Labor

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ENVIRONMENTAL CONDITIONS FOR A SATELLITE ON GROUND AND DURING LAUNCH

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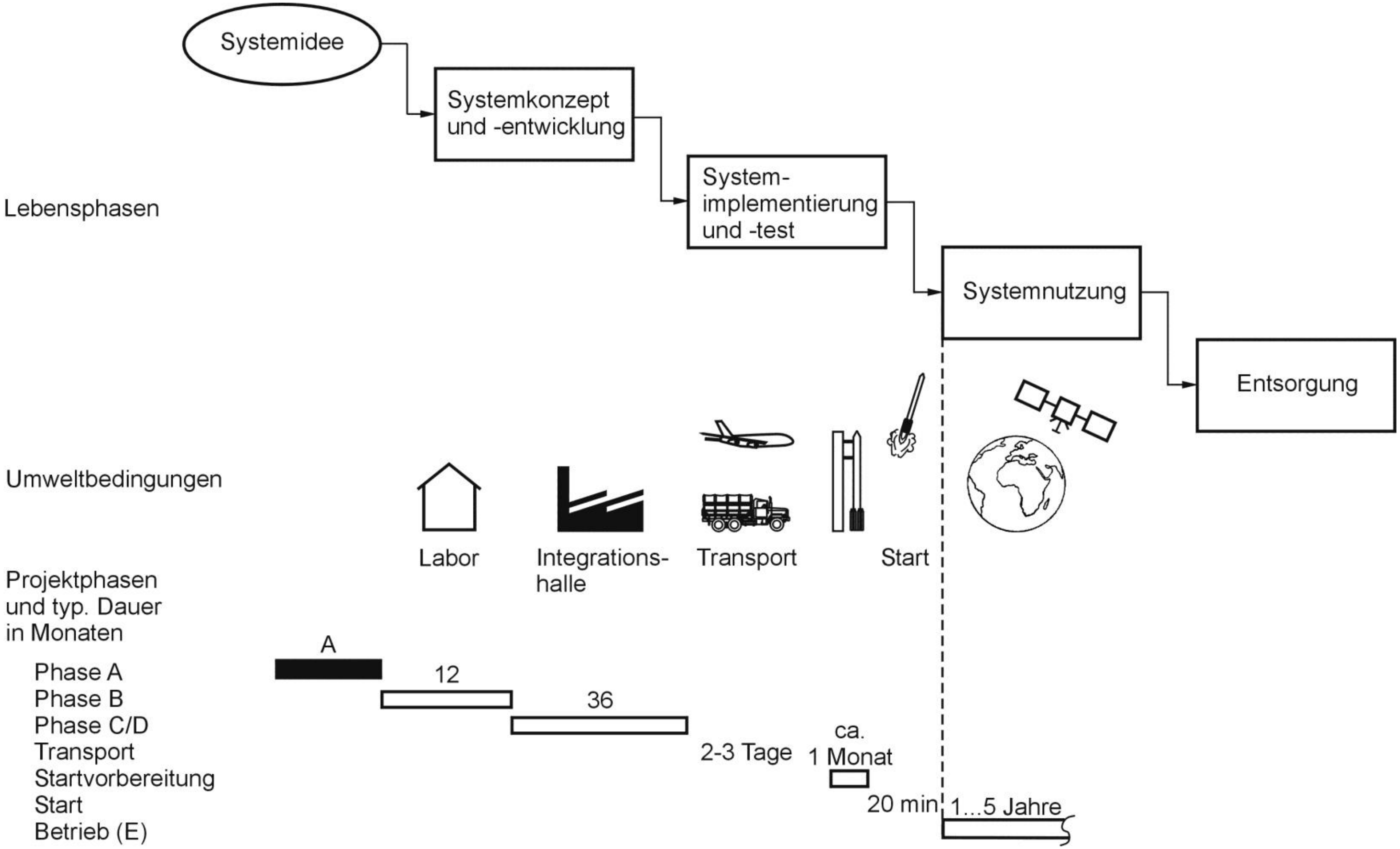
1. Satellite Life Cycle and Environmental Conditions



2. ASSEMBLY AND INTEGRATION ENVIRONMENTAL CONDITIONS

2. Assembly and Integration Environmental Conditions

Satellite assembly integration and test activities are carried out under lab conditions and/or cleanroom conditions.

a) Lab conditions

- temperate climate zone, (20±5 ºC, 50 % relative humidity),
- dust particles in typical city concentrations,
- particles < 5 μm floating in air (smoke, dust, ashes)
- "visible clean room", "gray room"

Flight model of the BIRD satellite of DLR during Acceptance Review under lab conditions before transportation to the launch pad („visible clean" room) [image: DLR]

2. Assembly and Integration Environmental Conditions

b) Clean room conditions

could be required for expensive satellites or for activities on special satellite equipment.

A **cleanroom** is a closed lab, where the contamination is under control.

Contamination is a process of pollution of surfaces or materials with contaminating substances like films or particulates.

A Cleanroom class like “class 1000” or “class 10.000” express the number of particles of size Ø≥ 0,5 µm permitted per cubic foot of air. (1foot = 30,48 cm).

References: ISO 14644-1 or US FED-STD-209E.

Satellite integration under cleanroom conditions [credits: ESA]

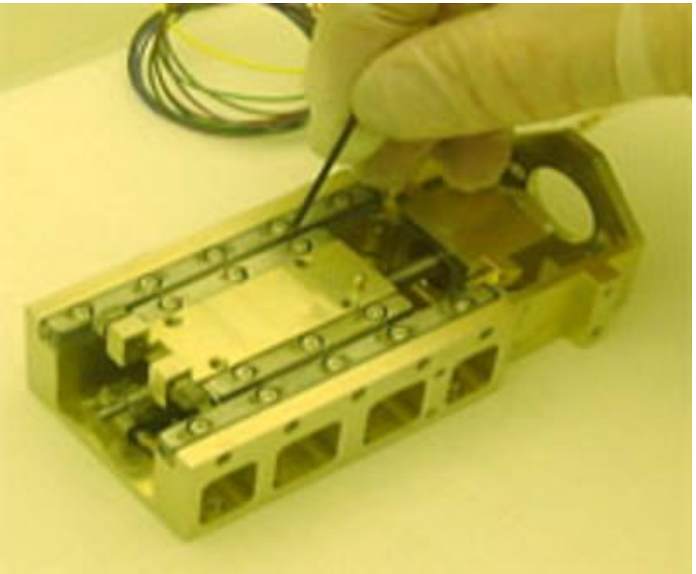
Effects of Contamination

Contamination of open integrated circuits (IC) or of optical focal planes can cause shortcuts, gaps, leak currents, and other damages.

Contamination of satellite surfaces can lead to degradation of properties and performance parameters of subsystems:

Surfaces change their
- Thermo-optical parameters like absorption, emission, reflexion and dispersion
- Tribological properties by outgassing of lubricants and additional frictions
- Electrical properties like surface conduction, emission
- Surface-gas-reaction in space (e.g. spacecraft glowing)

Contaminated material will be emitted in space and causes in sensor field of view to
- Light dispersion
- Absorption of light
- Background illumination.



Tribology: Translation Stage Sub-Assemblies after Test at ESTL. [Credits: ESA]

Typical Number of Particles ≥0,5 µm per ft^3 air

Area	**Number of particles per ft^3 air**
Industry region	4.000.000
City	1.000.000
Living room	200.000
Cleanroom class „100.000“	100.000
Rural environment	50.000
Clean room satellite Integration lab	10.000
Laminar flow cell within cleanroom	1.000
Laminar box within cleanroom environment	100

US FED STD 209E Cleanroom Standards[1])

Class	maximum particles/ft³					ISO equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥5 µm	
1	35	7.5	3	1	0.007	ISO 3
10	350	75	30	10	0.07	ISO 4
100	3,500	750	300	100	0.7	ISO 5
1,000	35,000	7,500	3000	1,000	7	ISO 6
10,000	350,000	75,000	30,000	10,000	70	ISO 7
100,000	3.5×10^6	750,000	300,000	100,000	700	ISO 8

[1]) The U.S. General Services Administration (GSA) released a Notice of Cancellation for FED-STD-209E, Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones, on November 29, 2001.

