Community for Space Prosperity

CUSP

DEFENCE AND SPACE

Fit4Space – The Space Environment

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CUSP

Community for Space Prosperity

Connect

A catalyst for **inclusive purposeful community engagement** and collaboration with Start-ups, SME’s, Primes, Government, Space agencies, entities, Academia and trade associations.

Inspire

Reaching out to schools, students, employees, new associates and partners to **inspire interest** in the Space sector.

Grow

Boosting confidence, exchange, ideas, innovation, partnerships and **skills** to grow new business, regional development and exports in support of **prosperity, jobs** and UK leadership in the space market.

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Space Environments

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Scott Morgan and Shawn Orford
Airbus Stevenage

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Spacecraft Environments

Thermal

Scott Morgan

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Aim

- To provide an overview of the space environment from a thermal perspective

- To cover the thermal aspects that need to be considered for the design of a Spacecraft given the space environment

Thermal Design Environments

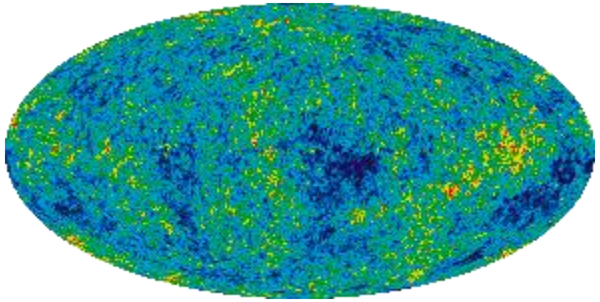
- **Assembly Integration and Test**
  - General ambient build environment for the spacecraft.
  - Dependent on the environmental control of the clean room, typically 22°C±3°C, 45 to 65% humidity.
  - Different classes of clean room (e.g. class 100,000), depending on requirements.
  - Test chambers used to simulate the more severe operational environments (in-orbit).
- **Shipment**
  - Spacecraft assembly is usually a transnational endeavour involving shipment of equipment between countries before final assembly.
  - Environmentally-controlled transport containers employed.
- **Launch**
  - On the launch pad (under faring).
  - Through the launch phase, before and after faring jettison.
- **In orbit**
  - Also re-entry becoming more important (removal of space debris).

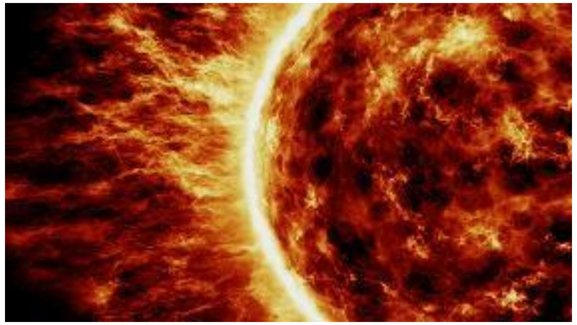
Launch Environment

- Under the faring, the spacecraft will be subject to the radiative heat from the faring due to aerothermal heating (dependent on launcher)
- After faring release, but before separation, rocket plume can have an impact – severe radiative environment.
- Attitude w.r.t Sun and Earth also different to final in-orbit conditions.
- Solar arrays, antennas etc. stowed. Usually a thermal design case.

