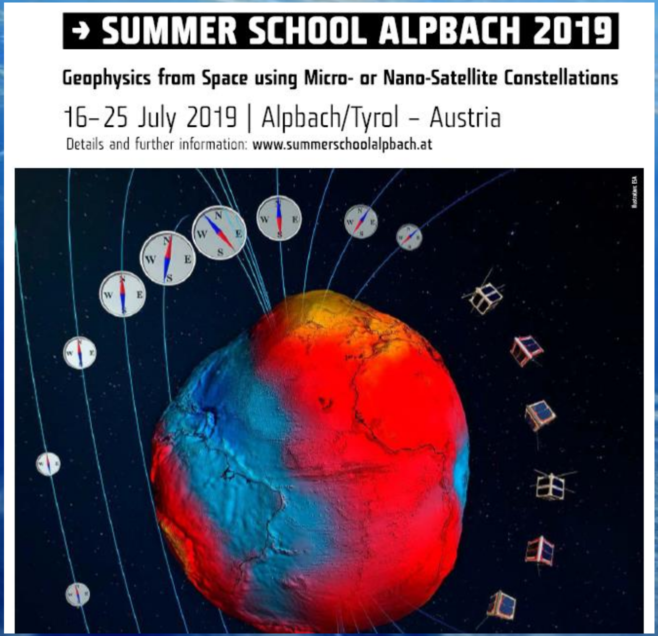
Summer School Alpbach 2019

Mission and System Design

Peter Falkner (ESA)

17-July 2019

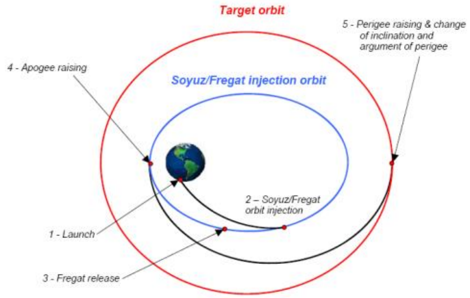


Content

- Mission Elements
- Mission Design Process
- Launcher
- Orbits & Environment
- Spacecraft Subsystems
- Operations
- Programmatics (Cost, Risk, Schedule)