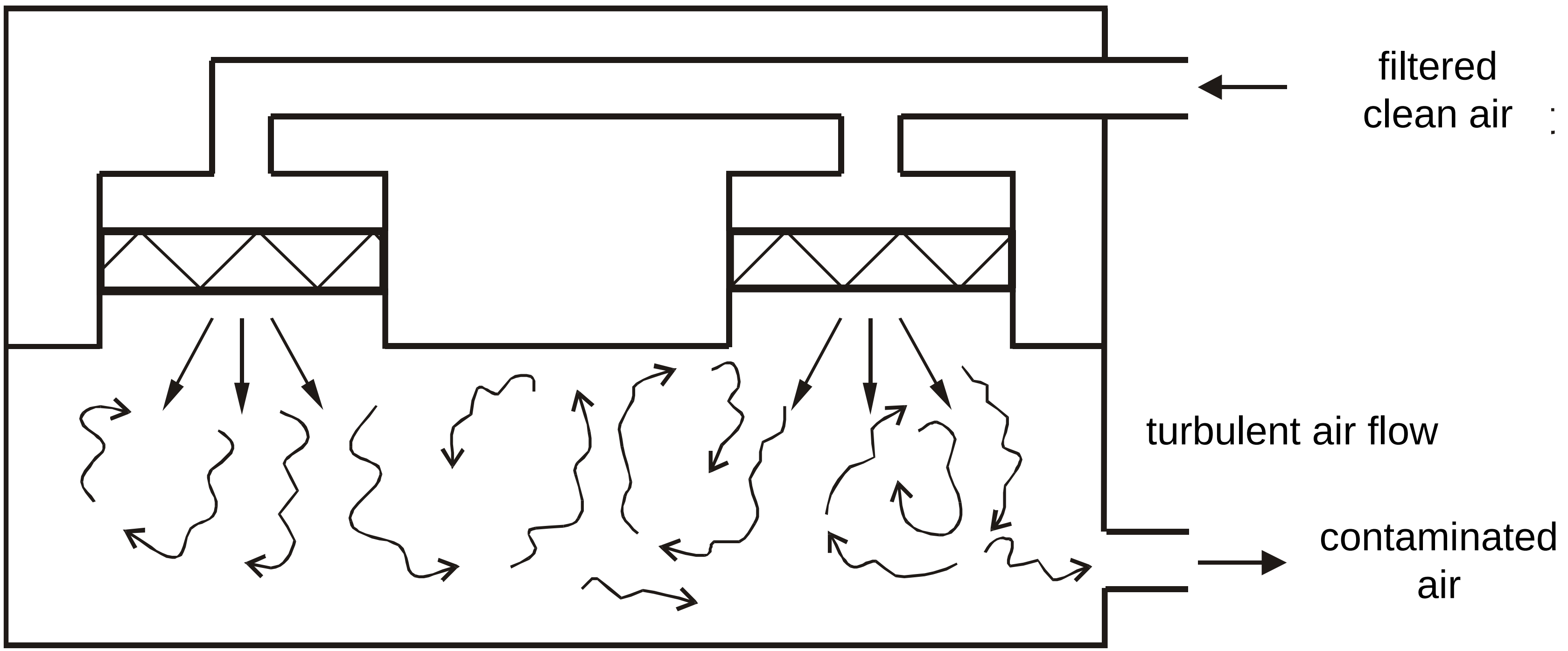
ISO 14644-1 Cleanroom Standards

Class	maximum particles/m³						FED STD 209E equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
ISO 1	10	2.37	1.02	0.35	0.083	0.0029	
ISO 2	100	23.7	10.2	3.5	0.83	0.029	
ISO 3	1,000	237	102	35	8.3	0.29	Class 1
ISO 4	10,000	2,370	1,020	352	83	2.9	Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1.0×10^{6}	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7	1.0×10^{7}	2.37×10^{6}	1,020,000	352,000	83,200	2,930	Class 10,000
ISO 8	1.0×10^{8}	2.37×10^{7}	1.02×10^{7}	3,520,000	832,000	29,300	Class 100,000
ISO 9	1.0×10^{9}	2.37×10^{8}	1.02×10^{8}	35,200,000	8,320,000	293,000	Room air

Key Measures for Contamination Control

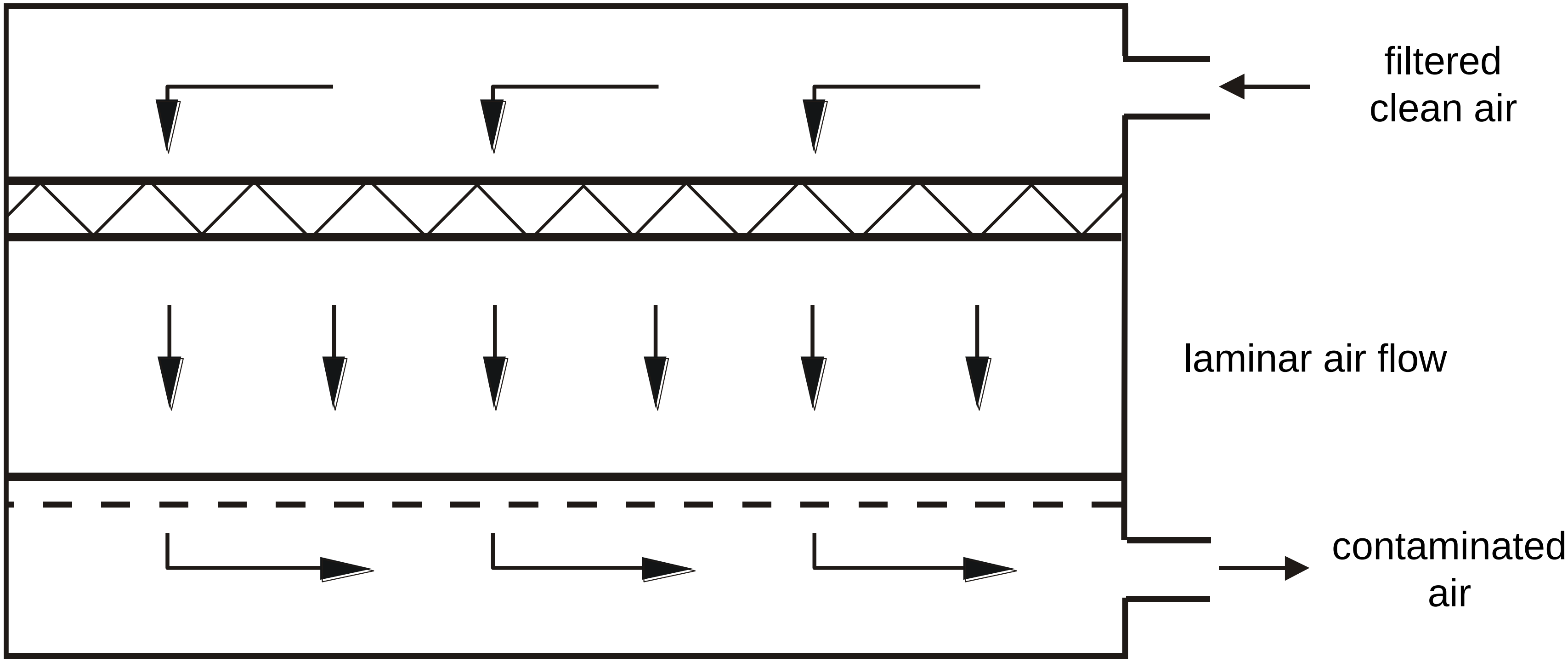
1. Cleanroom architecture: filtered and controlled air flow (turbulent or laminar)
2. Filtration in combination with High Efficiency Particle Air filter (HEPA)
3. Regular special cleaning procedures
4. Cleanroom garments
5. Cleanroom regulations for entrance and behaviour of humans in cleanrooms
6. Regulations for admission and for cleaning procedures for equipment, tools and materials from outside for use inside
7. Regular measurement and control of contamination conditions and cleanroom class
8. Regular exchange of filters
9. Special procedures to keep the electrostatic discharge conditions.

Cleanroom Architecture Concept: Turbulent Mixed Flow



Cleanroom conception of turbulent mixed air flow for cleanroom class 100.000

Cleanroom Architecture Concept: Laminar Flow



Cleanroom conception of laminar flow for cleanroom class 10.000 or better

Effect of Cleanroom Garments

	Emission of Particles (< 0,5 µm)	
Movement type	**Street clothes**	**Cleanroom Garments (Overalls, cap, mask)**
To sit without moving	3×10^5	7×10^3
Turn the head	6×10^5	10^4
Movement of body	10^6	3×10^4
Slow walking	3×10^6	5×10^4
Fast walking	6×10^6	10^5

Example of Cleanroom Conditions

Basic measures in cleanrooms:

- Downward air flow (0.5 m/s)
- Supply of filtered clean air
- Overpressure in cleanroom
- Double doors as air lock systems
- Cleaning up and use of air shower by bringing new equipment or tools in the cleanroom
- slow motion of humans
- Use of cleanroom garments

Cleanroom class	10.000
Temperature stability	± 1° C
Air humudity	45 ±2,5 %
Air overpressure	+ 25 Pa
Vibrations	≤ 0,1 bei 2 Hz
magnet. Field strength	T.B.C.
Noise	< 55 dB (A)
No dangerous substances	

3. TRANSPORT ENVIRONMENTAL CONDITIONS

Transport and Storage

A Satellite and its ground support equipment like handling tools, crane, checkout equipment have to carry to different places for tests and measurements during the pre-launch phase. For the launch the satellite has to be transported usually a long distance. The environmental conditions an the transportation have to taken into account and they have to be under control.