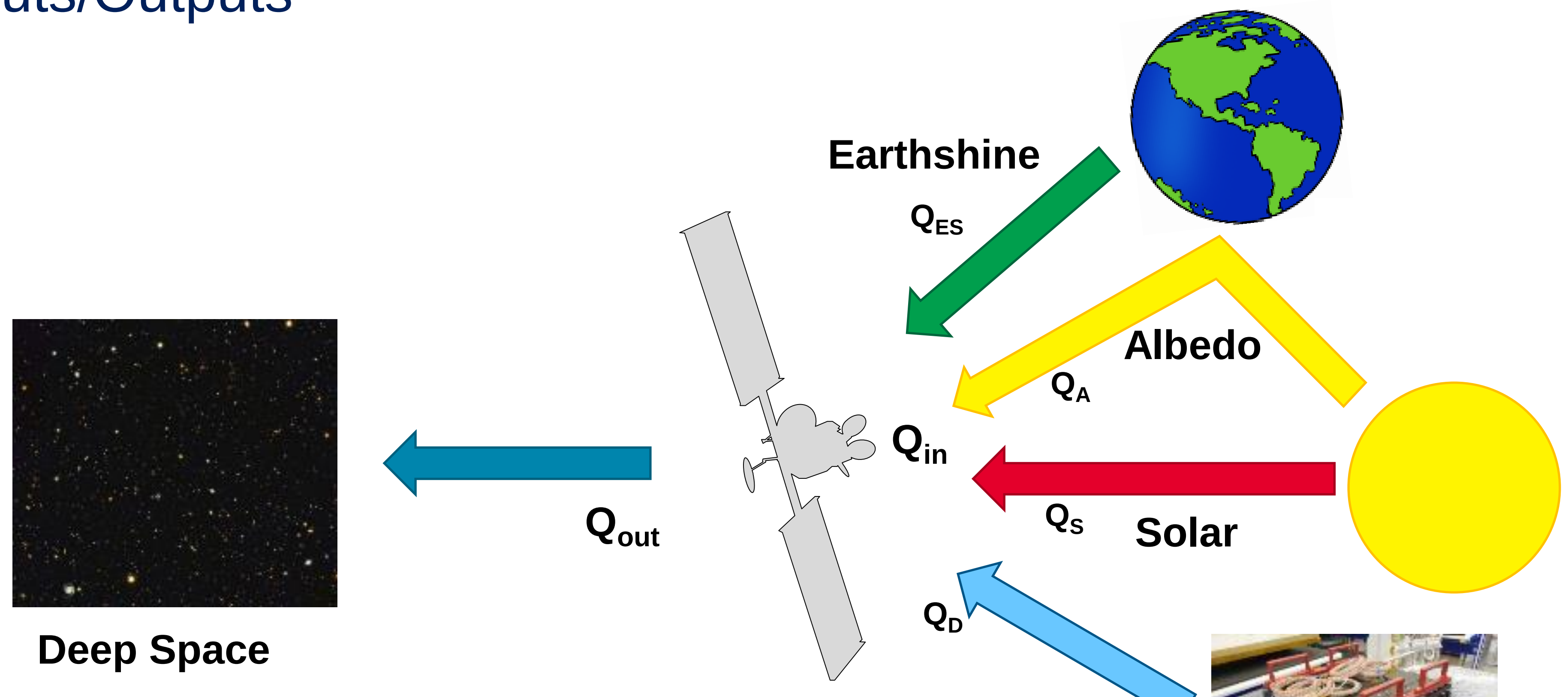
In-Orbit Environment

- **Space**
  - Radiation sink temperature = 2.7 K (-270°C)
  - Interplanetary vacuum (10^{-6} torr at 2200 Km): no convective exchange is possible
  - Indirect effects: out gassing and re-condensation
  - Weightlessness: Absence of natural convection in pressurised enclosure
- **The Sun**
  - Radiates as a black body of radius 69,600 km at 5781 K
  - Radiation peaks at 500 nm at visible wavelengths with some radiation in the UV and near infra-red wavebands.
  - Solar intensity at the orbit of the earth varies from 1326 to 1418 W/m2 as the earth-sun distance varies between 152 and 147 million km.
- **The Earth**
  - The earth radiates as a black body at an average temperature of 254 K. This radiation is in the far infra-red at a wavelength of about 10 mm. This is referred to as earthshine.
  - The earth reflects sunlight with a reflectivity (albedo) of about 0.31.
- **Other Celestial Bodies** (Planets, Asteroids…)





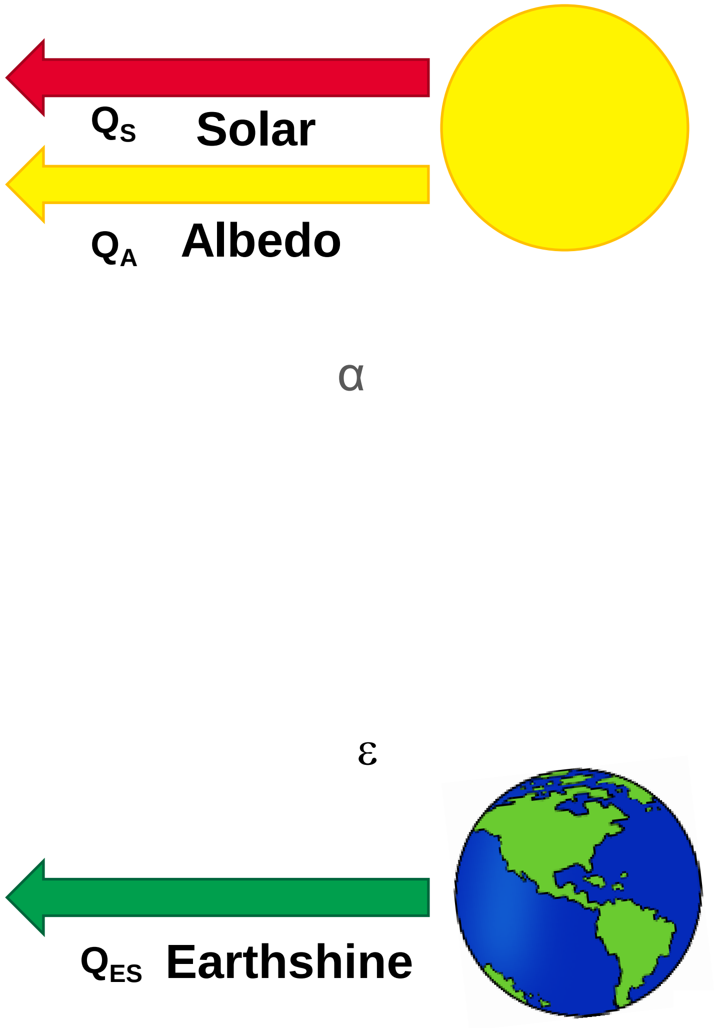
Heat Inputs/Outputs



$$Q_{IN} - Q_{OUT} = m.C_p.\frac{dT}{dt}$$

Difference between Heat In vs Heat Out = Rate of Change in Temperature

Environmental Inputs - Solar Flux and Albedo



- **Solar:**
  - 0.2 μm to 4 μm in the visible
  - Exchange is governed by absorptivity (α)

    α = mean absorptivity over the solar spectrum

- **Albedo:**
  - Solar radiation reflected by the earth and its atmosphere, in the visible
  - Exchange is also governed by absorptivity (α)

- **Earthshine:**
  - Emitted by the earth and its atmosphere in the infra-red (4 μm to 30 μm)
  - Exchange is governed by emissivity (ε) instead
    - See Kirchhoff's law (ε=α a IR wavelengths)

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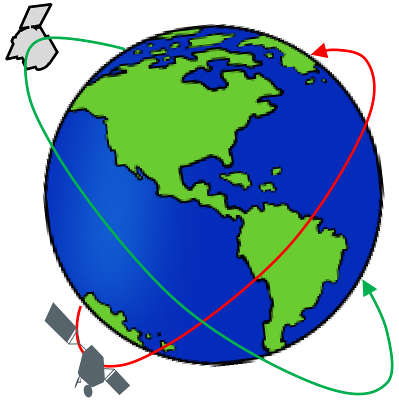
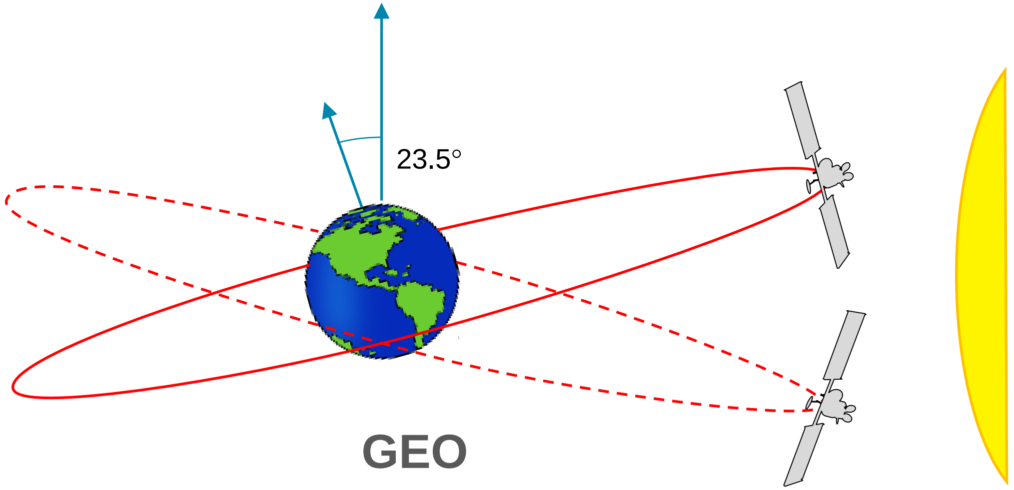
Orbits

- **Common Orbits**
  - **Low Earth Orbit (LEO)** (< 1000 km): orbital period about 100 minutes, high earthshine and albedo, in eclipse every orbit (except dawn-to-dusk sun synchronous orbit).
  - **Geostationary Orbit (GEO):** very high (36000 km), earthshine and albedo very low, orbital period 24 hours, eclipses only near equinox (72 minute maximum).
- **Seasons**
  - The earth's axis is tilted at 23º to the orbit plane.
  - The sun is overhead at 23º N at summer solstice (21st June) and at 23º S at winter solstice (21st December).
  - The sun is over the equator at the vernal and autumnal equinoxes (21st March and 21st September).



