the following paragraphs. Typical data are given for sine, random and shock environments. For different dispenser types, dedicated environments have to be defined on a case-by-case basis.

For the launch vehicle and payload coordinate system, refer to Figure 5-1.

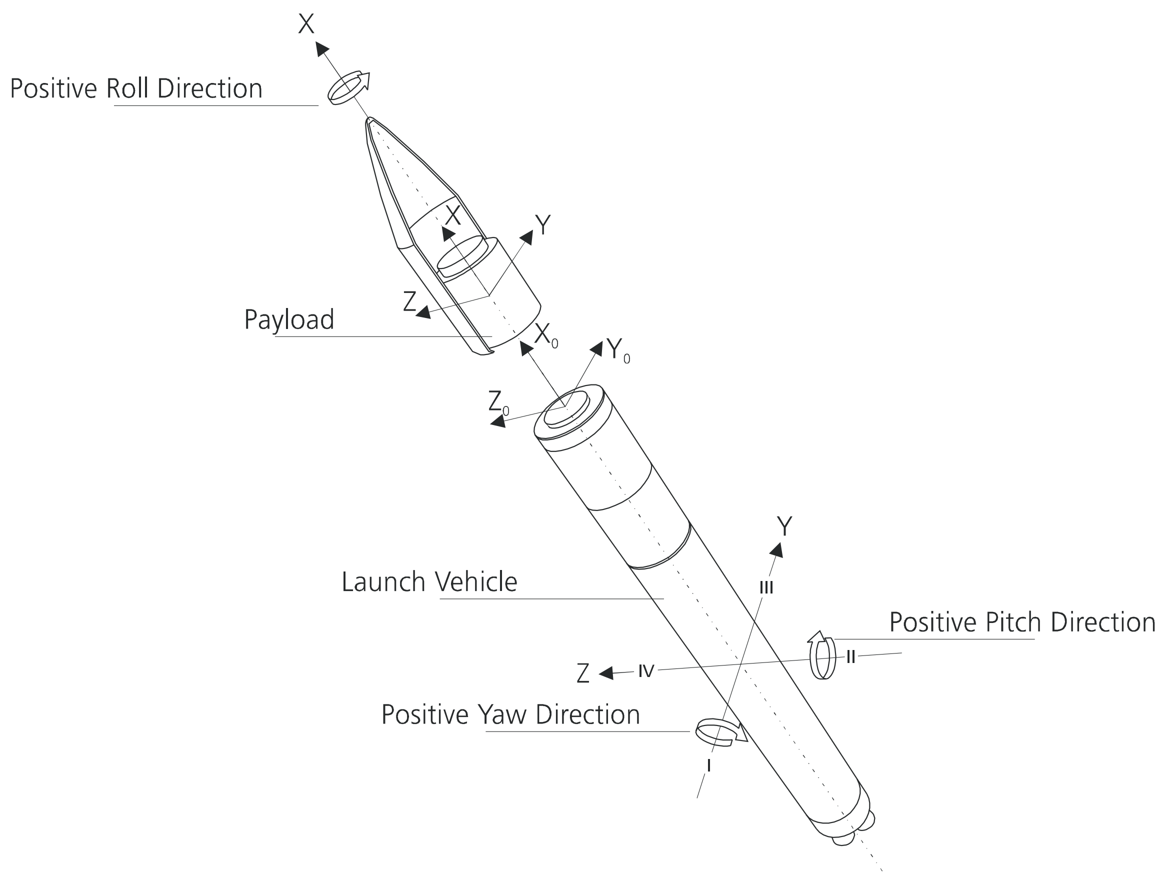
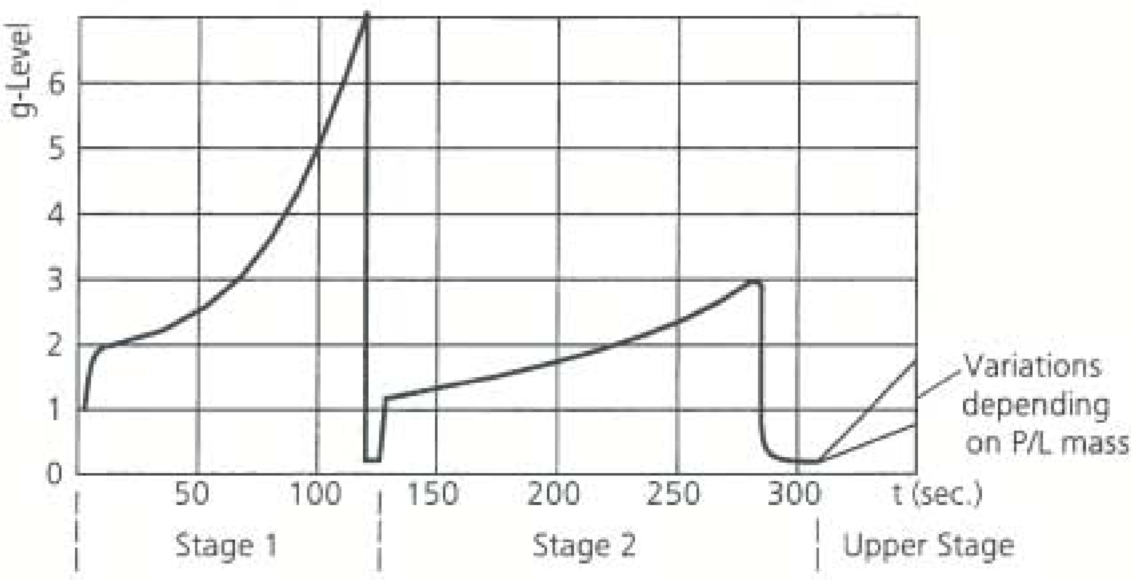


Figure 5-1: Launch Vehicle and Payload Coordinate System



**) For the definition of flight events, see Table 5.1.2-1*

Figure 5-2: Variation of Longitudinal Static Accelerations during Flight

Event [1]	**Condition**	**Acceleration** [2]				
		Longitudinal, n_x				**Lateral $n_{Y(Z)}$ Quasitatic** [3]
		Static	**Dynamic**	**Quasistatic**		
				max.	**min.**	
1	Lift-off	+ 1.8	± 1.8	+ 3.6	0	± 0.5
2	qmax	+ 2.8	0	+ 2.8	0	± 0.9
3	Max. Thrust of Stage 1	+ 7.1	± 0.9	+ 8.0	+ 6.2	± 0.5
4	Maximum g-Loads of Stage I	+ 7.2	± 0.9	+ 8.1	+ 6.3	± 0.5
5	Stage I/Stage II Separation	-	+ 8.1 -1.5	+ 8.1	-1.5	± 0.5
6	Maximum g-Loads of Stage II	+ 3.0	-	+ 3.0	+ 3.0	± 0.4
7	Flight of Upper Stage	+ 1.6	-	+ 1.6	+ 1.6	± 0.5

Note: "+": compression; "-": tension

1) See Figure 5-2

2) Acting at CoG of payload or payload cluster, respectively, in lateral (Y/Z) and longitudinal (X) directions simultaneously

3) Worst lateral direction with respect to resulting stresses / reactions to be considered for dimensioning

Table 5.1.2-1: Spacecraft Initial Design Accelerations Acting at the Spacecraft CoG (Flight Limit Load Factors)

The spacecraft coordinate system without index may be selected with the origin at the CoG of the spacecraft or in the attachment plane and with axes parallel to the launch vehicle coordinate system if the satellite is clocked orthogonally. The orbital block coordinate system with the index "O" is a useful tool for definition of the loads and performance of the CLA. Its origin lies in the *Breeze* attachment plane. The y and z axes concur with the launch vehicle stabilisation axes III and IV respectively.