Space Mission Elements

Orbit - Constellation

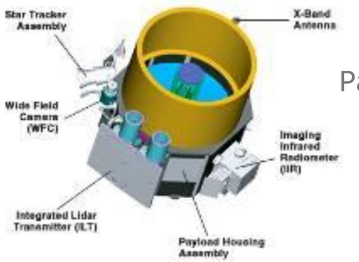


Launcher

(Science) Data Center

Spacecraft

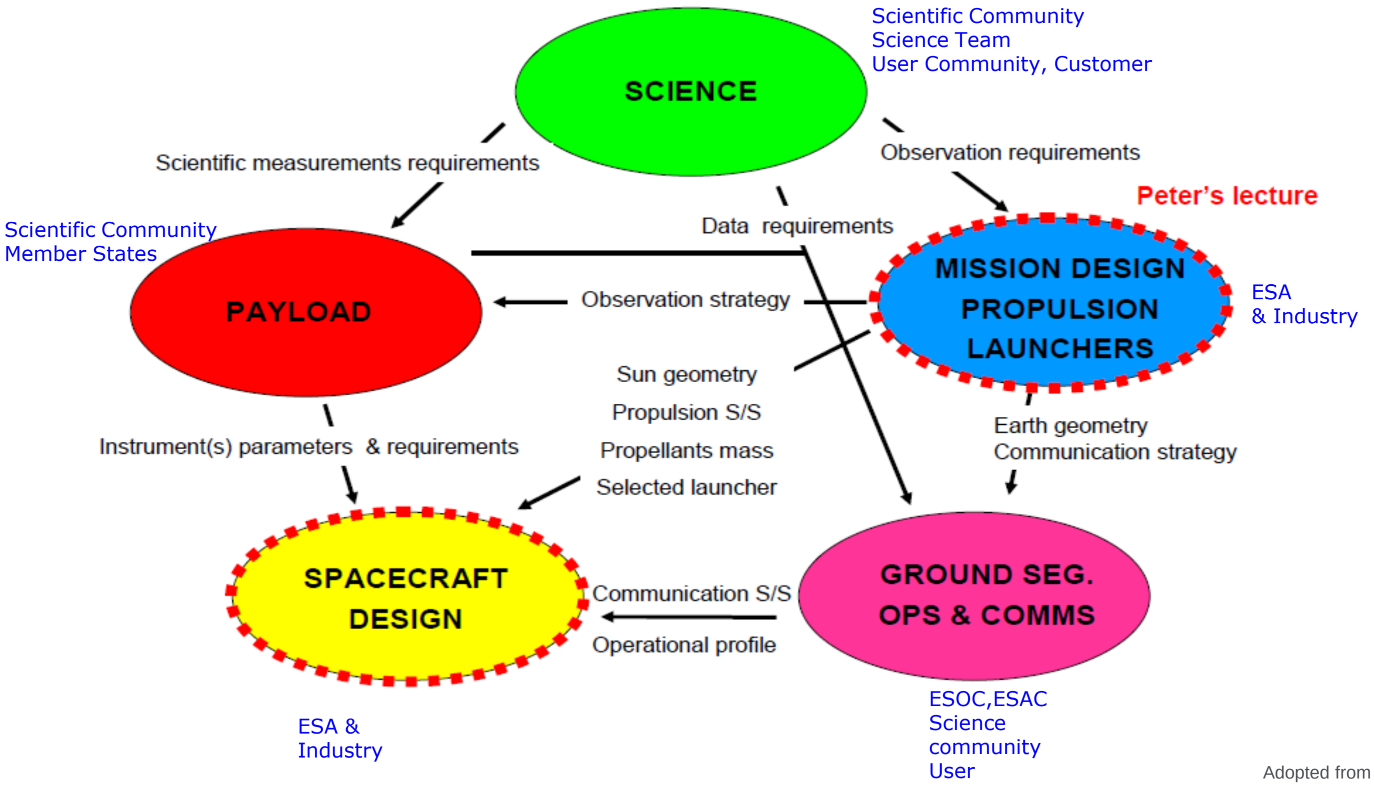
Mission Operation



Payload

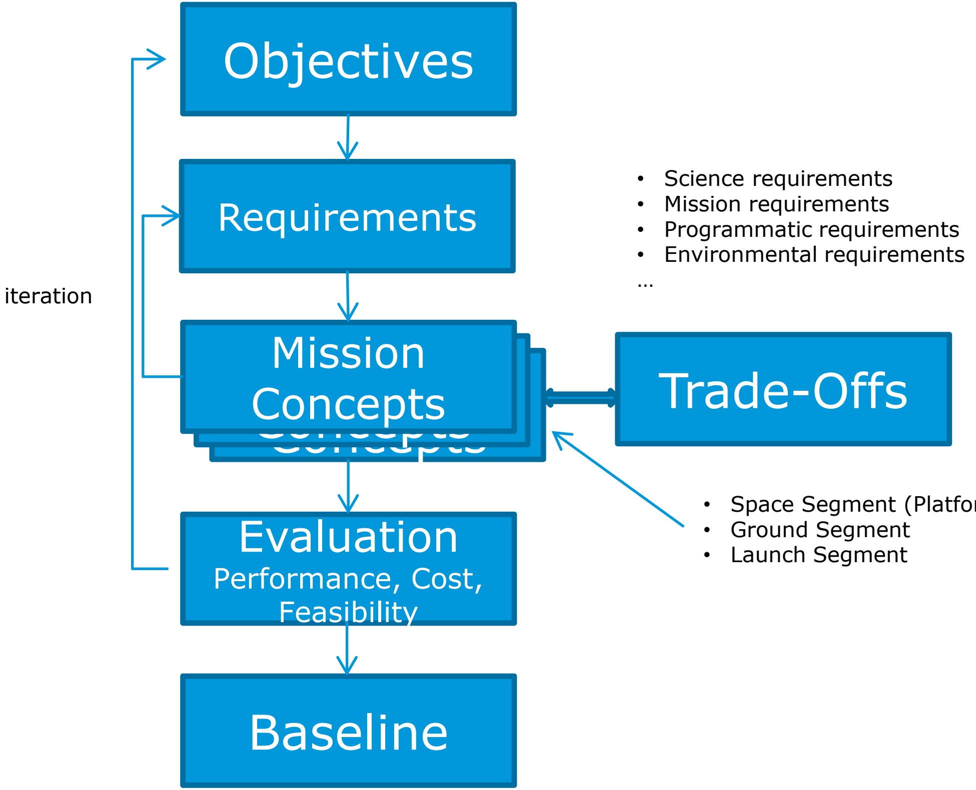
Ground Station(s)