The following parameters have to be taken into account:

- Time and duration of transport
- Transport way and stations
- Means of transportation (usually: lorry, airplane)
- Transport packaging and transport container
- Transport documents (export licence, custom declarations)
- Transport companion and receiver
- Mechanical-dynamical transport conditions
- Storage conditions especially at the airports
- Climate changes
- Recording and protocols of transport conditions

Transport and Storage

Short-range transport

between labs or buildings on well defined paths with defined equipment (handling device, crane, MGSE or other): Low loads, short exposure time

Long-range transport

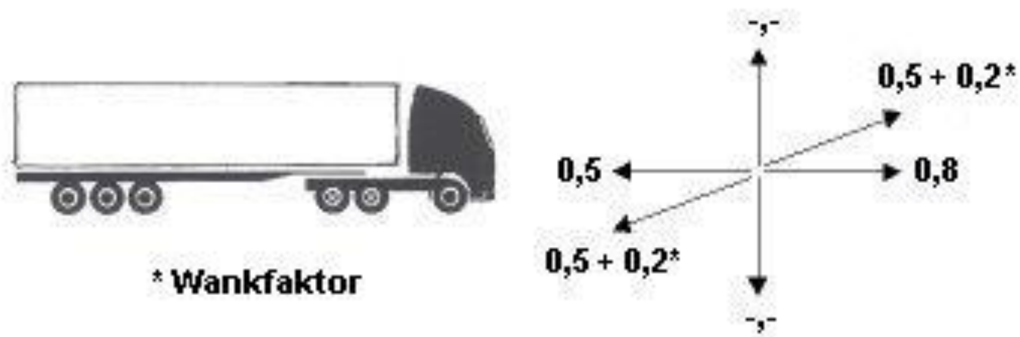
- To measurement facilities (e.g.. For remanent magnetism or for moments of inertia of the satellite) and back
- To the launch pad: sequence of different loads: road traffic or rail-road loads and airplane transportation loads
- Experience: the cargo handling process on airports are most stressful for the satellite and container, shock loads are not defined but they can exceed the launch shock loads!

Satellite transport convoi in India from airport Chennai to the launch pad Shriharikota (Shar) (Foto: ISRO]

Road Transport

Loads at road traffic

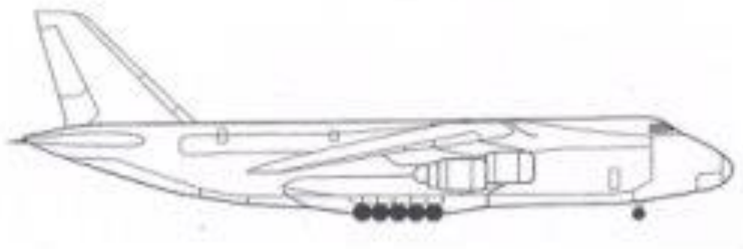
- Not well defined, vibrations can be in the order of magnitude of launch loads
- Exposure time can be much longer than during launch (many hours)
- Critical path: from integration building to the airport;
- from final airport to the launch pad usually thoughtful transport by experts

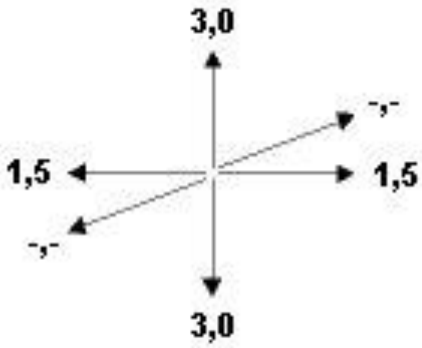


Dynamic loads at road traffic according to VDI-guide lines, [source: VDI-Richtlinie 2700ff]

Air Transport

Special attention should be paid to requirements on cargo for emergency landing!





For loads in air transport see national documents
Example figures from Delvag Luftfahrtvers. AG (Germany):

Airport handling:	ca. 1,0 g oder mehr
Emergency landing:	ca. 10 g für ca. 60 sec.

Shock Loads During Transport

Shock loads at road transportation are dominant in comprison to air transportation..

Typical values:

Maximum acceleration:	4 g bzw. 39,3 m/s^2
Shock duration:	5-10 ms
Number of shocks per minute.	ca. 60

Transport and Storage - Exposures and Measures

Exposures:

1. Mechanic-dynamical loads
   (accelerations, vibrations, shocks, tilting, free fall)
2. Climatic impacts
   (Temp. range, air humidity, rain, water, ice, snow, air pressure changes)
3. Chemical impacts
   (Aerosols, exhaust gases)
4. Biological impacts
   (Fungus, animals)
5. else
   (Flood, Fire, Theft)

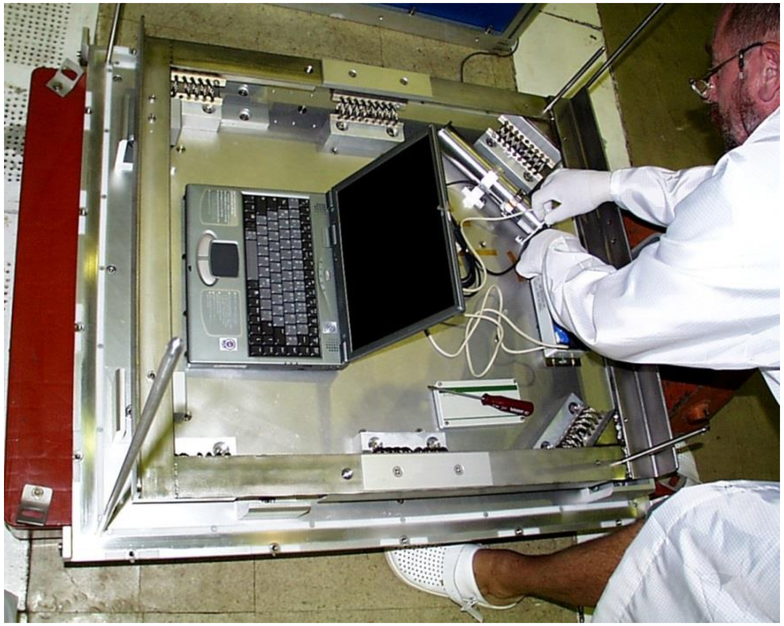
Measures:

- Vibration absorber
- Shock absorber
  (e.g. 20g, 25ms to 5g at satellite mounting point)
- Satellite is fix mounted on a construction support frame,
- Hermetic closed transport container with Mol-filter for air pressure balance,
- Nitrogen purging,
- Humidity absorber
- Shock recorder,
- Pressure and humidity recorder
- Transport assurance, if it possible

Transport and Storage–
Example of a Satellite Transport Container

Vibration absorber and shock absorber within the transport container of the micro satellite BIRD (92kg)
[credits: Astro- und Feinwerktechnik GmbH]

Example of a Satellite Transport Container



Integration of the shock recorder in the transport container of the BIRD satellite [photo: DLR]

Micro satellite BIRD (with cover) fixed at mounting plate of the transport container [Foto: ISRO]

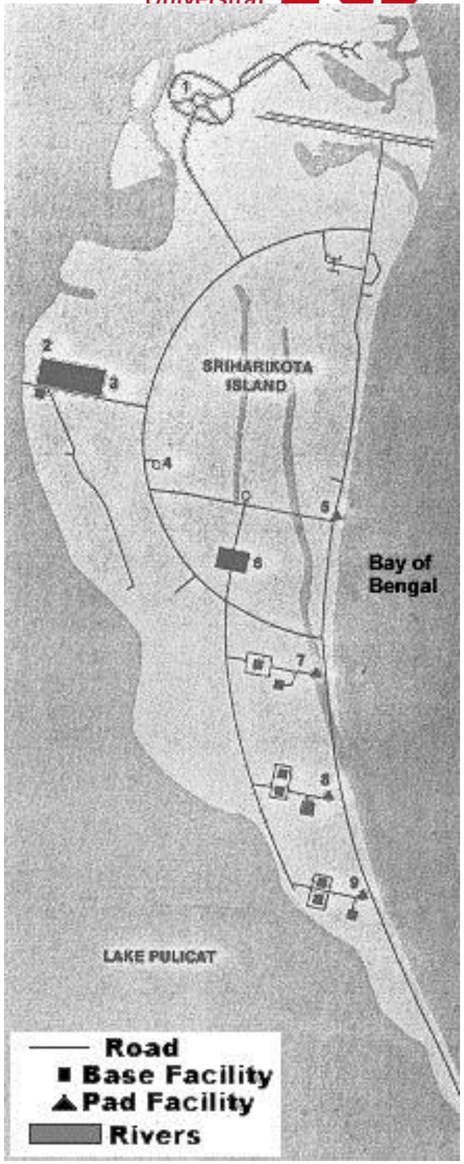
4. ENVIRONMENTAL CONDITIONS AT THE LAUNCH SITE