5.1.2 *Quasistatic Accelerations*

During ascent, the payload will experience flight-time-dependent static accelerations as shown in Figure 5-2. Low frequency transient ("dynamic") accelerations which act simultaneously depend on the payload dynamic characteristics. Typical dynamic accelerations are included in Table 5.1.2-1 to provide a basis for initial dimensioning of the payload primary structures. These initial values are subject to modification according to coupled load analysis with a dedicated spacecraft dynamic mathematical model.

5.1.3 *Low Frequency Vibration*

The low frequency longitudinal and lateral vibration environment spectra experienced at the payload-to-adapter interface (spacecraft separation plane) are presented in Table 5.1.3-1 and Figure 5-3 respectively.

Frequency Hz	Acceleration, g	
	Longitudinal	Lateral
5 - 10	0.8	0.5
10 - 20	0.8 - 1.2	0.5
20 - 40	1.2 - 0.8	0.5
40 - 100	0.8	0.5

Table 5.1.3-1: Low Frequency Vibration Environment

5.1.4 *Acoustic Noise*

The spacecraft is exposed to an acoustic environment throughout the boost phase of flight until the vehicle is out of the atmosphere. Acoustic noise is generated by engine noise, buffeting and boundary layer noise. The level is highest at lift-off (142 dB) and in the transonic phase (135 dB) with a reference pressure of $2*10^{-5}$ Pa = 0 dB. Lift-off noise lasts approximately 5 seconds whereas the duration of the transonic period is approximately 40 seconds. These yield a fatigue equivalent noise duration of 10.3 seconds. Noise is substantially lower outside these periods. The related noise spectrum is defined in Table 5.1.4-1 and Figure 5-4. The given spectra reflect guaranteed upper limits, including worst case fill-factor for spacecraft within the payload fairing.