Mission Design Process



Adopted from D. Moura

Mission Design Process



- Science requirements
- Mission requirements
- Programmatic requirements
- Environmental requirements

…

- Space Segment (Platform, Payload)
- Ground Segment
- Launch Segment

Hints for the Mission Design

- Kiss principle = Keep it Simple (Stupid)
- Avoid Christmas trees (by adding unneeded stuff to make it attractive)

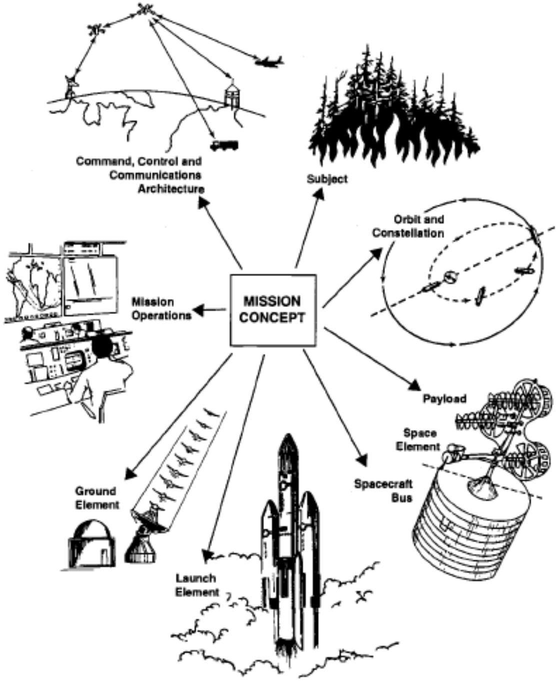
System Design / End-to-End view

<u>Study Phase 0</u>:

- Analysis of Mission Objectives
- Analysis of Mission Constraints
- Definition of Science & Measurement Requirements
- Definition of Mission Architecture (s)
- Definition of Payload / Performance
- Analysis of Environment
- **Iteration / Trade phase !**
- Cost, Risk, Schedule, Technology Development

<u>Goal:</u>

- **feasible mission profile**
- **satisfying requirements <u>and</u> constraints**



SMAD E3 , p. 13 Space Mission Architecture

Launch Vehicle

The new ESA launcher

VEGA-C

Illustration of the two Ariane 6 variants planned, A62 (left) and A64 (right)

- Provide access to space
- **Main trade**: performance/reliability/cost
- Trade: direct transfer vs. optimisation of launcher insertion orbit (spacecraft design dependent)
- Attention (!): launch environment/constraints (incl. launch site)
- Cost: Soyuz Fregat-2B (75 M€), Ariane 5 ECA (165M€), VEGA (45M€) *
  Ariane 62 (~75M€), Ariane 64 (~150M€), VEGA-C (~40M€)*