Example: Launch site in Shriharikota (India) (SHAR – Shriharikota Launching Range)

- total area: 145 km^2
- coastal length: 27km
- mobile service tower
- clean room for payload
- launch control centre
- real-time tracking systems
- weather observation station
- 3 radar facilities in Shriharikota
- 5 ground stations of the Telemetry, Tracking & Command Network of ISRO

Map Legend:

1. Explosives storage
2. Accommodation
3. Technical centre
4. Telemetry building
5. Sounding rocket complex
6. Explosives storage
7. Liquid booster satellite launch complex
8. Launch vehicle complex
9. Synchronous satellite launch complex

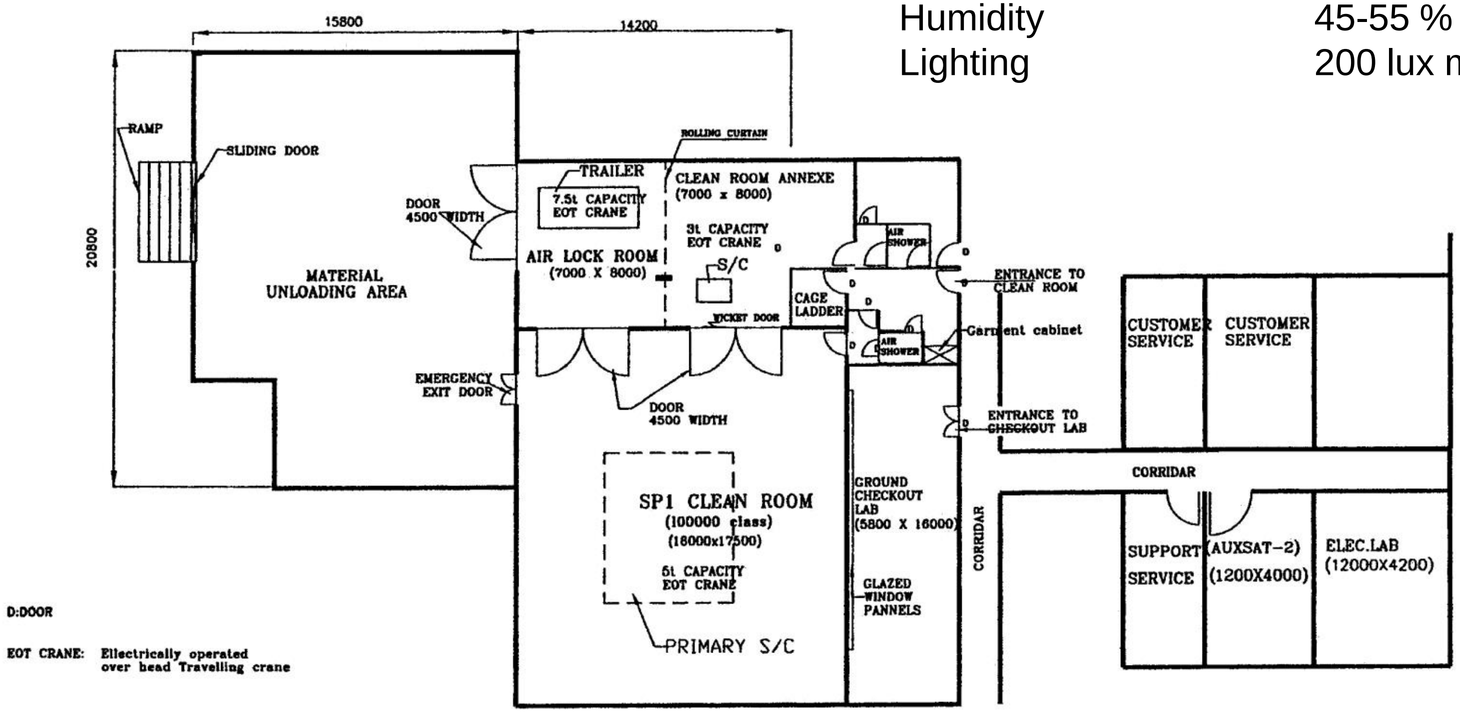


Example of Check-out Rooms at the Launch Site

System Check-out labs:

typical parameters [PSLV-Dok.]:

Cleanliness	100,000 class
Temperature	21-23° C
Humidity	45-55 % RH
Lighting	200 lux min.

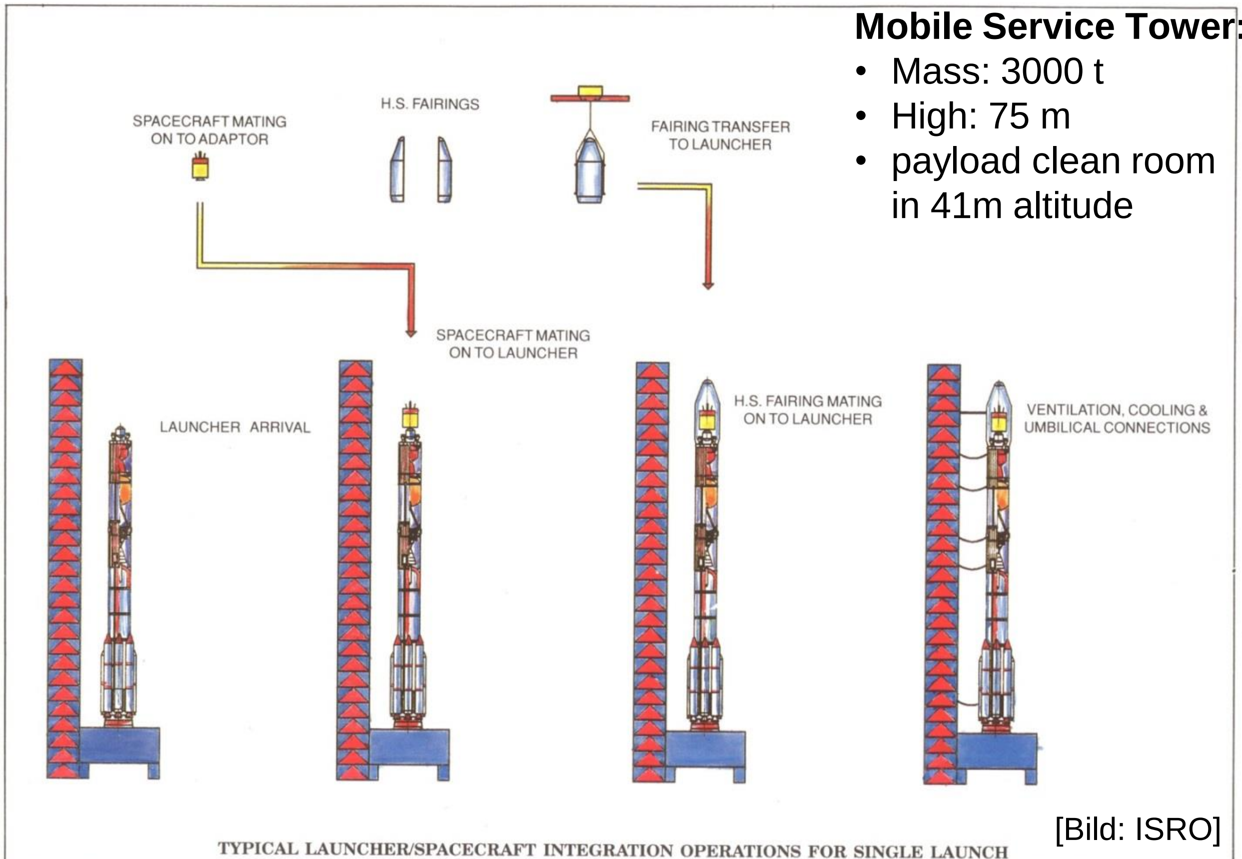


System checkout labs in Shriharikota (India) [PSLV-Dok.]