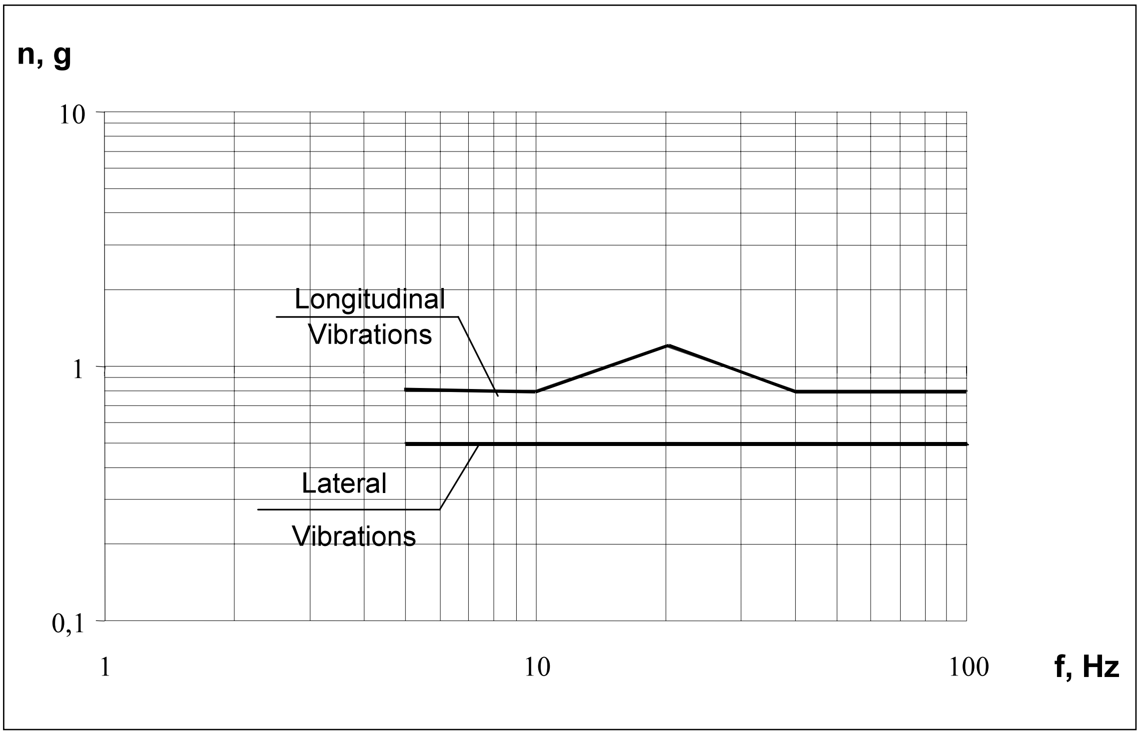


Figure 5-3: Low Frequency Vibration Environment at the Separation Plane

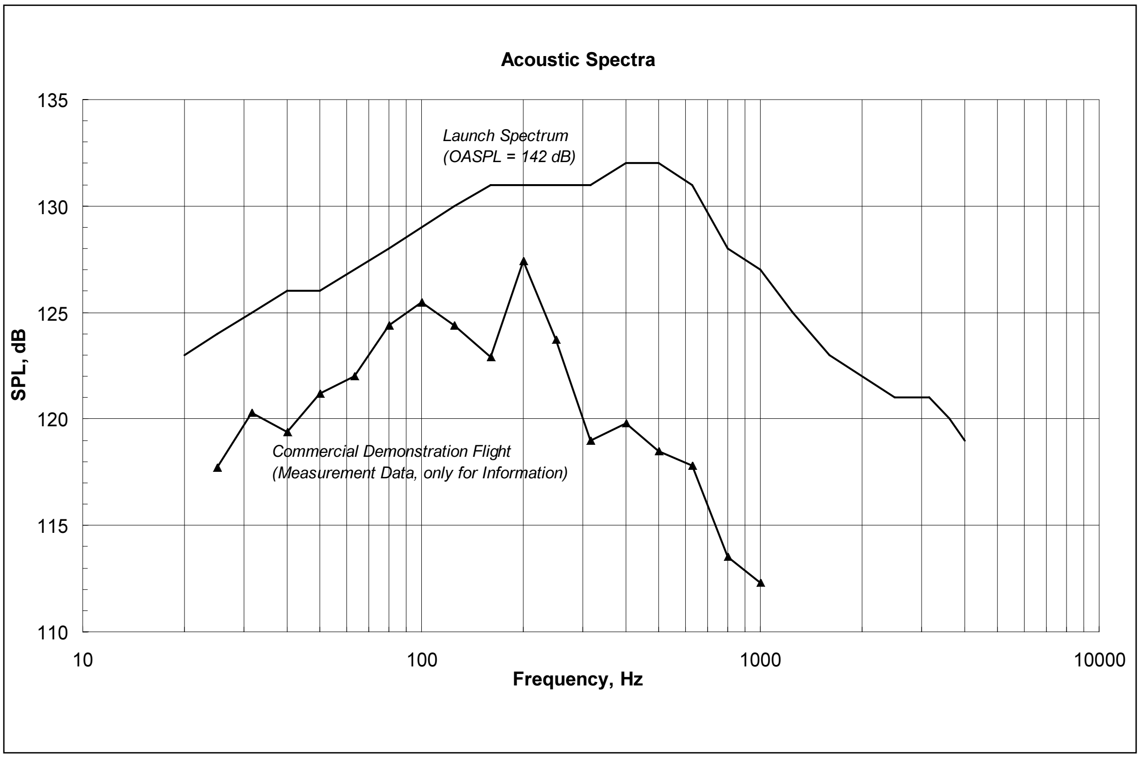


Figure 5-4: Acoustic Noise under the Fairing

Central Frequency of 1/3 Octave Range, Hz	Acoustic Noise Composition [dB]	
	Lift-off [1]	q max, M = 1 [2]
20	123	117
25	124	117
31.5	125	118
40	126	119
50	126	119
63.5	127	120
80	128	121
100	129	122
125	130	123
160	131	124
200	131	124
250	131	124
315	131	121
400	132	125
500	132	125
630	131	124
800	128	121
1000	127	120
1250	125	118
1600	123	117
2000	122	116
2500	121	116
3150	121	115
3620	120	114
4000	119	113
OSPL, dB	142	135
Approximate duration	5 sec.	40 sec.
Composite duration	10.3 sec.	

1) Corresponds to event 1 of Table 5.1.2-1

2) Corresponds to event 2 of Table 5.1.2-1

Table 5.1.4-1: Acoustic Vibrations under the Fairing during Flight

5.1.5 *Random Vibration*

Random vibration is mainly generated by the acoustic noise field under the payload fairing and is also transmitted via the launcher structure. This random vibration environment is generally the design driver for small components and structural elements of the satellite. Therefore EUROCKOT recommends to perform an acoustic test to accurately reflect the in-flight random environments experienced. Because the vibration level depends on the dynamic properties of the payload adapter structure this test should be performed with the spacecraft attached to a flight-like payload adapter (not hard mounted) to accurately represent the flight configuration. In the case of customers with small compact satellites it may be more convenient to perform a random vibration test. In this particular case, the customer is asked to contact EUROCKOT directly for definition of the appropriate random vibration test levels.

5.1.6 *Shock*

The spacecraft is subjected to a shock environment during separation of the fairing, upper stage / launch vehicle separation and payload / upper stage separation.

Table 5.1.6-1 and Figure 5-5 indicate the shock spectra at the spacecraft for fairing and payload separation events. The spacecraft is subjected to shocks, principally during its separation from the *Breeze* upper stage. The shock levels at the spacecraft separation plane are associated with the separation system selected (see Section 4.2). The levels for the proposed MLS separation system are represented by the upper curve of Figure 5-6. Typical shock levels for clamp ring / band separation systems depend primarily on their pre-tension and size. Examples of shock levels for systems supplied by SAAB-Ericsson and CASA can also be seen in the figure. For detailed information and for other sizes and pre-tensions, please contact EUROCKOT. In addition, the spacecraft is exposed to the shock environment during separation of the fairing and on the occurence of *Breeze* / second stage separation. The lower curve of the respective figure covers the fairing separation shock. *Breeze* / second stage separation shock levels are lower.

Shock loads can act along all three axes.

Frequency Hz	**Acceleration, g (SRS, Q=10)**	
	Fairing Separation *	**Payload Separation ****
100	50	100
700	640	1500
1000	1000	2400
1500	1000	4000
5000	1000	4000
10000	1000	2000

Notes: * Shock depends on the separation system: this is for the Russian MLS separation system. For other systems, please ask EUROCKOT.

** Fairing separation shock is defined at the base of the payload adapter. For taller fairing payload adapters shock at the SC to adapter interface plane will be lower.

Table. 5.1.6-1: Shock Environment

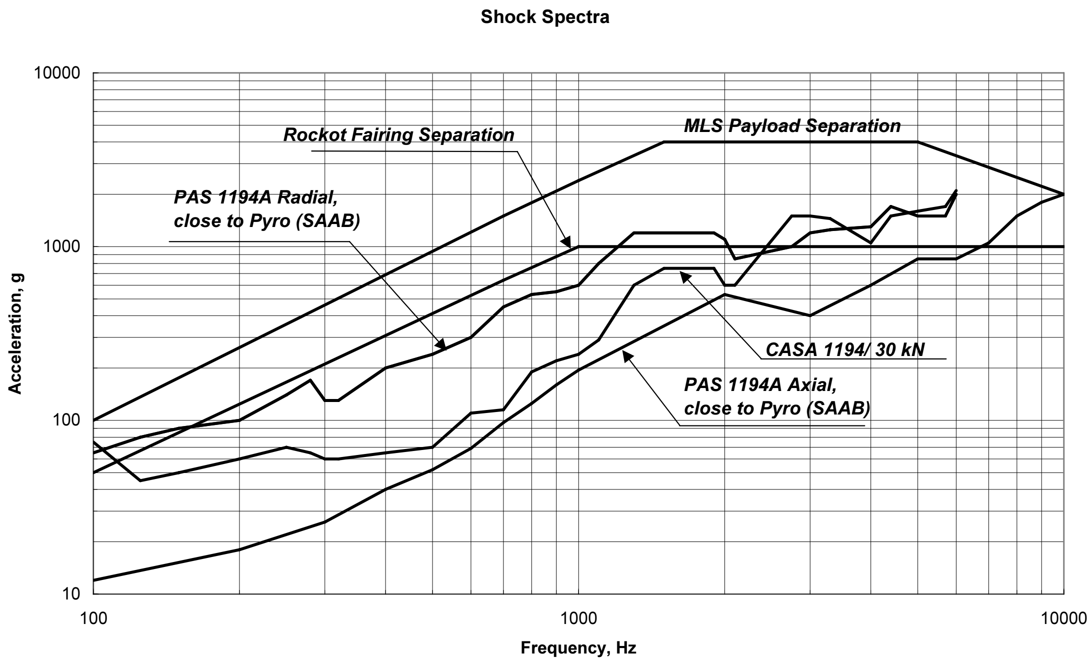


Fig. 5-5: Shock Environment

5.1.7 *Loads during Transportation and Handling*

Table 5.1.7-1 presents the maximum predicted load factors to which the payload may be subjected during the transportation and handling phase at Rockot´s launch site at Plesetsk. The right-handed coordinate system used for this table is defined with positive X-axis in the transport direction, and positive Y-axis vertical away from earth. For the simulation of all possible cases of transportation within Russia, the input loads to the transport containers are defined in Table 5.1.7-2; see for example the transportation scenario in Section 10.1.4. Table 5.1.7-3 indicates the allowable loads on the spacecraft container during independent transportation via different modes of transport. Figure 5-6 shows the layout of accelerometers during transportation, e.g. by road. Tables 5.1.7-4 and 5.1.7-5 and Figure 5-8 show the load environment during transportation by rail. Tables 5.1.7-6 and 5.1.7-7 and Figure 5-9 present the load environment during independent transportation by helicopter. Table 5.1.7-8 and Figure 5-10 show the load environment during independent transportation by road. Figure 5-7 shows the layout of accelerometers during upper composite transportation. The spacecraft loads during transportation within the upper composite are indicated in Table 5.1.7-8 and Figure 5-11.