  * Note: LV cost indicative for the purpose of Alpbach SSA 2019 costing exercise
- Possibility of sharing launch (e.g. Herschel / Planck, Smart-1, ARIEL, shared GTO) ⇨ Cost sharing
- Performance: SF-2B ~ 3.200 kg to GTO (~ 5.000 kg A62)
  A5 ECA ~ 10.000 kg to GTO (~ 11.000 kg A64)
- For details ⇨ **see launcher user manuals** (web or Alpbach Server/../Peter Falkner)
- For A62/A64: use SF-2B/A5 performance + scaling (from GTO performance)
  same for VEGA-C (vs. VEGA) scaling based on LEO performance

Next generation ESA launcher:
⇨ VEGA-C, Ariane 62 and 64
⇨ Before maiden flight (2020)
⇨ Some performance uncertainty

Launcher	Vega	Soyuz	Ariane-5 Generic	Ariane-5 ECA
Orbit	SSO/LEO	GTO	GTO	GTO
Payload mass, kg	1500 (700 km)	3000	6600	10000

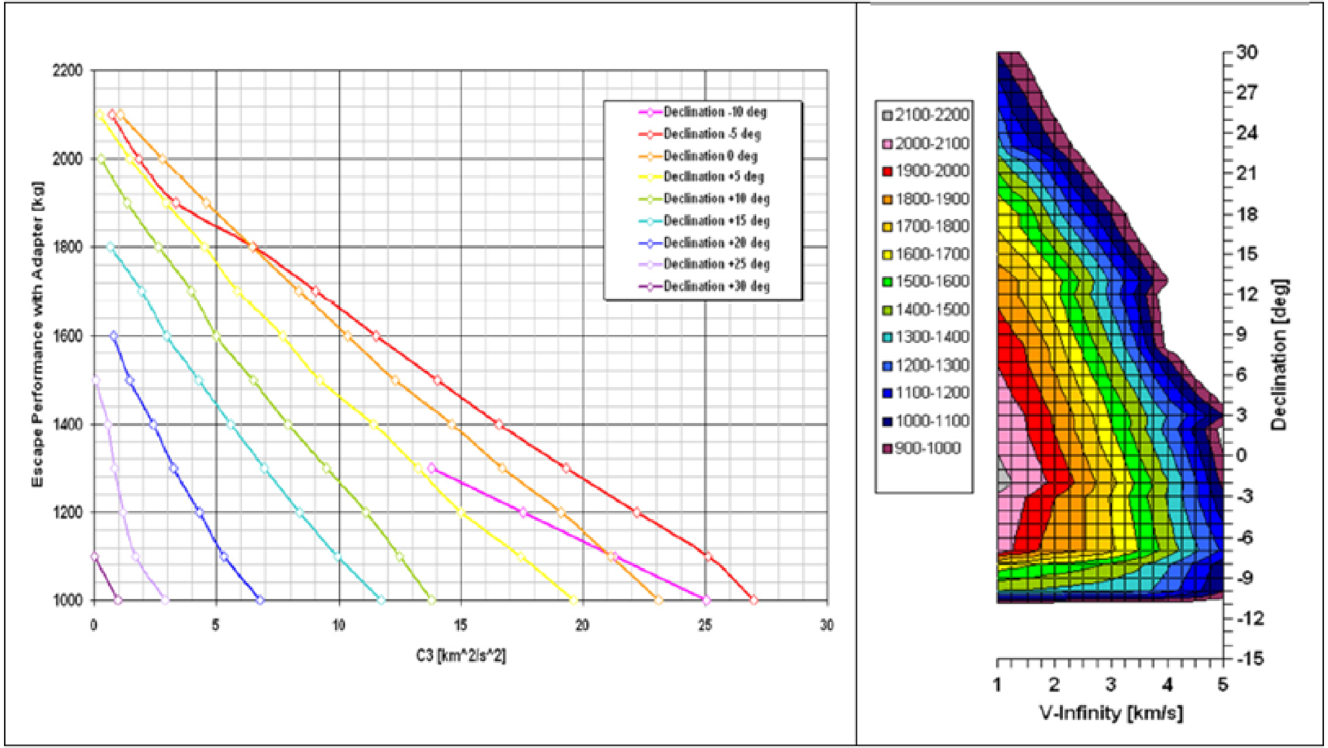
SSO/LEO: Sun Synchronous Orbit/Low Earth Orbit, GTO: Geostationary Transfer Orbit