Example of Payload Integration

Mobile Service Tower:

- Mass: 3000 t
- High: 75 m
- payload clean room in 41m altitude



[Bild: ISRO]

Launch of PSLV-C14 and Mobile Servie Tower in background [photo: ISRO]

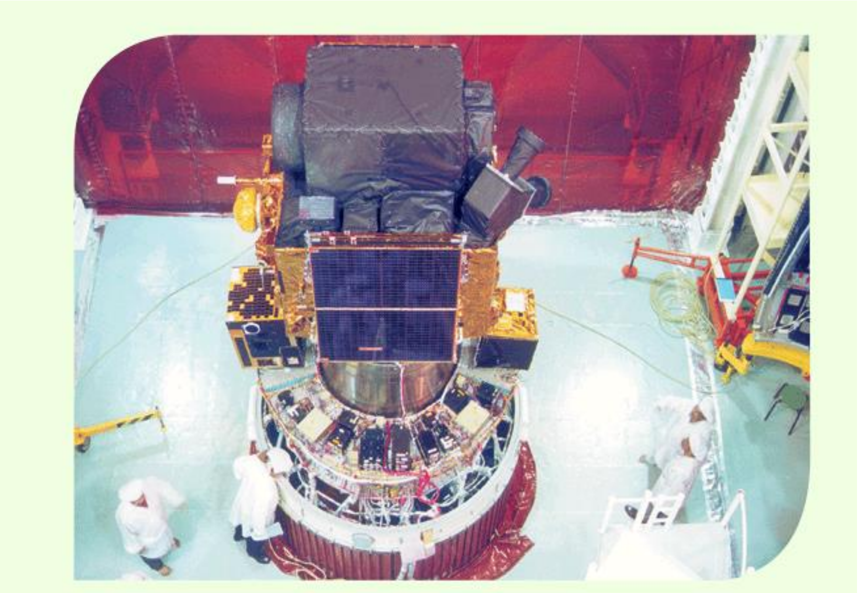
Example of Payload Integration

Payload integration on upper stage

- Launch service tower for perpendicular rocket integration
- Nearly cleanroom conditions
- Continuously flow of filtered air

Example: Launch Service Tower [PSLV-Dok.]

Air temperature:	15° C to 25° C, selective
Rel. Humidity:	40 % to 60 %
Air flow rate	1800 kg/hr
Cleanroom class	10.000
Air flow velocity.:	2 m/s max.



Payload-Integration room of PSLV [photo: ISRO]

5. TYPICAL LAUNCH LOADS FOR A SATELLITE

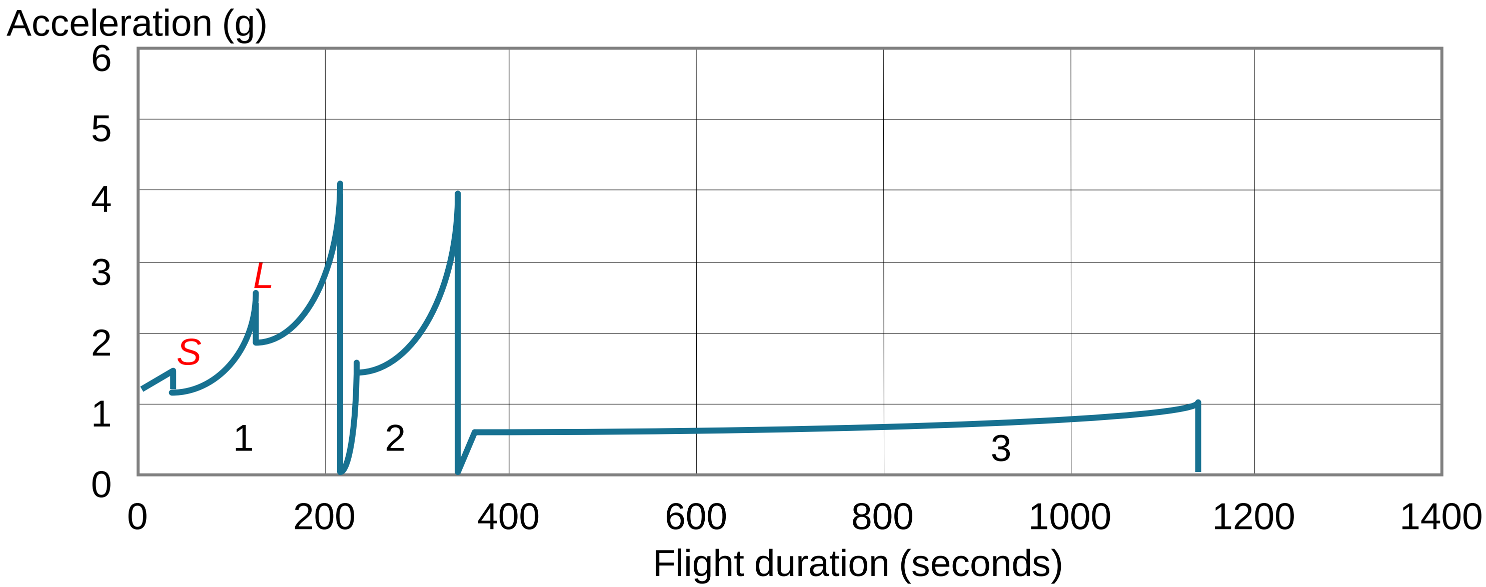
Launch Loads

- mechanical-dynamic loads are dominant
- vibrations of the engines are transmitted to the payload (satellites) via the rocket structure
- dangerous resonance cases of coupled systems could be generated
- high noise-levels affect the structure
- increasing aerodynamic loads
- shock wave arises at transition of subsonic range to the supersonic range
- transient shock loadings by staging (burn out and blow off) and ignition of the next stage
- the mechanical loads can be classified concerning their time response
- During the launch a combination of different loads occur at the same time.
- The launch loads can be coarse divided into
    - (quasi) static and
    - dynamic loads.

Ariane-5 launch [photo: ESA]

Quasi-static Loads

- thrust loads (accelerations)
- forces of inertia
- aerodynamic forces
- reasons: caused by jet propulsion and winds, relative small structure



Typical acceleration of a Ariane 4SL [source: P.Berlin, 2005]

Example Values of Quasi-static Loads

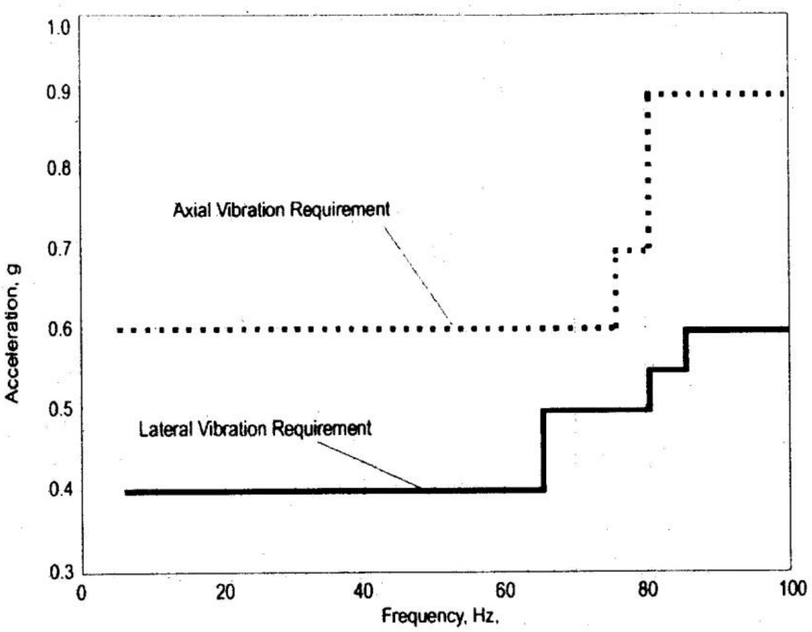
Event	Condition	Quasi-static Acceleration				
		Longitudinal (x)				Lateral (y/z)
		Static	Dynamic	Max.	Min.	
1	Lift-off	+ 1.8	± 1.8	+ 3.6	0	± 0.3
2	Wind/Gust Transonic	+ 2.8	0	+ 2.8		± 0.8
3	Max. Thrust of Stage 1	+ 7.1	± 0.9	+ 8.0	+ 6.2	± 0.5
4	Maximum g-Loads of Stage 1	+ 7.2	± 0.9	+ 8.1	+ 6.3	± 0.5
5	Stage 1 Engine Cut-off	< 0.05	+ 8.1 - 6.1	+ 8.1	-6.1	± 0.5
6	Maximum g-Loads of Stage 2	+ 3.0	0	+3.0	+ 3.0	± 0.4
7	Flight of upper Stage	+ 1.6	0	+ 1.6	+ 1.6	± 0.5

[Eurockot-Dok., Issue 2, June 1999]

Quasi-harmonic Vibrations

(harmonic oscillations, sine vibrations)
Causes:

- burning instabilities (in particular with rocket motor ignition and cut-off)
- periodic jet fluctuations, typical frequency range: 10-20 cycles per second
- self excited oscillations in the closed cycle structure, tank, fuel injection system, combustion chamber
- typical frequency range: 60-90 cycles per second