Condition	Load Factors [g]		
	n_X 1)	n_Y 2)	n_Z 3)
Transportation	± 1.5	1 ± 0.5	± 0.3
Handling	± 0.3	1 ± 0.5	± 0.3

1) In direction of vehicle motion
2) Vertical
3) Lateral

Table 5.1.7-1: Loads during Transportation and Handling

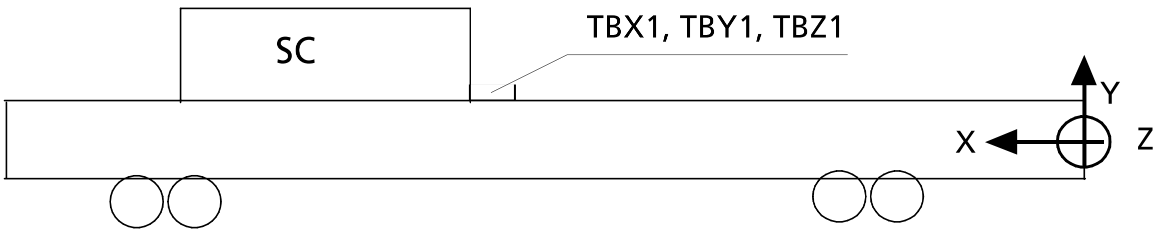


Figure 5-6: Transportation of Spacecraft in Transportation Container

Mode	Direction	Amplitude (g)	Half Period (msec)	Impulse Shape	Number of Impulse
Air	± X	3.0	100	**Half Sine**	1200
	± Y	1 ± 1.5	100		1200
	± Z	1.7	100		1200
Truck	± X	3.0	30	**Half Sine**	4000
	± Y	1 ± 1	30		4000
	± Z	0.5	30		4000
Rail	± X	2.5	30	**Half Sine**	4000
	± Y	1 ± 1	30		4000
	± Z	0.5	30		4000

Table 5.1.7-2: Dynamic Input Shock to the Spacecraft Transportation Container for Transport Simulation Tests (for all Transport Options in Russia)

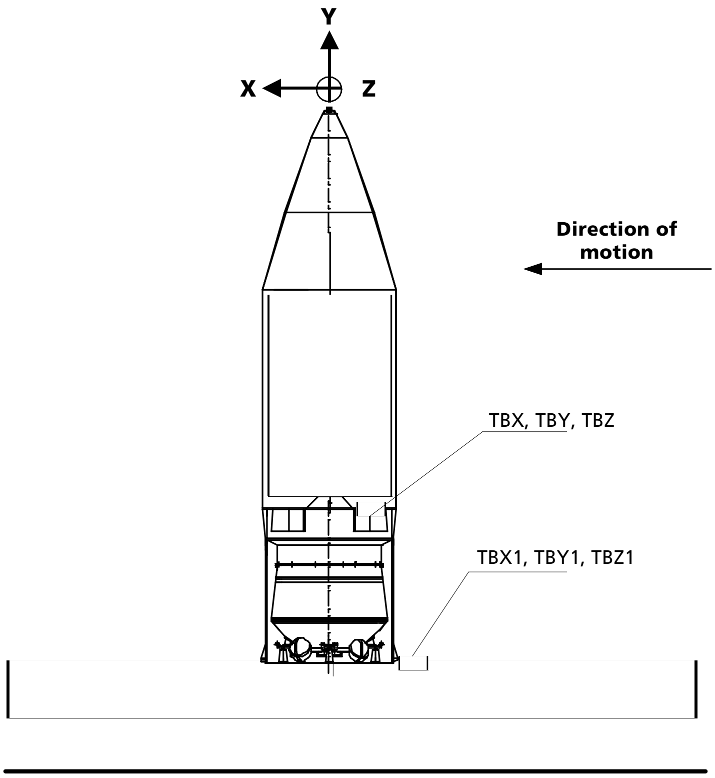


Figure 5-7: Spacecraft Transportation as Part of the Upper Composite (distance L = 7 km; velocity v = 3-5 km/h)

Transportation	Axis Direction	Amplitude, g	Time, ms	Form of Impulse
Road	±X	3.0	30	Half-sine
	±Y	2.0	30	Half-sine
	±Z	0.5	30	Half-sine
Rail	±X	2.5	30	Half-sine
	±Y	2.0	30	Half-sine
	±Z	0.5	30	Half-sine
Helicopter	±X	1.0	30	Half-sine
	±Y	1.5	30	Half-sine
	±Z	1.0	30	Half-sine
Aeroplane	±X	3.0	100	Half-sine
	±Y	2.0	100	Half-sine
	±Z	1.7	100	Half-sine

Note: One impulse only.

Table 5.1.7-3: Allowable Impact Loads at Spacecraft Container

Frequency, Hz	Axis		
	X-X	Y-Y	Z-Z
	Spectral Density 10^4 g²/Hz		
2	7.5	7.5	15
4	57.5	330	33
8	200.0	320.0	66.0
10	60.0	320.0	80.0
14	28.0	83.3	33.0
20	27.5	15.0	32.0
25	27.5	12.0	31.0
30	2.75	15.0	30.0
35	50.0	11.0	18.5
40	18.0	10.0	3.7
45	12.5	8.3	3.7
50	12.5	7.5	3.7
Time, minutes	420	420	420

Table 5.1.7-4: Maximum Random Vibration Loads During Rail Transport of Spacecraft in Shipment Container

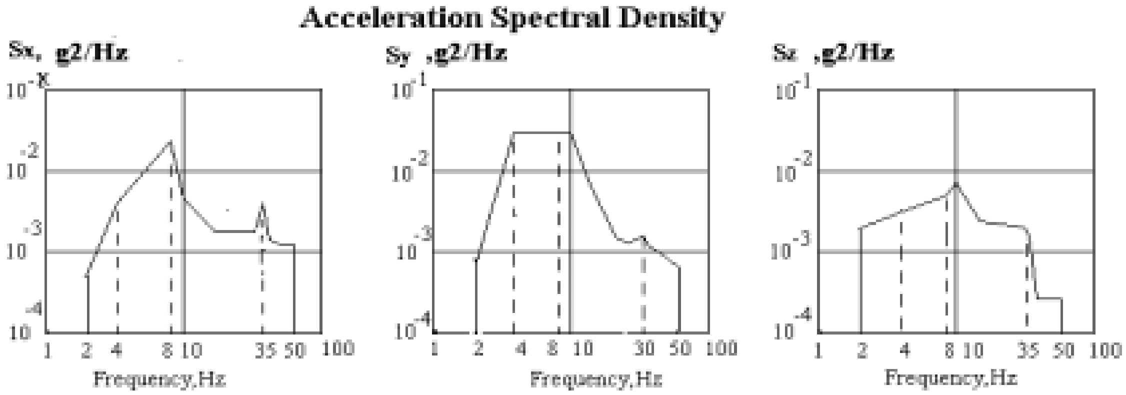


Figure 5-8: Random Vibration Spectra at Adapter/*Breeze* Interface during Transportation of the SH

Axis Direction	Maximum Amplitude of Vibration Acceleration, g	Process Duration, s	Number of Loadings
X-X	1.5	0.16-0.035	100
Y-Y	1.1		
Z-Z	0.6		

Note: Impulses are either half-sine or triangular in form.