LEO

(All manner of orbits possible)



GEO

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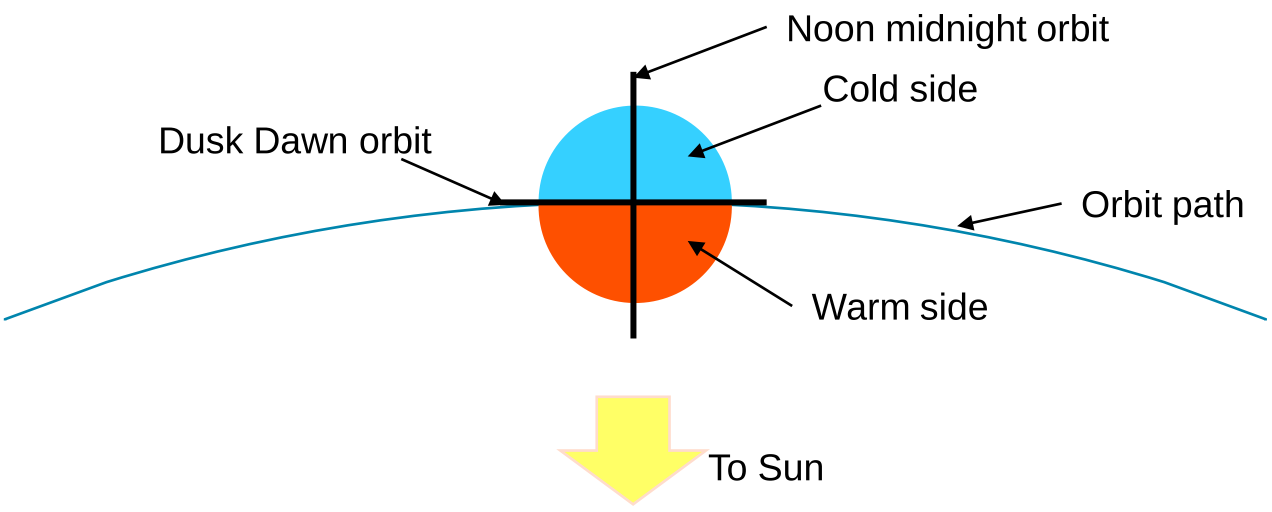
Orbits Continued and Planetary Environments



- Different planets generate very different Environments, The table below shows the effective temperature for IR flux from a selection of planets
- The table also shows the solar constant at that distance and the albedo, which scales the albedo flux
- Planets can also be modelled by a temperature map (accounting for differences in day and night temperature if needed)

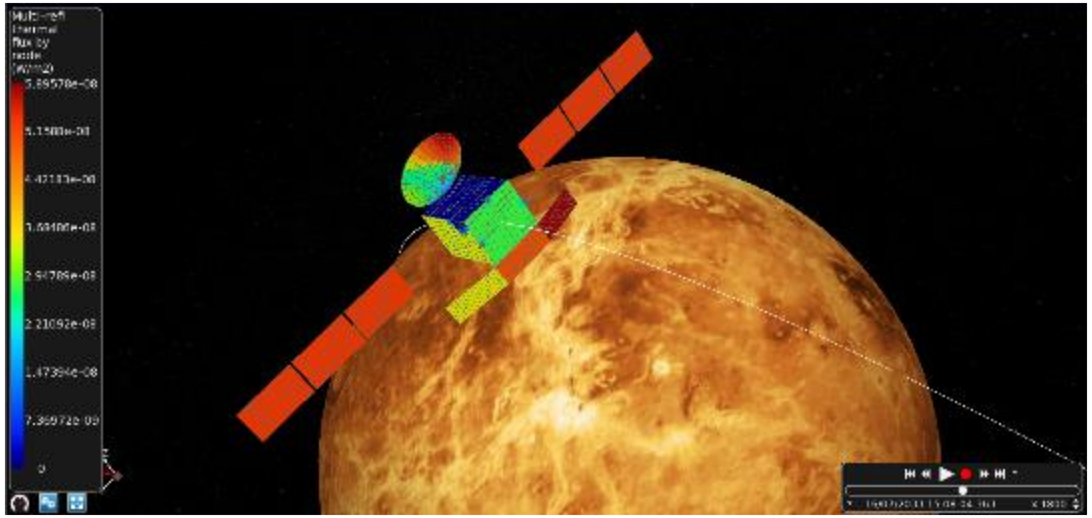
Planet	Solar Constants	Albedo	Planet IR temperature (day/night)
Mercury	9160 W/m^2	14%	427°C/-183°C
Venus	2620 W/m^2	69%	-43°C/-43°C
Earth	1373* W/m^2	43%	-25°C/-25°C
Mars	591 W/m^2	17%	20°C/-140°C
Jupiter	53 W/m^2	54%	-127°C/-163°C

- The orbit around the planet also has a big impact on the flux that the spacecraft receives
  - Dawn/Dusk orbits tend to have minimal albedo due to the angle to the sun, however have no eclipse and so constant solar flux, and also usually a high temperature for the IR flux
  - Noon-midnight orbits have a large albedo flux during the sun side part of the pass, but then none in the night, with an eclipse too.