Atlas IIAS, IIIA and IIIB sine vibration requirements

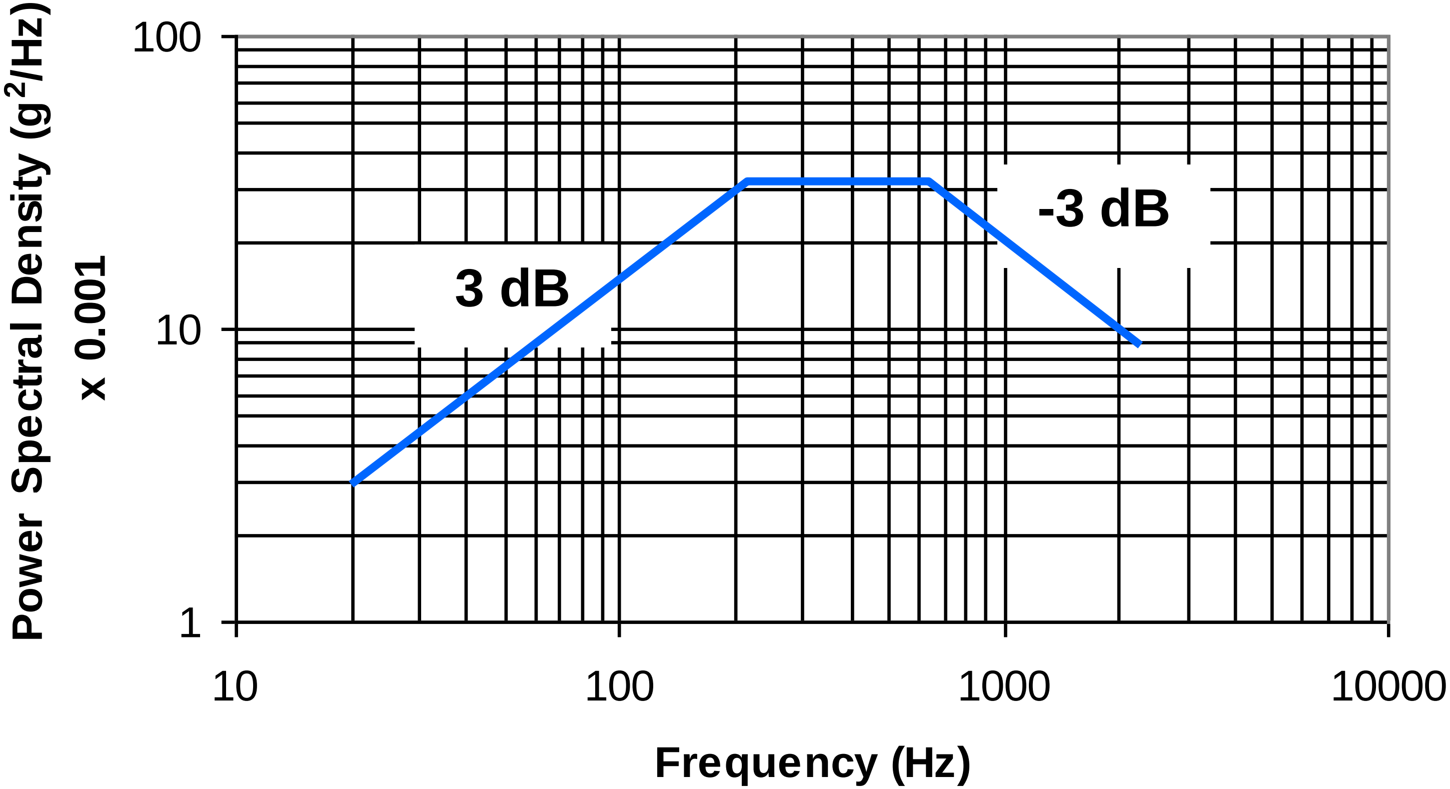
Random Vibrations

Reasons:
- vortex shedding
- turbulences
- gusts
- engine noises
- boundary layer noise

Effects on rocket payload:
- direct sound load within the launch fairing
- levels introduced by rocket structure

Modelling:
- coupled dynamic analysis of launcher and payload with the help of the method of finite elements
- Forecast of the vibro acoustic loads by means of half empirical methods, like e.g. the static energy analysis

Typical Random Vibration Level at Launch



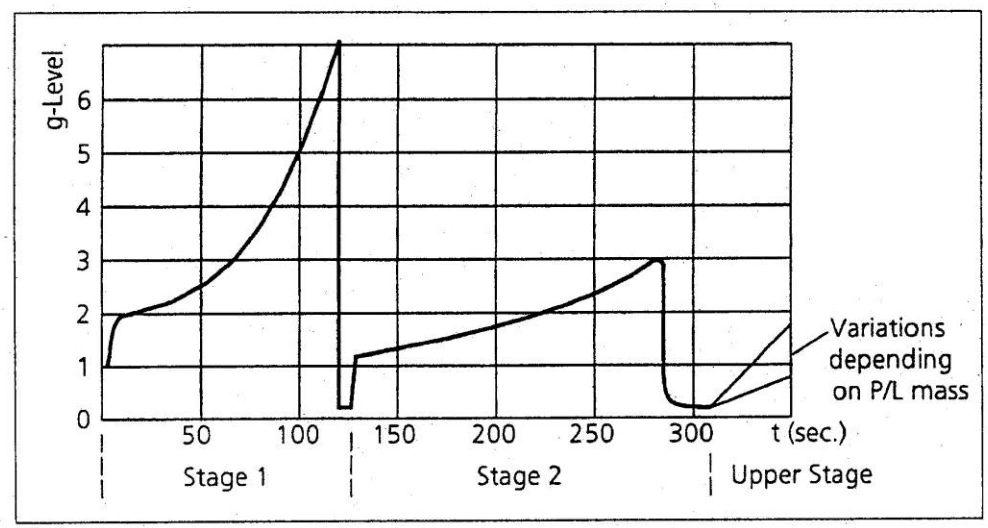
[source: P.Berlin, Satellite Platform Design, 2005]

Shock Loads

(shock = transient loads)

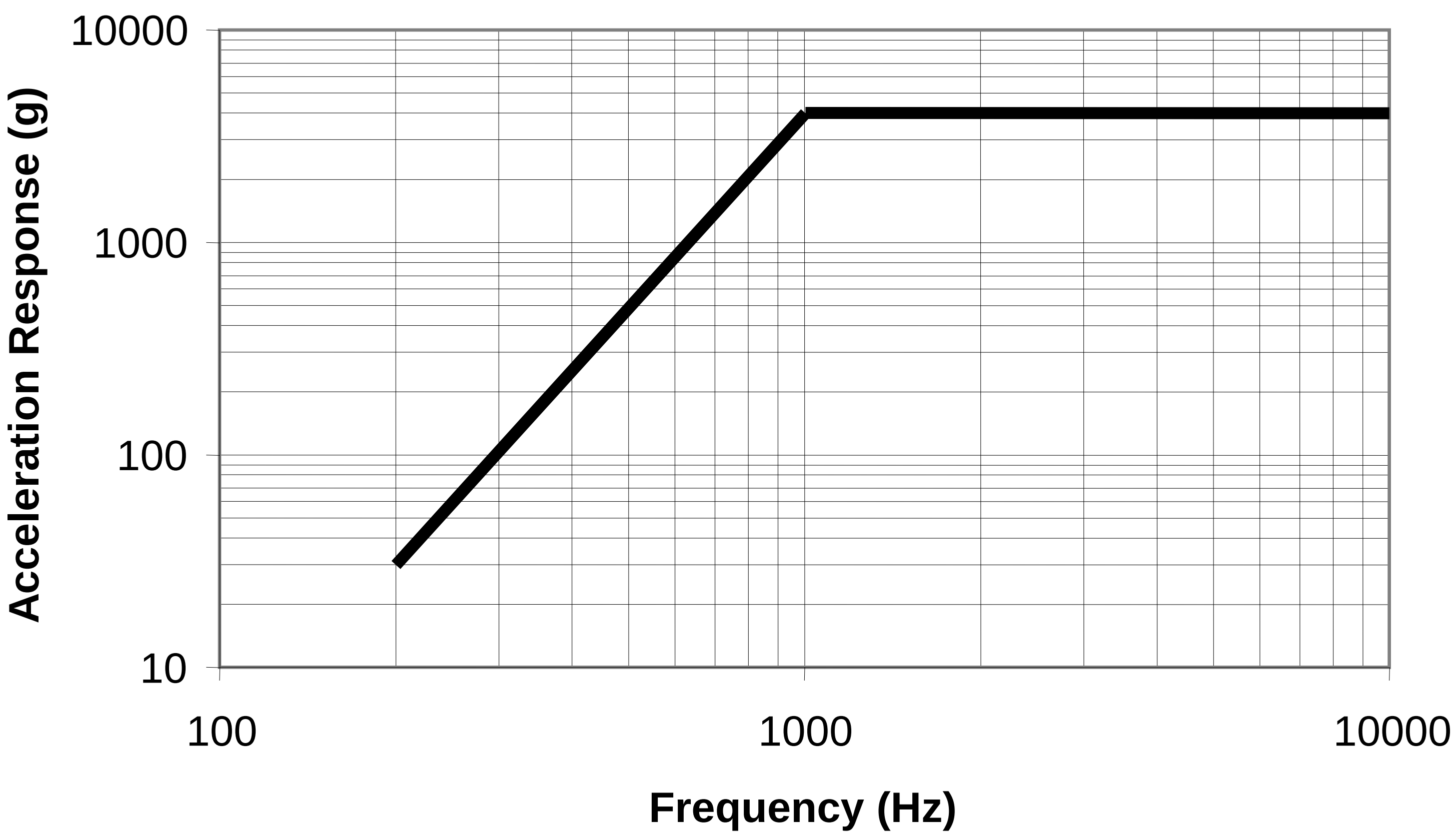
Causes:

- Thrust cut-on and cut-off
- Shear winds and gusts
- Stage separation
- sonic boom
- separation of the payload
- large flexible structure



Typical thrust cut-on and cut-off during launch [Doc. Eurockot, June 1999]

Typical Shock Spectrum at a Rocket Launch



[modified, source: P. Berlin, Satellite Platform Design, 2005]

Acoustic Vibration

Causes:

- engine noise
- wind noises, gusts
- structure noises

Lift-off: Maximum value at „lift-off " caused by firing of the engines and reflected exhaust gas towards ground

Ascent: Operations of a multiplicity of mechanical components (e.g. turbo pumps) excites the structure to oscillations. „The shroud" produces a secondary acoustic field

Reaching the sonic speed: unsteady flow field around the rocket re-excites the shroud to strong vibrations

- 2 x of highest levels of 130 – 140 dB:
  - at „lift-off "(approx. 10 seconds.) and
  - during the transitional phase to the supersonic velocitiy (approx. 40 seconds.),
- otherwise lower levels.