The current ESA launcher

Vega performance

Orbit	Lift mass
700 km circ., i=90°	1430 kg
400 km SSO, i=97.03°	1480 kg
700 km SSO, i=98.19°	1325 kg
1000 km SSO, i=99.48°	1140 kg

LV example: Soyuz performance for escape



Orbit Design

⇨ see lecture by Marcus Hallmann (DLR)

Mission Analysis

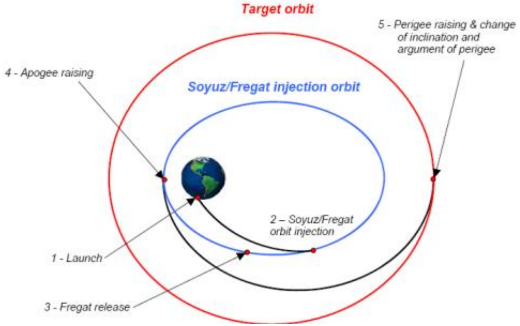
- Launch and transfer from Earth
- Insertion into target orbit
- Orbit and maintenance
- End-of-Life disposal (space debris regulation!)

⇨ All manoeuvres to be summarized in Δv-budget

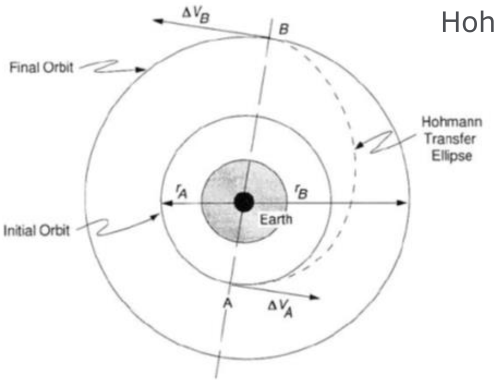
⇨ use "rocket equation" to calculate propellant need

Important: analysis of perturbations

- e.g. third bodies perturbations (lunar, solar,..)
- solar radiation pressure (translation, rotation)
- micrometeorites, space debris
- for LEO,LVO,LMO: atmospheric drag, J-factors



Hohmann Transfer



Hohmann Transfer. The Hohmann Transfer ellipse provides orbit transfer between two circular, co-planar orbits.

Atmospheric drag & Solar radiation pressure:

$$a_D = -(1/2)\rho\,(C_D\,A/m)V^2$$

$$a_R \approx -4.5 \times 10^{-6}(1+r)\,A/m$$

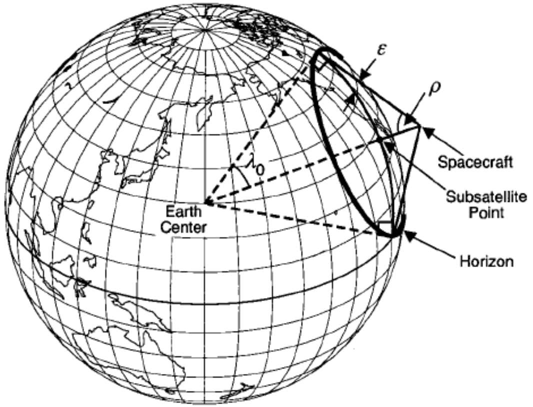
ρ is atmospheric density, A is the satellite's cross-sectional area, m is the s/c mass, V is the satellite's velocity with respect to the atmosphere, and C_D is the drag coefficient

Solar radiation: A is the satellite cross-sectional area exposed to the Sun in m^2 , m is the satellite mass in kg, and r is a reflection factor.