Atomic Oxygen

- Atomic Oxygen is a single atom of Oxygen, not in an O2 molecule
- It is found in the high atmosphere (LEO<600km) of several planets and is extremely reactive
- It is generated by UV radiation splitting Oxygen molecules
- Atomic Oxygen will erode most materials, including Kapton
- Silicon Dioxide and Beta cloth are particularly resistant

- Analysis can be performed around Earth and around other planets with some limitations
- Simulation can account for wind and thermal velocity effects, as well as reflections
- Output of simulation is the fluence on a surface over an orbit (in atoms /cm2)



Spacecraft Environments

Mechanical

Shawn Orford

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Aim

- To provide an overview of the Mechanical Environments that are applicable for a Spacecraft Design
- This presentation will cover the Mechanical Loads that need to be considered for the design of a Spacecraft:
  - On-ground
  - During Launch
  - In-orbit

Classical Loads for Spacecraft During Their Lifetime

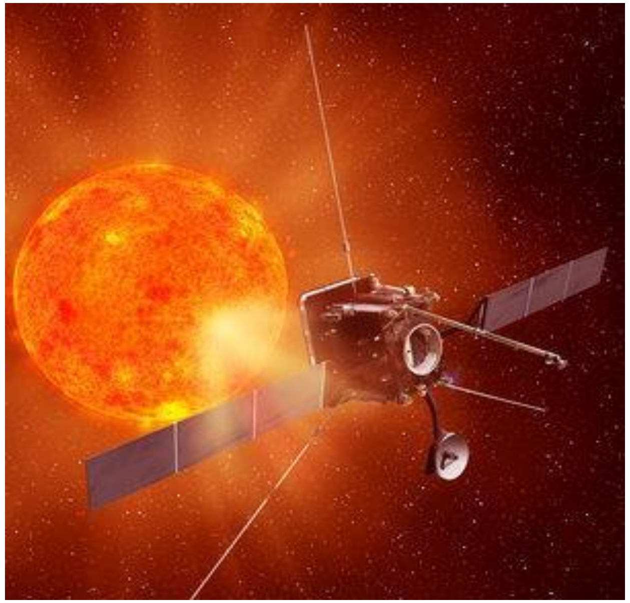
On Ground

Integration
Handling / Lifting
Transportation

Launch

Constant Acceleration
Sinusoidal Acceleration
Vibroacoustic
Random Vibration
Mechanical Shock

In Orbit



Mechanical Shock
Thermal
Differential Expansion
Gravity release
Hygroscopic (Moisture release)
Microvibration

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ON GROUND LOADS

On Ground Loads

- Integration:
  - Integration occurs with the spacecraft in various configurations, incomplete structure.
  - Integration occurs at different spacecraft orientations (horizontal, vertical, in-between, rotations about its axis).
  - Integration occurs under a 1g environment.

On Ground Loads

- Handling/Lifting
  - Spacecraft is moved around the factory on trolleys.
  - Spacecraft is lifted at lifting points. The lifting points must support the entire mass of the spacecraft plus the mass of adapters.
  - Significant safety factors applied.

On Ground Loads

- Transportation
  - By road, rail, sea, air
  - Spacecraft could be vertical or horizontal (cantilevered) within the transport container
  - Can be specified as static acceleration (g) or shock acceleration (g) over a specified time period.
  - Significant safety factors applied.

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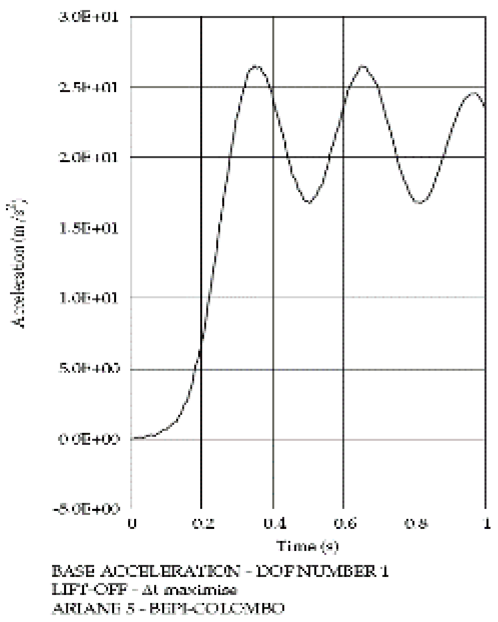
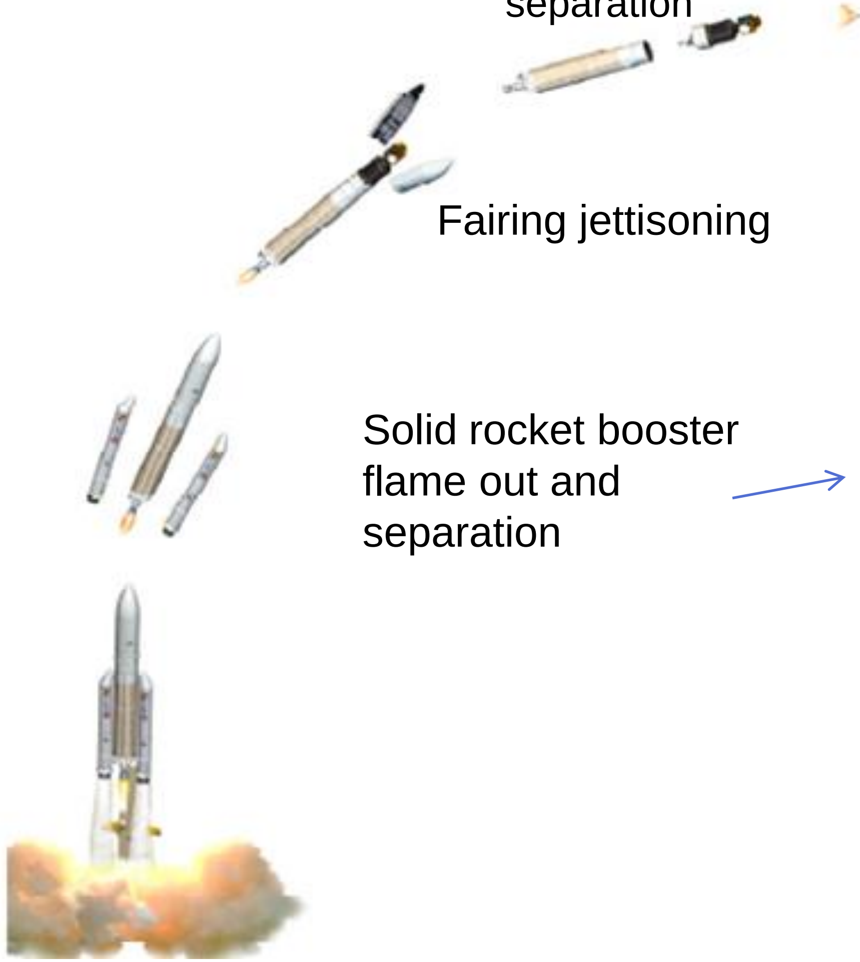
LAUNCH LOADS