Acoustic Characteristics

Sound pressure level I in decibel (dB) related to the reference pressure 2x10–5 Pa.
Sound Pressure level

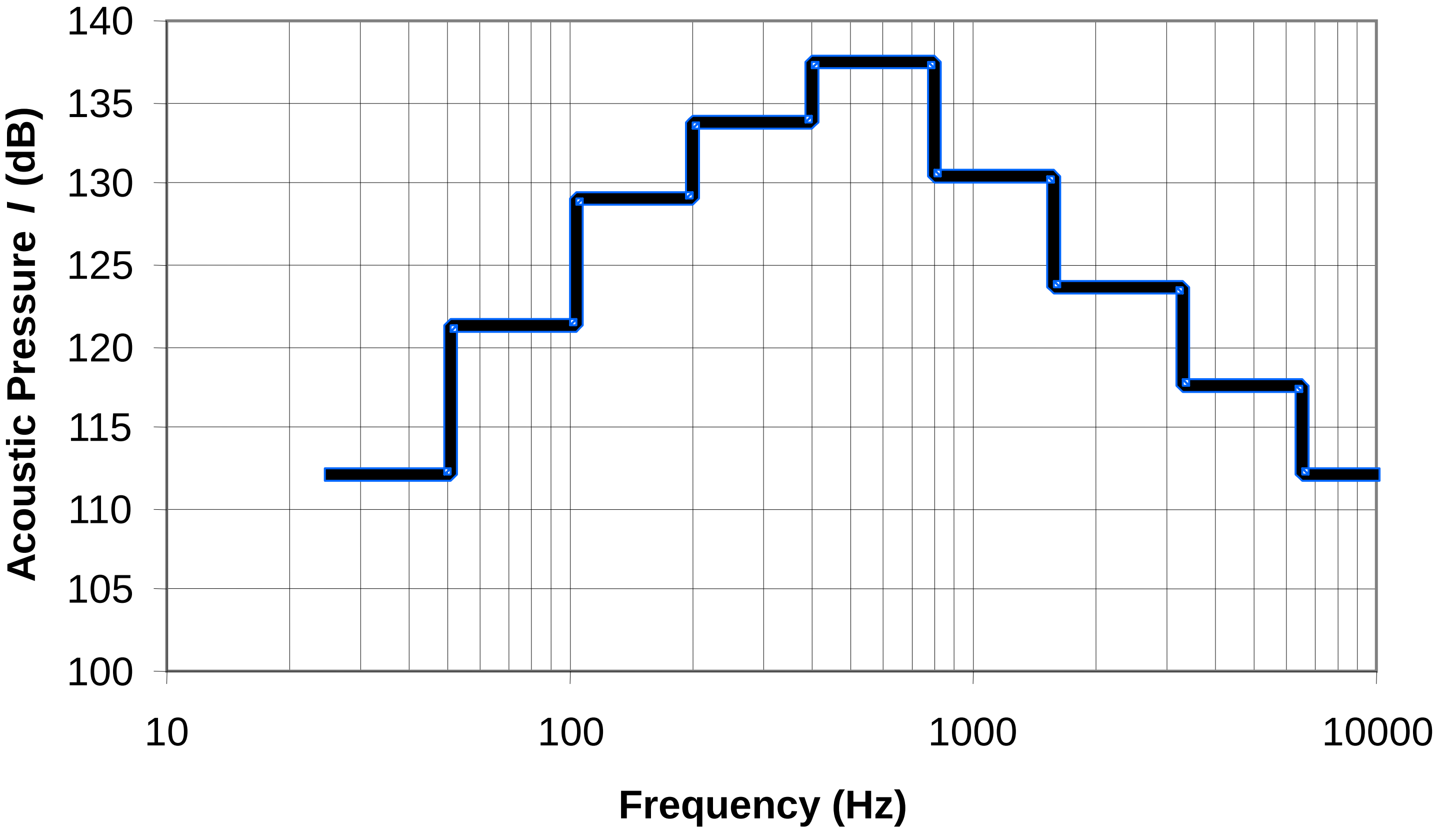
$$SPL = 20 \log_{10}\left(\frac{F}{2x10^{-5}\ \mathrm{Pa}}\right) \quad \text{in dB}$$

with F = acoustic field intensity

For light flexible and wide structures, like e.g. solar arrays or antennas acoustic vibrations can constitute **clearly higher** loads than mechanical-dynamical loads (vibrations).

Frequency indications:
octave = frequency difference of the factor 2
octave band = frequency band with upper frequency = 2 times lower frequency
1/3 -octave band = octave band with one-third spacing
example: f=…, 2000, 2500, 3150, 4000,… cycles per second

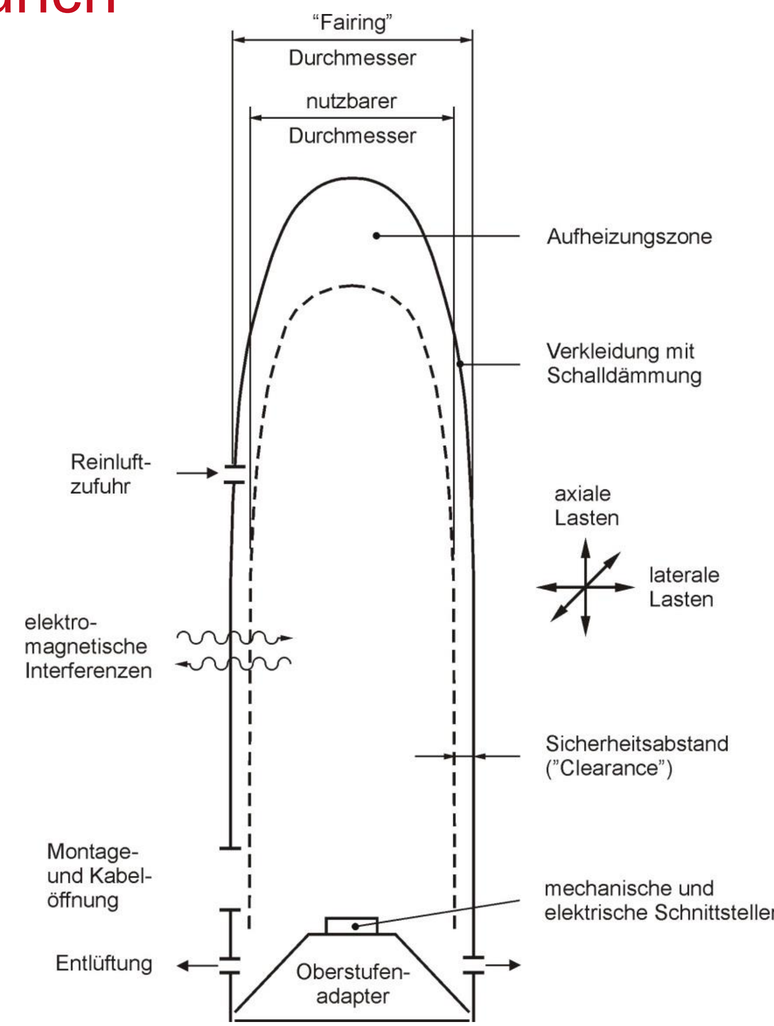
Typical Acoustic Vibration Loads



[P.Berlin, Satellite Platform Design, 2005]

Temperature Conditions During Launch

- Thermal protection system of the payload fairing keeps the heat shield surface temperature within the conical nose cone of $\leq 120°$ C
- The acoustic blank limits the temperature at the internal surface to 20°C
- After separation of the payload fairing in approx. 100 km height the free molecular flow affects (Heat flow < approx. 1200 W/ m^2)
- After separation solar radiation, albedo and the Earthshine in the IR wavelength range affect the payload.