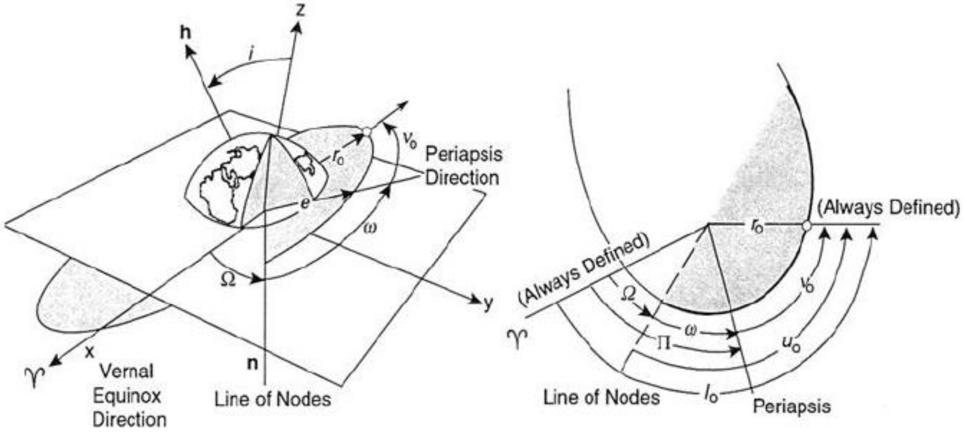
Orbit Selection

Driven by (contradicting) requirements:

- Target observability, resolution, revisit time, link budgets, visibility from ground stations, eclipse duration, radiation, stability,…
- Cost of orbit acquisition and maintenance (e.g. drag, J-term perturbations, 3rd body perturbations etc…)
- Consider Space debris regulations !



Relationship Between Geometry as Viewed from the Spacecraft and from the Center of the Earth. See also Fig. 5-12.



Definition of the Keplerian Orbital Elements of a Satellite In an Elliptic Orbit.

Some Examples

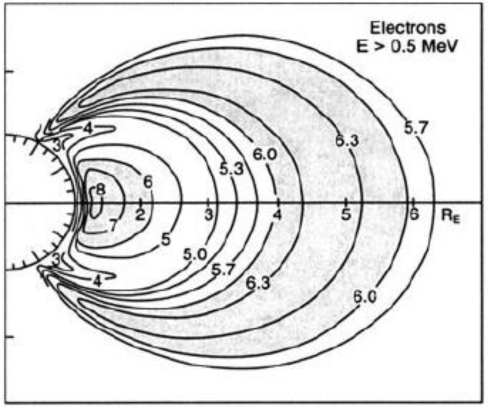
Earth Orbit		Earth Trailing		L2	
XMM-Newton	48h, 7000x114000km, 39°, RD[3]	**NASA Spitzer**	Drift-away 0.1AU y^{-1}	**SoHO**	Only libration mission by ESA, L_1, RD[6]
Integral	72 h, 9000x153000 km, 51.6°, RD[4]			**Herschel**	Large-amplitude orbit (quasi-halo), launch 2008, 3-axis platform, RD[7]
Corot	900 km circular polar LEO			**Planck**	15° Lissajous orbit, co-launch with Herschel, spinner, RD[7]
ISO	24 h 1000x70500 km, 5.3°, RD[5]			**GAIA**	15° Lissajous orbit, launch on Soyuz 2-1b from Kourou, spinner, RD[8]
HST	600 km circular 28° LEO				