Launch Loads



Main engine ignition, Solid rocket booster ignition and lift off



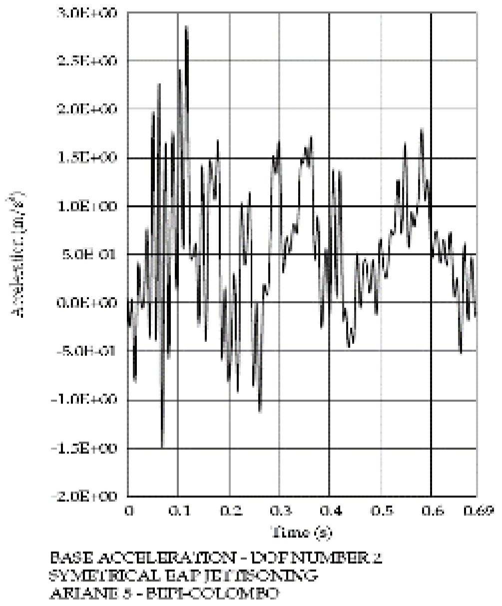
Main engine shutdown and separation

Upper Stage Ignition

Upper Stage Shutdown

Fairing jettisoning

Solid rocket booster flame out and separation

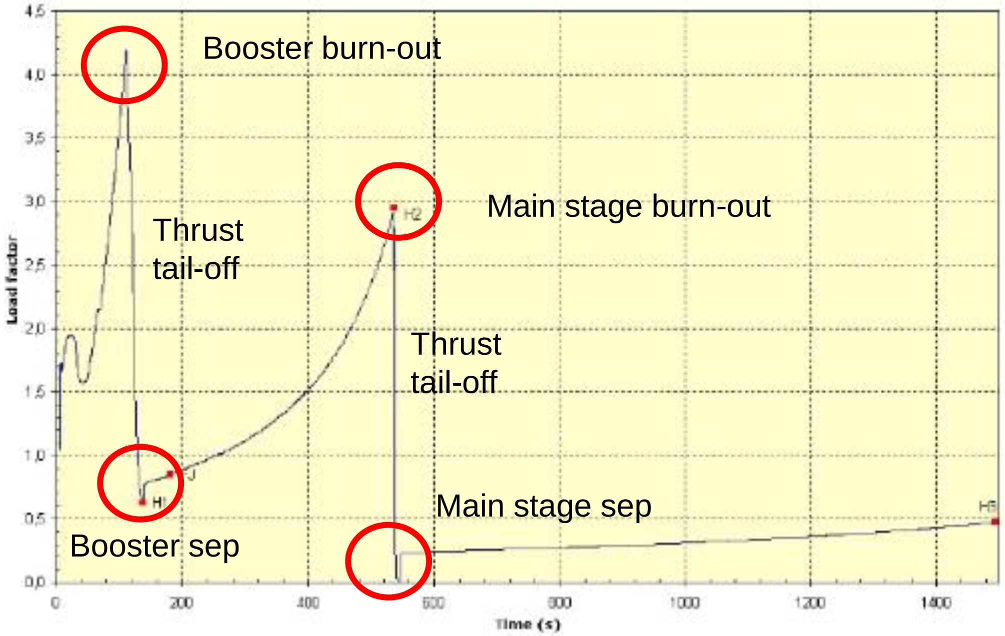


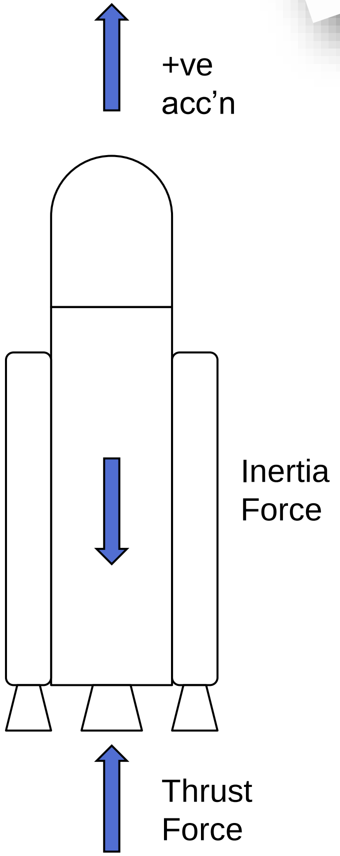
Launch Loads – Quasi-Static

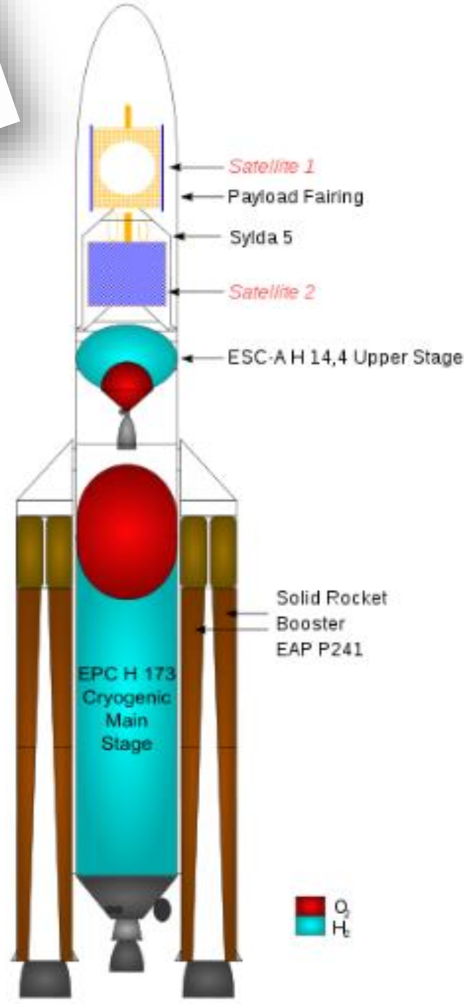
- Where do the quasi-static loads come from?
  - Loads due to flight events e.g. Lift-off, Q Max, booster release, …
  - Each event comprises a static (constant acceleration) and dynamic (time-varying) component of acceleration
  - Inertial effects can be ignored (relatively ‘slow’ change)
- When is it at it’s worst?
  - Typically worst at end of rocket booster / main stage burn phases (i.e. max thrust, least fuel mass)
- How can it be minimised?
  - Static component - cannot be minimised. Function of launcher performance / capacity
  - Dynamic component - Launcher design aims to limit transfer of SRB oscillating loads by isolation (structural damping)

Acceleration (g) / Critical flight events	Longitudinal		Lateral
	Static	Dynamic	Static + Dynamic
Lift-off	- 1.7	± 1.5	± 2
Maximum dynamic pressure	- 2.7	± 0.5	± 2
SRB end of flight	- 4.55	± 1.45	± 1
Main core thrust tail-off	- 0.2	± 1.4	± 0.25
Max. tension case: SRB jettisoning	+ 2.5**		± 0.9

The minus sign with longitudinal axis values indicates compression.
Lateral loads may act in any direction simultaneously with longitudinal loads.
The Quasi-Static-Loads (QSL) apply on payload C of G.
The gravity load is included.