Table 5.1.7-5: Maximum Short Time Dynamics during Independent Transportation by Rail

Frequency, Hz	Axis		
	X-X (in Motion Direction)	Y-Y (up/down)	Z-Z (in Lateral Direction)
	Spectral Density 10^5 g^2/Hz		
2-4	100	1000	100
4-10	100-1000	1000	100-1000
10-20	1000	1000	1000
20-30	1000-250	1000-20	1000-250
30-50	250-30	20	250-30
50-100	30-10	20	30-10
100-130	10-100	20-100	10-100
130-160	100	100	100
160-250	100-2.5	100-1.5	100-2.2
acting time	90	90	90

Table 5.1.7-6: Maximum Random Vibrations for Spacecraft Transportation by Helicopter from Talaga to Plesetsk; L = 280 km (long duration)

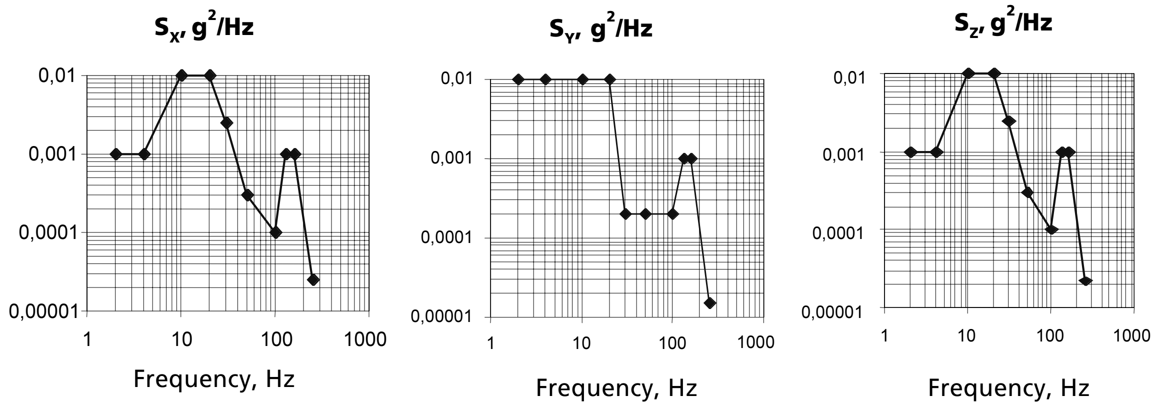


Figure 5-9: Acceleration Spectral Density for Helicopter

Frequency, Hz	Axis		
	X-X	Y-Y	Z-Z
	Loads, g		
2.2-3	0.009-0.018	0.029-0.054	0.048-0.09
7.2-9.2	0.05-0.085	0.05-0.085	0.083-0.17
13.2	0.105	0.174	-
17.6	0.144	0.32	0.45
30-500	1-1.5	1-1.5	1-1.5
Time, minutes	10	10	10

Table 5.1.7-7: Maximum Short Duration Dynamic Loads during Spacecraft Transportation by Helicopter

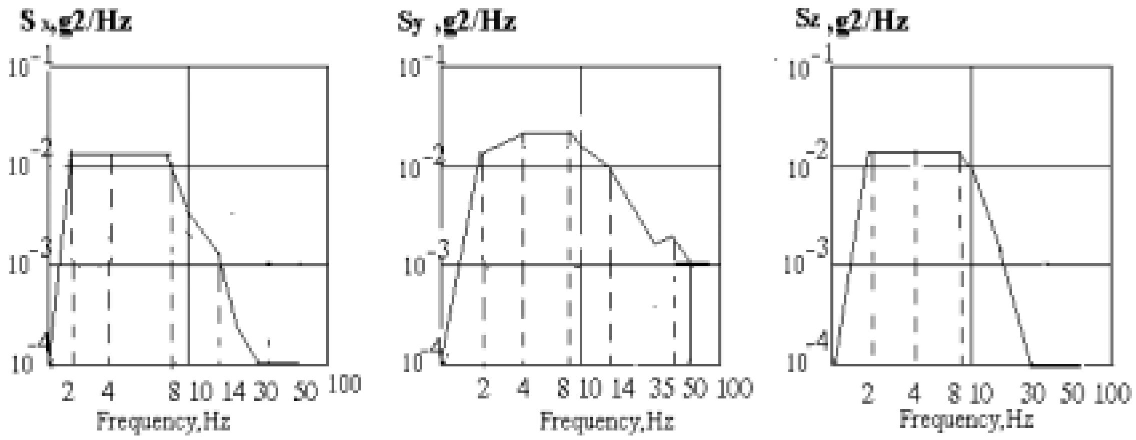


Figure 5-10: Acceleration Spectral Density for Road

Frequency, Hz	Axis		
	X-X	Y-Y	Z-Z
	Spectral Density, 10^3 g^2/Hz		
2	15	15	15
4	15	30	15
8	15	30	15
10	6.0	20	10
14	1.4	10	1.5
20	0.42	5	0.5
25	0.18	3.2	0.18
30	0.1	2.5	0.1
35	0.1	2.8	0.1
40	0.1	1.4	0.1
45	0.1	1.2	0.1
50	0.1	1.0	0.1
Time, minutes	10	10	10

Note: Spectral density values with probability of 0.997.