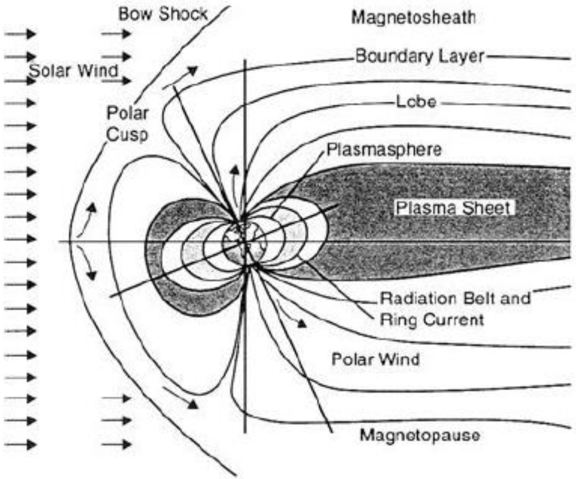
Space Environment

- Solar cycle (11-years) ⇨ flares
  Solar Protons: 1 MeV to > 1 GeV
- Radiation belts of Earth, Jupiter,…
  electrons, protons
  ⇨ SEU, total dose, background,…
- Cosmic rays
- Spacecraft charging
- Magnetic field
- Solar radiation pressure (SRP)
- Thermal environment (solar flux, albedo, eclipses, drag, (re-)entry,…)
- Vacuum, atomic oxygen in the upper atmosphere

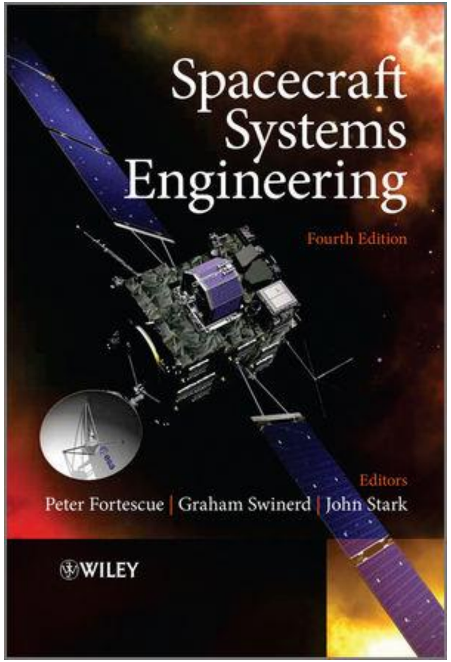
- **Radiation effects electronics, materials and increase noise in detectors (background)**

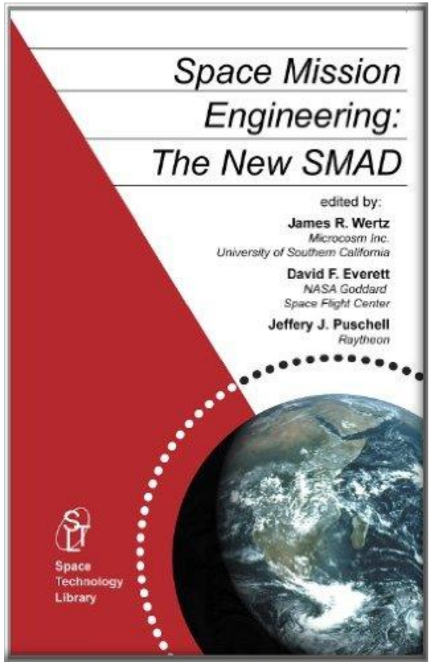
⇨ Extensive testing during development needed !