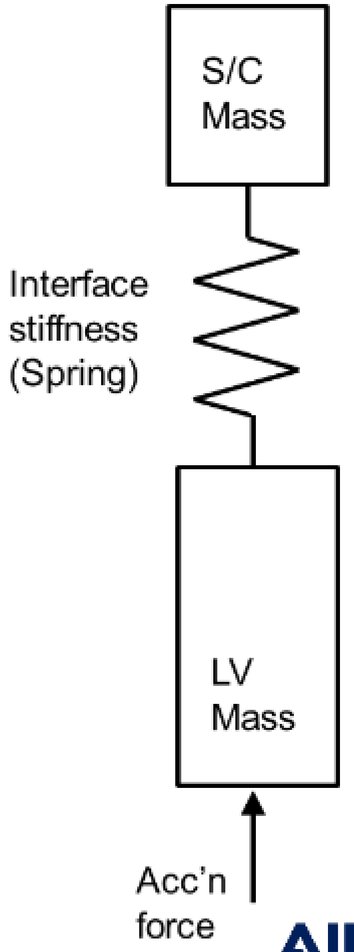






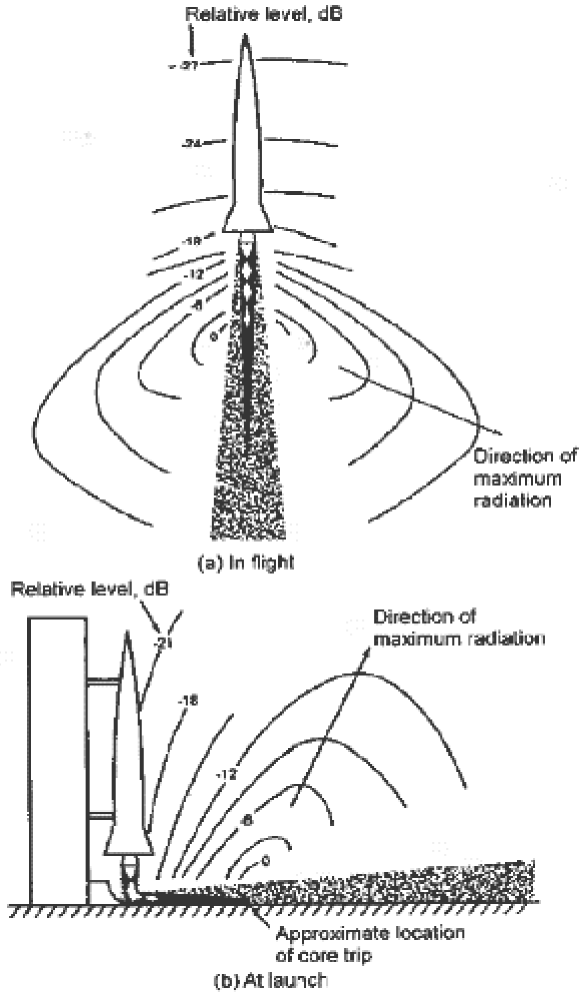
Launch Loads - Sinusoidal Acceleration

- Where do sinusoidal loads come from?
  - Dynamic load is time dependent and for which inertial effects cannot be ignored
- When is it at it's worst?
  - Lift-off (or 2nd stage motor start-up) where fast build-up of thrust causes an impulse that excites the low frequency domain (5 – 120Hz)
  - Low frequency thrust oscillations due to uneven nature of rocket fuel burning (particularly liquid fuel)
  - 'Pogo-stick' effect that typically occurs just before burn-out of stage. This due to mis-firing / 'coughing' of motor as fuel runs out
- How can it be minimised?
  - Control of dynamic behaviour by the decoupling of systems



Launch Loads – Vibroacoustic

- Where does acoustic come from?
  - Noise of launch vehicle engines
  - Separation of airflow along the launch vehicle
  - Aerodynamic noise
- When is at it's worst?
  - During lift off when sound waves are deflected from launch pad
  - During transonic flight (velocity less than speed of sound) when air density is high, turbulent airflow
  - Typically is experienced for the first 60s of flight
- How can it be minimised?
  - Water spray at launch pad to reduce deflected noise
  - Use of acoustic absorbing materials inside launcher faring



Launch Loads - Random Vibration

- Where does it come from?
  - Mostly originates as a product of acoustic (typically is not specified in the launcher user manual)
  - But is specified in SOYUZ launcher manual arising from rail transportation (vibration)
  - Some Random Vibration generated directly from the rocket motors but is not so significant for the payload
- When is it at it’s worst?
  - In the same events as acoustic since it is (in most cases) derived from acoustic
- How can it be minimised?
  - By minimising acoustic environment
  - Control of dynamic behaviour by the decoupling of systems

Launch Loads – Shock Loads

- Where does it come from?
  - Shock occurs due to the firing of explosive bolts/nuts to allow separation of rocket stages, fairing jettisoning, release of satellite, and appendage deployment
- When is it at it's worst?
  - Clamp band firing when the satellite separates from the launch vehicle is typically most severe
  - Fairing jettison event is significant for VEGA & Rockot launchers
  - S/C Appendage deployment is usually less severe but potentially closer to sensitive equipment
- How can it be minimised?
  - Use of isolation systems
  - e.g. Elastomeric layer of material to attenuate the shock

IN ORBIT LOADS

In Orbit Loads

- Shock Loads
  - Due to release of appendages, solar arrays, antennas, booms etc…
  - Normally less severe that launch vehicle separation but can be driving loads for nearby sensitive instruments.
- Thermal Differential Expansion Loads
  - CTE mismatch within Spacecraft structural design can result in high thermal stresses and misalignments
  - Can be minimised by re-distributing the load (e.g. flexible cleats)
- Gravity Release
  - Spacecraft structures are built under 1g environment. In-orbit the gravitational effect is released which will change alignments
- Hygroscopic Loads (moisture release)
  - Applicable for CFRP structures. Moisture is held within the structure on-ground which is released in orbit which will change the shape and hence change the alignment of the structure.
- Microvibration
  - Moving parts within the spacecraft, e.g. reaction wheels will cause in-orbit vibrations that need to be considered for sensitive optical instruments due to potential jitter.