Table 5.1.7-8: Maximum Random Vibration Loads during Transportation by Road

Frequency, Hz	Axis		
	X-X	Y-Y	Z-Z
	Spectral Density, 10^5 g^2/Hz		
2	7.5	7.5	15.0
4	57.5	330.0	33.0
8	200.0	320.0	66.0
10	60.0	320.0	80.0
14	28.0	83.3	33.0
20	27.5	15.0	32.0
25	27.5	12.0	31.0
30	2.75	15.0	30.0
35	50.0	11.0	18.5
40	18.0	10.0	3.7
45	12.5	8.3	3.7
50	12.5	7.5	3.7
Time, min.	18	18	18

Table 5.1.7-9 Maximum Random Vibration Loads During Spacecraft Rail Transportation Within Upper Composite

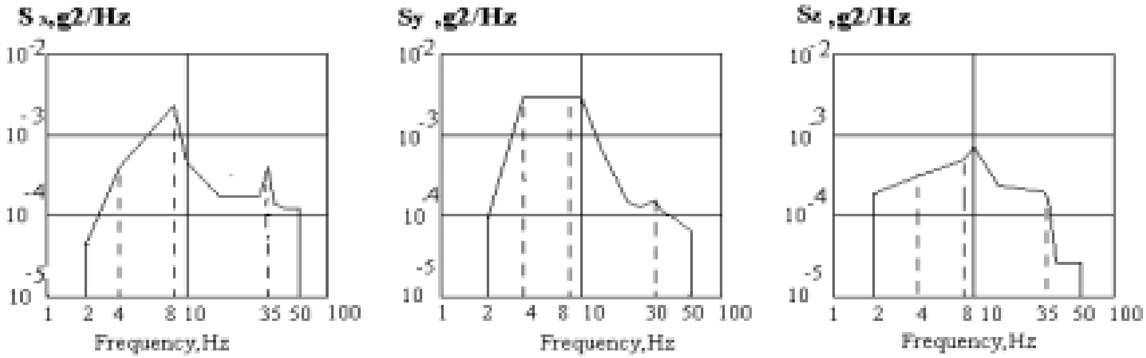


Figure 5-11: Acceleration Spectral Density for Tranportation in Upper Composite

5.2 *Thermal Environment*

This section describes the thermal environment the payload must endure during the ground and flight segments of the mission.

5.2.1 *General*

For the definition of the spacecraft thermal environment, three phases of the mission are considered:

- The spacecraft preparation phase within the preparation buildings
- When the spacecraft is encapsulated inside the fairing during transportation to the launch pad and after mating with the launch vehicle during the pre-launch phase
- The in-flight environment phase

5.2.2 *Environmental Conditions in the Preparation Building*

The payload is processed in 100,000 class clean rooms with a regulated temperature of 18 to 25 °C and a relative humidity between 30 and 60% in the Integration Facility.

5.2.3 *Pre-Launch Temperature Control within the Fairing*

After encapsulation, temperature control is provided in the following cases:

- During upper composite transportation: By passive (a thermal cover and fairing thermal insulation) and active (a thermal conditioning railcar) temperature control

- During upper composite lifting to the Service Tower for installation on the booster unit: By passive temperature control, i.e. thermal cover, fairing thermal insulation and upper composite thermal inertia
- During transport stiffening ring removal and during mounting of the transport launch container extension: By passive temperature control, i.e. fairing thermal insulation and upper composite thermal inertia
- During upper composite on-pad operations: By passive (fairing thermal insulation) and active (upper composite air conditioning system and booster unit air conditioning system) temperature control; the upper composite air conditioning will be provided up to L-5 minutes, and will resume at L+5 minutes in the case of a launch abort.

The upper composite air conditioning during transportation from the Integration Facility to the launch pad and while at the launch pad is presented in Figures 5-12 and 5-13 respectively.

The basic performance data of the thermal conditioning railcar is presented in Table 5.2.3-1.

The air temperature inside the fairing is between 10 and 25°C during active temperature control, and between 5 and 30°C when no active temperature control is provided. These ranges will be updated on the basis of thermal analysis results. The thermal analysis will be performed by means of the spacecraft thermal and geometric mathematical models to be provided by the Customer. The adapter hardware temperature, fairing inside air temperature and humidity will be measured and recorded by the ground measurement system during the upper composite transportation en route to the launch pad and during on-pad processing, as shown in Table 5.2.3-4.

A supplementary spacecraft battery air conditioning loop can be provided as an optional service.

The characteristics of the air supplied by the upper composite air conditioning system are indicated in Table 5.2.3-2. The characteristics of the air supplied by the spacecraft battery air conditioning system are shown in Table 5.2.3-3.

This system is compatible with class 100,000 cleanliness and has a main air velocity within the fairing: from 0.5 to 2 m/s.

Air conditioning is provided up to lift-off and is interrupted only for periods with durations not exceeding one hour each (with regard to the ambient temperature of the launch site, the air temperature will be adjusted prior to the interruptions, to ensure that the temperature inside the fairing will remain within the specified limits.)

Parameter	Value
Supplied air temperature, °C	10...30 (adjustable)
Temperature control accuracy, °C	± 2
Relative humidity, %	30...60
Air flow rate, m^3/h	≥4000
Air pressure head at system outlet, Pa	2000
Supplied air cleanliness, class	100,000

Table 5.2.3-1: Thermal Conditioning Car Performance Data

Parameter	Value
Supplied air temperature, °C	10...25 (adjustable)
Temperature control accuracy, °C	
Relative humidity, %	≤ 60 %
Supplied air dew point, °C	≤ - 20 max.
Air flow rate, m^3/h	4000
Air pressure head at upper composite inlet, Pa	3000
Supplied air cleanliness, Class	100,000

Table 5.2.3-2: Upper Composite Air Coinditioning System Performance Data

Parameter	Value
Supplied air temperature, °C	7…20 (adjustable)
Supplied air dew point, °C	≤ - 20 max.
Air flow rate, m^3/h	200
Positive pressure, Pa	12000
Supplied air cleanliness, class	100,000

Table 5.2.3-3: Spacecraft Battery Air Conditioning System Performance Data (Optimal Service)

Parameter	Number of sensors	Measurement Range	Measurement Accuracy
Fairing internal air temperature within ~3,000 mm of fairing separation plane	2	-10…40°C	± 0.7°C
Fairing internal air humidity within ~3,000 mm of fairing separation plane	2	30…60 %	± 3%
Adapter hardware temperature at 1/2 adapter height	2	0…40°C	± 0.7°C