Typical payload fairing of a rocket
(by Larson, Wertz SMAD, 2nd ed., 1992)

Electromagnetic (EMC) Environment

- For the safety of the electromagnetic compatibility (EMC) between rocket and payload(s) a frequency plan is prepared for each launch.
- The payload must prove that the required RF-field intensities are fulfilled according to the frequency plan or that the transmitters cannot be switched on during the launch.

Example of EMC Requirements

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

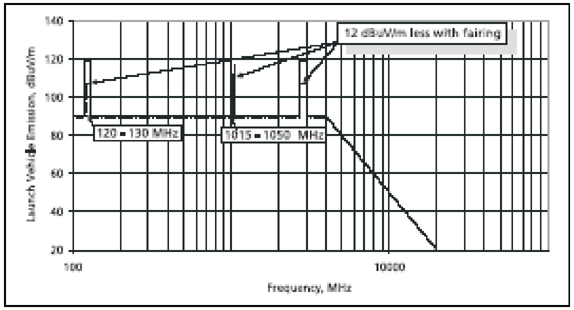


Figure 5-15: Launch Vehicle RF Environment

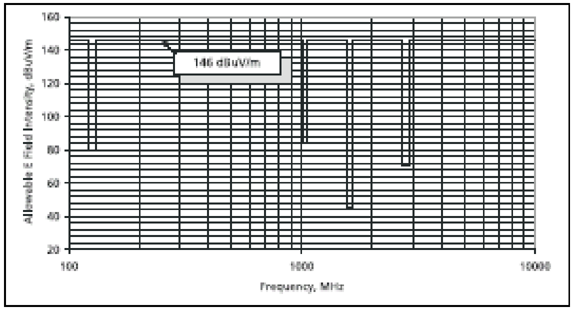
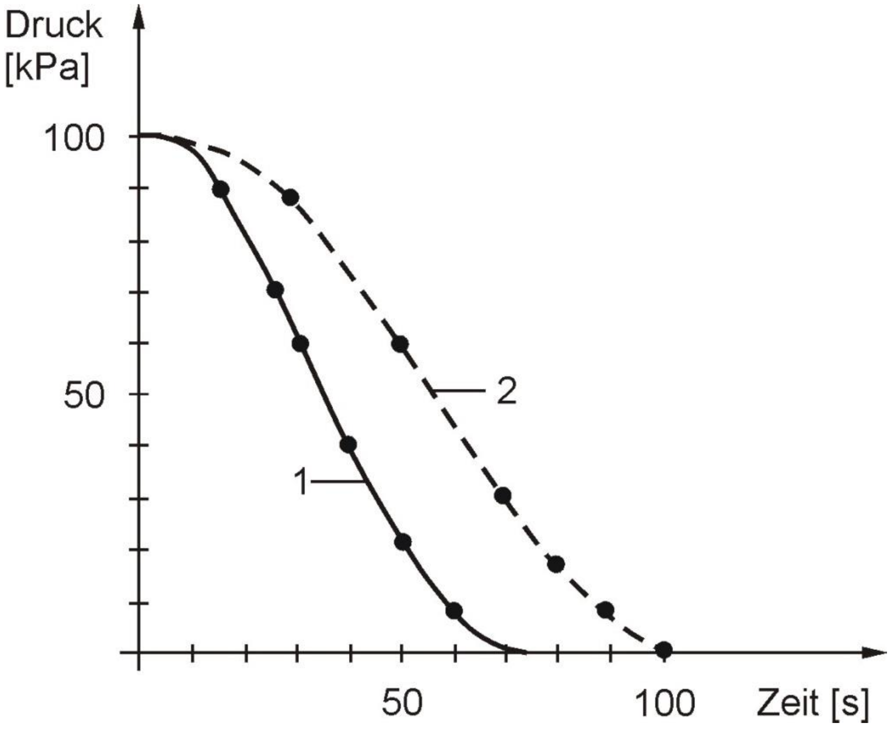


Figure 5-16: Restrictions on RF Use by the Spacecraft during Launch

[Source:
Eurockot User's Guide]

Typical Pressure Conditions During Launch

- ventilation within the heat shield secures that difference between static internal and external pressure is <10 kPa
- ventilation holes ensure a bleeding of the fairings
- max. pressure change rate: $\Delta p \leq 20$ mbar/second



Change of the static pressure in the payload fairing during launch (1-PSLV, 2 – Eurokot)

Example of Micro-satellite Launch Requirements (1/3)

Source: PSLV AP User's Manual, Section 4 - Environment

Quasi static loads
Longitudinal acceleration (Static + dynamic): + 7 g /-2.5 g
Lateral acceleration (Static + dynamic): ± 6 g
Frequency requirements
Fundamental frequency in longitudinal axis > 90 Hz
Fundamental frequency in lateral axis > 45 Hz

Tab. Sine Vibration Test Levels

	Freq. Range (Hz)	Qualification level	Acceptance level
Longitudinal axis	4-10 10-100	10 mm (0 to Peak) 3.75 g	8 mm (0 to Peak) 3 g
Lateral axis	2-8 8-100	10 mm (0 to Peak) 2.5 g	8 mm (0 to Peak) 2 g
Sweep rate		2 Oct/min	4 Oct/min

Example of Micro-satellite Launch Requirements (2/3)

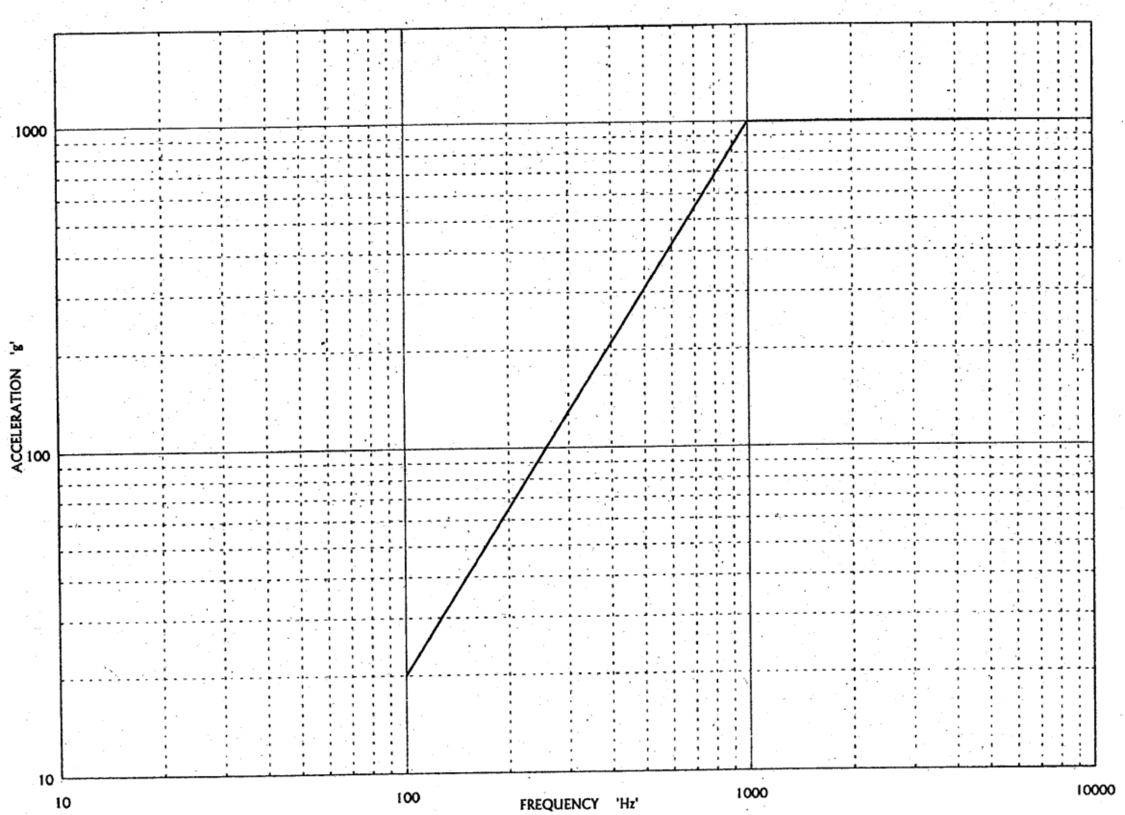
Source: PSLV AP User's Manual, Section 4 - Environment

Tab. Random Vibration Test Levels

Frequency	Qualification PSD (g^2/Hz)	Acceptance PSD (g^2/Hz)
20	0.002	0.001
110	0.002	0.001
250	0.034	0.015
1000	0.034	0.015
2000	0.009	0.004
gRMS	6.7	4.47
Duration	2min/axis	1 min/axis

Example of Micro-satellite Launch Requirements (3/3)

Source: PSLV AP User's manual, section 4 - Environment



Shock test levels for auxiliary satellites

Literature

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