Thank you

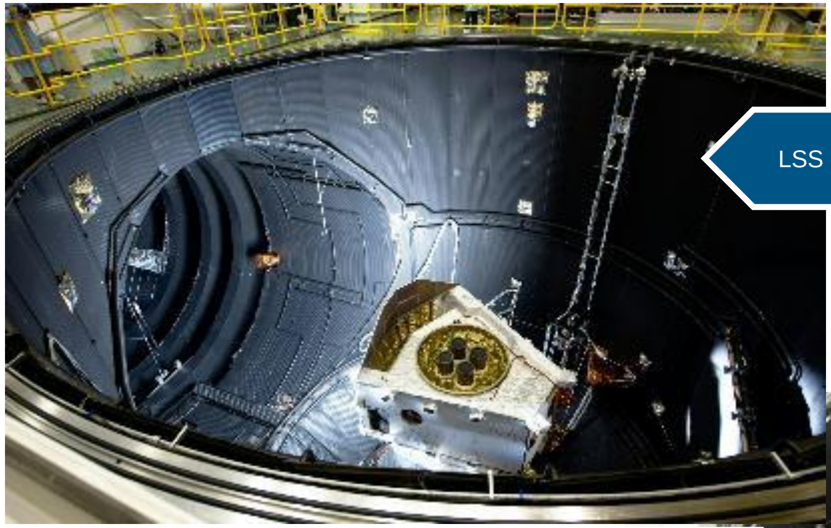
Backup Slides

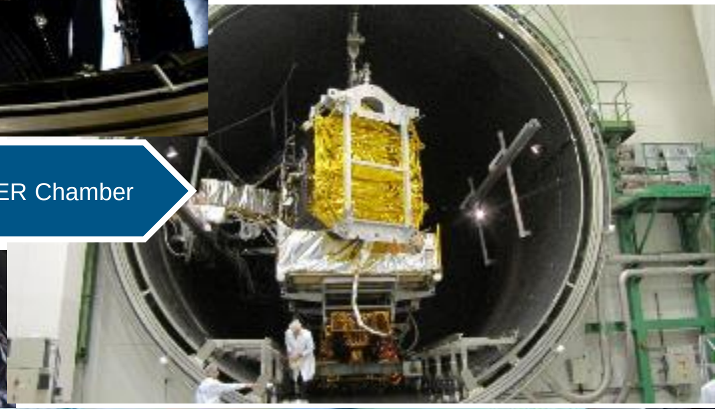
Test Methods and Facilities

- **Thermal Vacuum (TV or TVAC)**
  - To show that the complete spacecraft system operates successfully at temperatures above and below the extreme temperatures expected in flight
  - Typical target: to keep as many units as possible just inside their acceptance temperatures (sometimes the qualification limits).
  - Spacecraft and payload tested in all operating modes.
- **Thermal Balance Tests (TB)**
  - To verify the accuracy of the thermal mathematical model used to determine the spacecraft thermal design.

Chambers need to be:

- Capable of evacuating to near vacuum conditions ($<10^{-5}$ Pa)
- Capable of cooling to near deep-space temperature (< -170°C)
- Capable of Solar Simulation (not always required)


LSS Chamber


SIMMER Chamber


SIMLES Auxiliary Chamber

IABG Space Simulation Facility

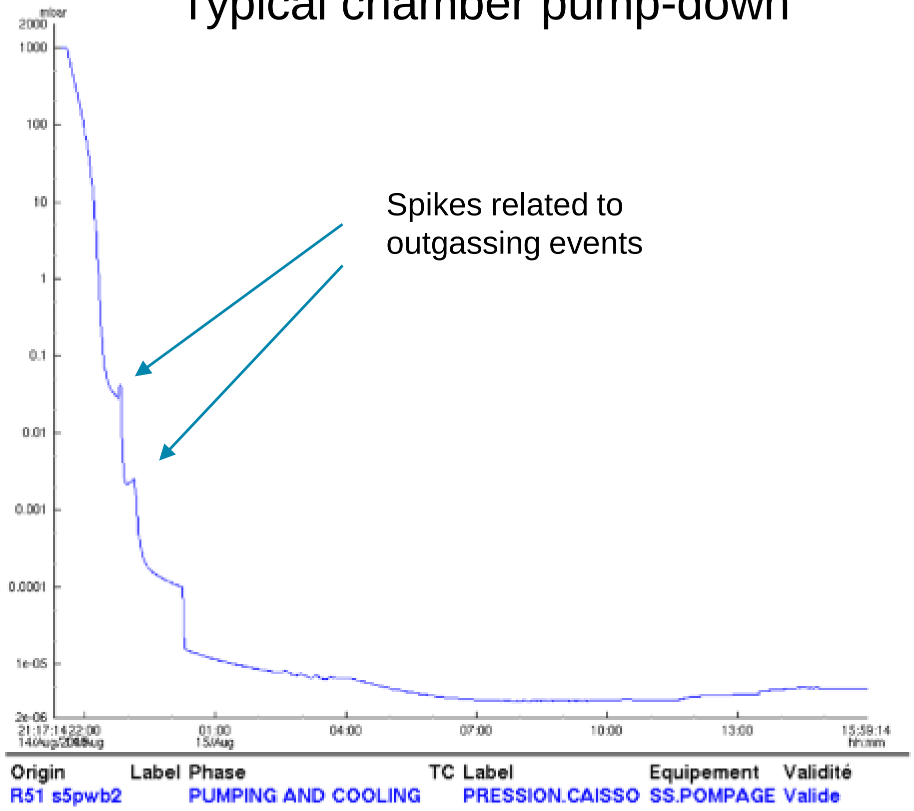
AIT Considerations for TVAC

- Thermal vacuum (TVAC) are complex tests:
  - As test requires an evacuated, cooled chamber, (typically 24 hours to reach test conditions) stopping is not option without significant cost/schedule impact.
  - Once underway, a 24-hour shift pattern is maintained to complete all testing and monitoring to ensure spacecraft health for the duration of the test.
- Significant amounts of electrical and mechanical ground support equipment (EGSE/MGSE) are required to support functionality in the chamber:
  - Solar array power simulators.
  - Harness connections to connector brackets to allow test equipment to ‘talk’ to the spacecraft.
  - Test monitoring and control hardware (thermocouple and thermistors.
- All MGSE/EGSE needs to be vacuum and temperature compatible, and not degrade the spacecraft performance.