Table 5.2.3-4: Measured Parameters

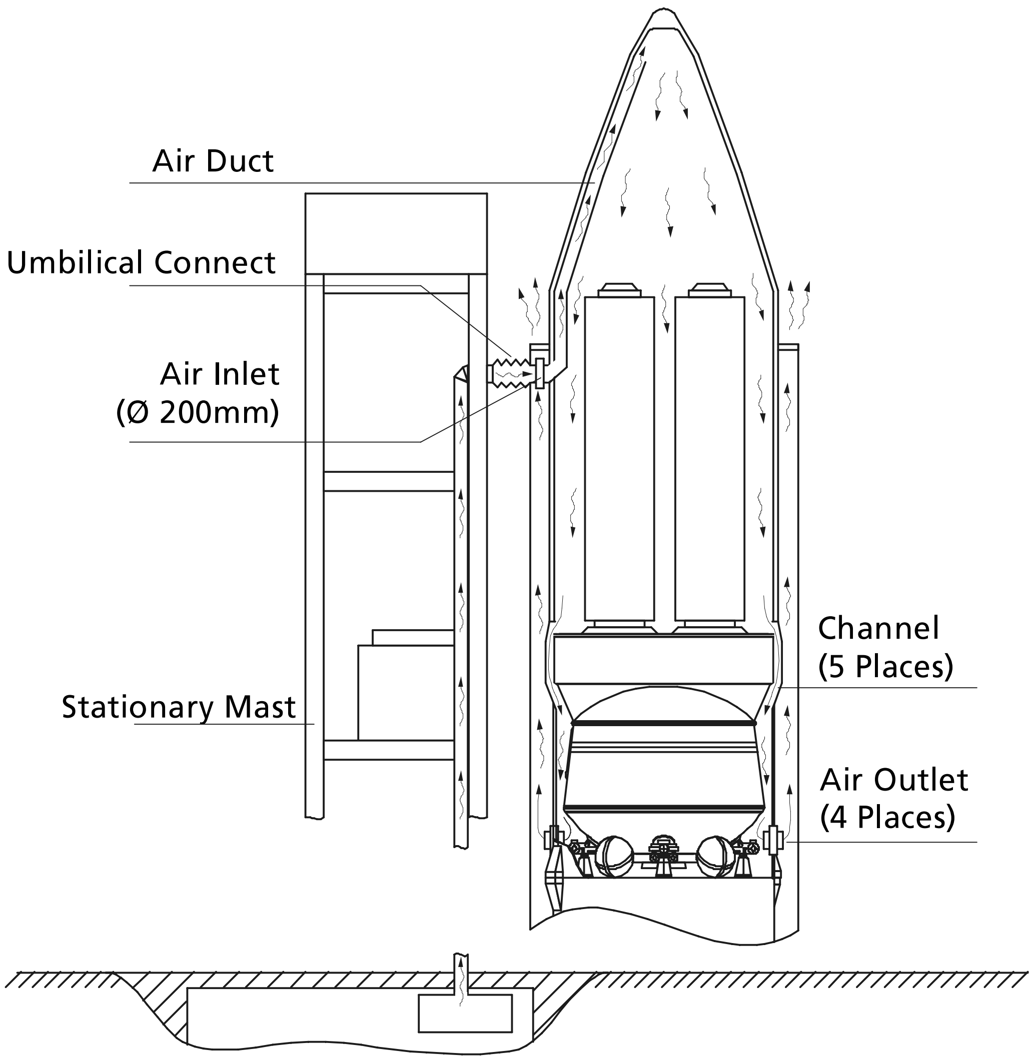


Figure 5-12: Air Conditioning of the Upper Composite at the Launch Pad

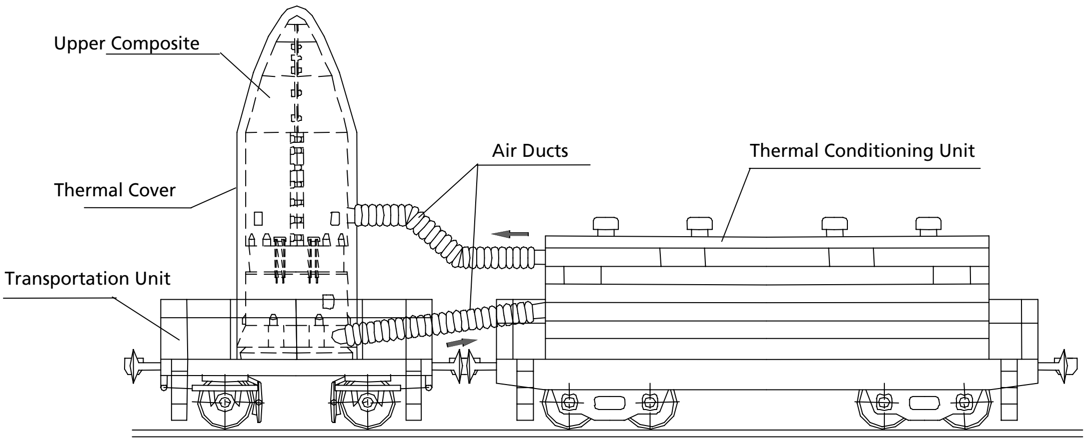


Figure 5-13: Air Conditioning of the Upper Composite during Transportation

5.2.4 *In-flight Temperature under the Fairing*

The payload fairing protects the payload during the ascent to a nominal altitude of about 120 km.

The in-flight adapter hardware temperature lies within the range minus 50°C to plus 40°C range without considering the payload-induced environment. During the ascent, the net flux density radiated by the fairing does not exceed 500 W/m^2 at any point.

Since the upper stage *Breeze* employs an internal temperature control system to keep the temperature of the equipment bay that directly interfaces the payload below 50°C, no induced heat load from here is expected. After the fairing has been jettisoned, the payload is exposed to the free molecular heating (FMH) flux, solar radiation and terrestrial infrared. The FMH flux is defined in Section 5.2.5.

5.2.5 *Aerothermal Flux at Fairing Jettisoning*

The time for jettisoning the fairing is determined to ensure that the aerothermal flux of 1135 W/m^2 will not be exceeded. This flux is calculated as free molecular heating acting on a plane surface perpendicular to the velocity direction.

5.2.6 *Heat Impact during the Coasting Phase*

After the fairing has been jettisoned, the spacecraft is exposed to solar radiation flux, albedo and terrestrial infrared. During the coasting phase, any orientation of the +X axis of the upper composite is allowed within a half cone angle of 100° towards the sun (see Figure 3-1, Section 3.4).

5.3 *Fairing Static Pressure during the Ascent*

The payload compartment is vented during boosted flight. Payload compartment pressures and depressurisation rates are a function of fairing design and trajectory. A typical predicted pressure drop profile for the Rockot payload fairing during the ascent phase is shown in Figure 5-14. The maximum depressurisation rate will not exceed 4 kPa/s (40 mbar/s). Static pressure within the fairing during flight is measured and transmitted to the ground using the on-board telemetry system.

5.4 *Contamination and Cleanliness*

Pyrotechnic systems used for stage separation, the fairing and the payload are leak-proof and do not cause any organic contamination or debris. Several pyrotechnic device operations occur during the Rockot flight regime. In all cases, contamination of the spacecraft is avoided either by hermetically closed containment of the pyrocharge or via the geometry of the plume to the launch vehicle. All non-metallic materials in the upper composite are selected according to the Russian GOST standard, which specifies the use of materials with acceptable out-gassing properties. Class 100,000 (US Fed. Std 209 D) air cleanliness is continuously provided in the payload preparation rooms and inside the fairing until lift-off. The corresponding processes are qualified and the air quality is verified.

5.5 *Electromagnetic Environment*

In order to ensure electromagnetic compatibility (EMC) between the launch vehicle and the payload, a frequency plan is prepared for each launch. The Customer must supply all data needed to support appropriate EMC analyses.