Molecular Contamination

- It is important to be aware of the behaviour of materials under vacuum conditions and the tendency to outgas and release contaminants.
  - At basic level, pressure is the effect of molecular collisions on a surface. When a material is subject to decreasing pressure (e.g. during the TVAC pump-down phase), the material itself can release particles into the lower-pressure environment of the chamber.
  - These contaminants originally come from a variety of sources including adhesives used during manufacture and ground environments during build and test.
  - Molecular Contamination levels are usually measured in g/cm^2.
- During preparation of materials and parts for TVAC, there are two means to control this:
  1. Minimise sources of initial contamination e.g. fingerprints (using gloves), other clean-room sources e.g. adhesives and lubricants. Covers for key equipment.
  2. Perform material ‘bake-outs’: a process whereby the materials are heated in a smaller chamber to high temperatures and (typically) low pressures.
- For this reason the initial part of a TVAC is usually a hot phase, to help remove residual contaminants via a ‘cold trap’ in the chamber

Typical chamber pump-down



SPACECRAFT MECHANICAL TESTS

Spacecraft Mechanical Tests

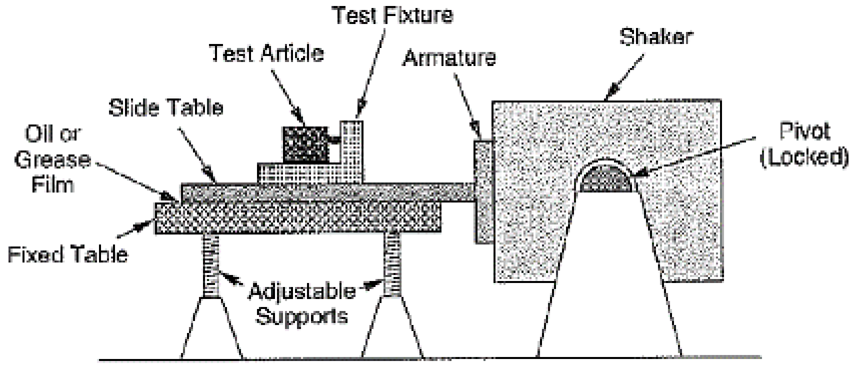
- Static
- Sine Vibration
- Acoustic
- Shock and deployment
- Other
  - Mass property measurements, Microvibration, Thermal Elastic Distortion

Static Testing

- Often performed on primary structure of the spacecraft (main load carrying elements) statically tested to cover launcher quasi-static loads
- Loads applied with either weights or hydraulic jacks.
- Quasi-static loading can be applied on a vibration table.

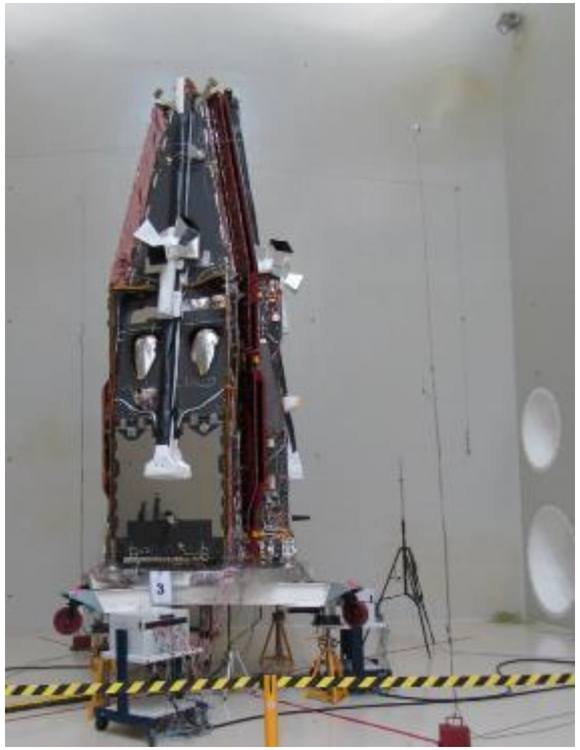
Sine Vibration

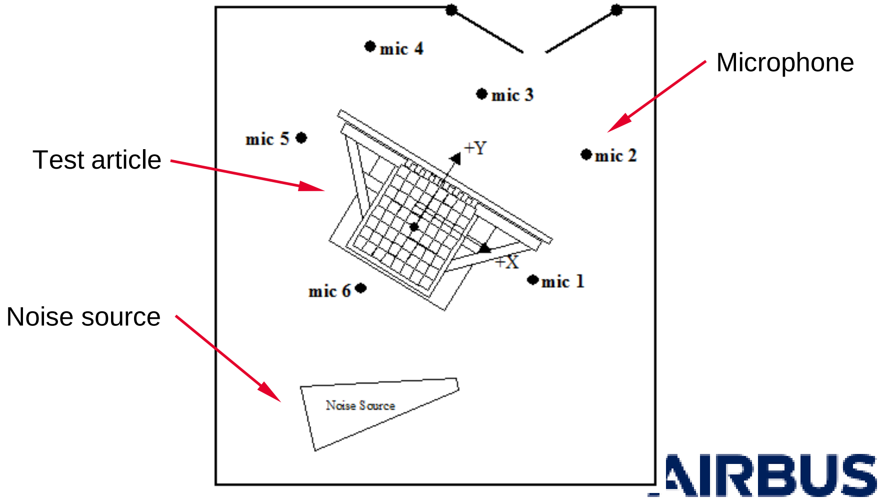
- Can be used for modal survey, quasi-static, sine and random testing
- Test in each individual spacecraft axis
- Accelerometers used to recover accelerations around the structure, at key interfaces and on key appendages.
- Force measurement device can be used at the base
- Strain gauge results can also be recovered if needed.



Acoustic

- Launcher acoustic environment should be simulated.
- Testing performed in a reverberant chamber.
- Direct field acoustic testing (speakers arranged around the spacecraft) is also possible.
- Aim to ensure even sound pressure levels around the spacecraft.
- Microphones used to measure sound level.
- Accelerometers used to recover accelerations around the structure, at key interfaces and on key appendages.





Shock and deployment

- Shock and deployment tests performed at spacecraft level:
  - Clampband release and shock testing
  - Solar array release and deployment testing
  - Antenna release and deployment testing
  - Any other deployable system e.g. deployable booms, separation systems between modules
- Source shocks and shocks through the structure measured with accelerometers