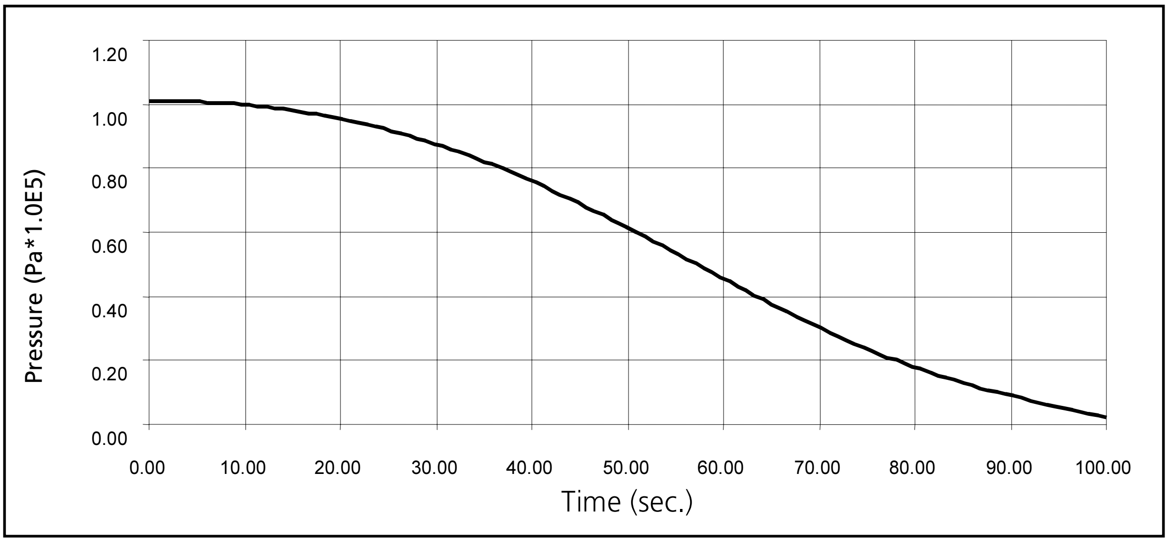


Figure 5-14: Variation of Fairing Static Pressure during the Ascent

5.5.1 Launch Vehicle

The launch vehicle is equipped with the following transmission and reception systems:

- Two telemetry systems with transmitters and antennas, namely one in the in-terstage and one in the second stage
- A telemetry system with two transmitters and antennas in the *Breeze*-KM stage

During on-ground testing and during flight, the transmission systems create electric and magnetic fields. Their characteristics are presented in Table 5.5.1-1 and Figure 5-15.

5.5.2 EMC Requirements for the Spacecraft

In order to avoid electromagnetic interference with the launch vehicle, the spacecraft should observe the restrictions given in Table 5.5.2-1 and Figure 5-16.

Radio Transmitter	Emission Frequency (MHz)	Max. Antenna Emissive Power (dBWt)	Calculated Level of Electrical Field Intensity in Adapter Plane (dBμV/m)	
			With Fairing	Without Fairing
Telemetry 1	120 - 130	12.3	107	119
Telemetry 2	1040 - 1050	8.0	105	117
Telemetry 3	1015 - 1025	6.8	100	112
Telemetry 4	1015 - 1025	6.8	100	112
Tracking	2700 - 3000	20.0 (in pulsed mode)	107	119

Table 5.5.1-1: Parameters of the *Rockot* transmitters

Frequency Band, (MHz)	Tolerated Level, (dBμV/m)
120 - 130	80
1015 - 1050	80
1570 - 1640	45
2700 - 2900	70

Table 5.5.2-1: Restrictions on RF Use be the Spacecraft during Launch

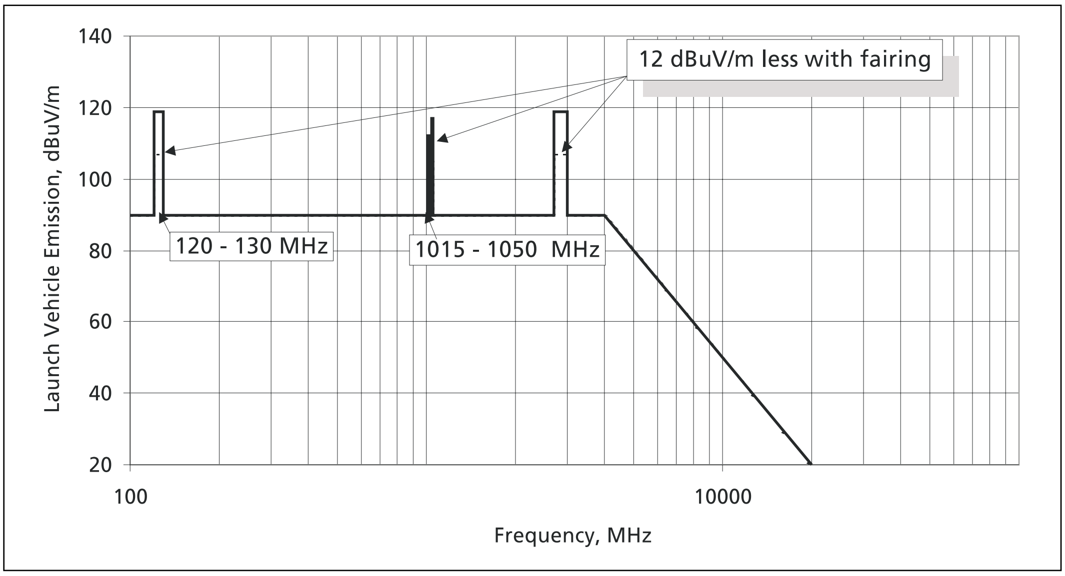


Figure 5-15: Launch Vehicle RF Environment

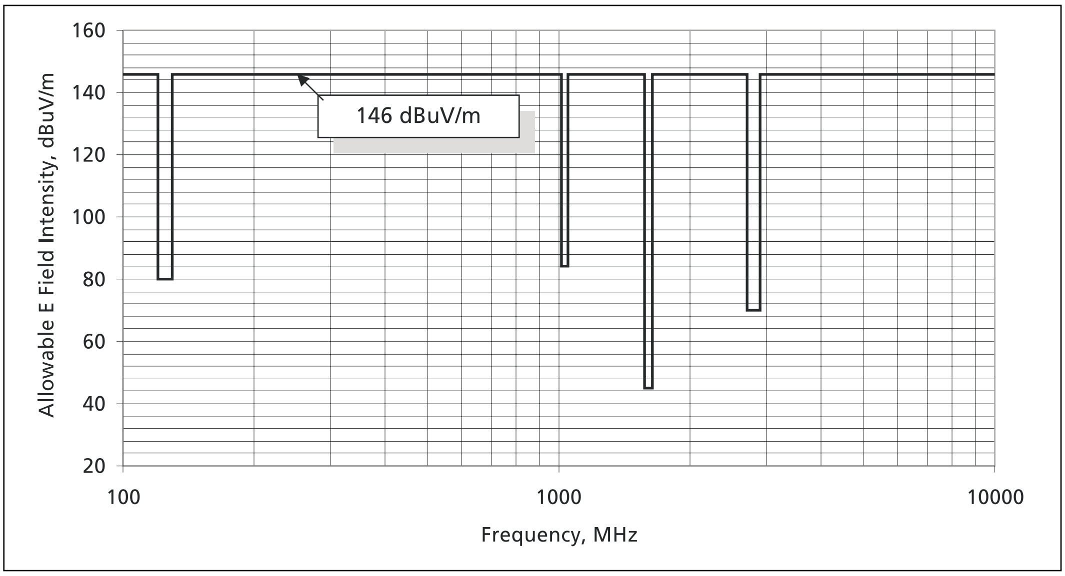


Figure 5-16: Restrictions on RF Use by the Spacecraft during Launch