Spacecraft Subsystems





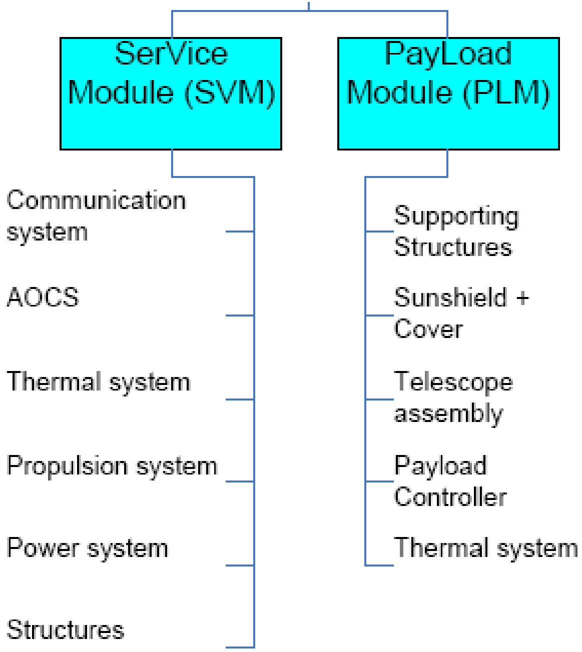
Spacecraft Subsystems

1. Structures & Mechanism
2. Propulsion
3. AOCS
4. Thermal Control System
5. Power
6. Onboard Computer & Data Handling
7. Telemetry, Tracking & Commanding (TT&C)
8. **Payload**

Important:

Interrelation and mutual dependence of subsystems

⇨ concurrent design



Product tree

(1) Structures & Mechanism

Distinguish:

- **Primary structures** (carrying s/c major loads, interface to launcher)
- **Secondary structures** (carrying equipment) & appendages

- Structure need to provide stiffness in all mission modes at lowest possible mass (most driving: launch, main propulsion manoeuvres, separation of stages, pyros firing etc.)
- **Sizing parameters**: acceleration, shock, vibration, acoustic noise (large surfaces!)
- **Critical parameter**: Strength, stiffness, density, thermal characteristics (expansion, conductivity), handling (machining), cost
- Thermal deformations / co-alignment requirements ⇨ important for Payload !
- Eigen frequencies > launcher induced frequencies = driving stiffness

$$\sigma \equiv \frac{\text{Load}}{\text{Area}} \equiv \frac{P}{A}$$

Stress σ [N/m²]

$$\varepsilon \equiv \frac{\Delta L}{L}$$

Strain ε

$$\nu \equiv \frac{\varepsilon_{lateral}}{\varepsilon_{axial}}$$

Poisson's ratio

$$E \equiv \frac{\sigma}{\varepsilon}$$

Young Modulus E [N/m2]

(1) Structures & Mechanism

Moving parts:

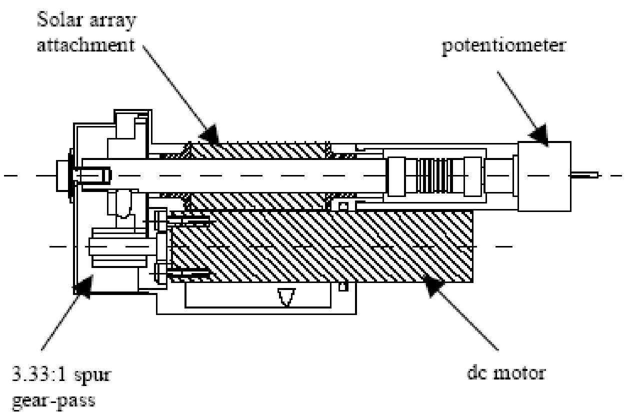
- Reliability is critical (lubrication in space, long storage, thermal range)
- Introduce vibrations, shock, shift of CoG

Examples:

- Launch lock mechanism (hold down release mechanism (HDRM))
- Deployment of structure, appendages and booms (e.g. solar panel, sun shield, antennae, …)
- Separation mechanism (separation of stages, multiple s/c,..)
- Pointing mechanism (e.g. payload, HG-antenna, panels)
- Reaction wheels, Flywheels,…
- Deployable instrument covers
- Motors and gears: e.g. Maxon
- Active Cooler
- Frangibolt actuator

⇨ **Mechanism are a source of mechanical noise (micro-vibrations)**

HDRM



(2) Propulsion

Provides: acceleration and torques
For: transfer, orbit insertion, attitude maincorrection and orbit corrections

Main engines (e.g. 400 N engine, I_{sp} ~320s)
- large delta-v, large I_{sp}, drive propellant need
- chemical (solid, liquid mon-, bi-prop),
- electrical (I_{sp} ~3000-4500s)

RCS-thruster and micro-thrusters
- Chemical
- Electrical
- Cold gas

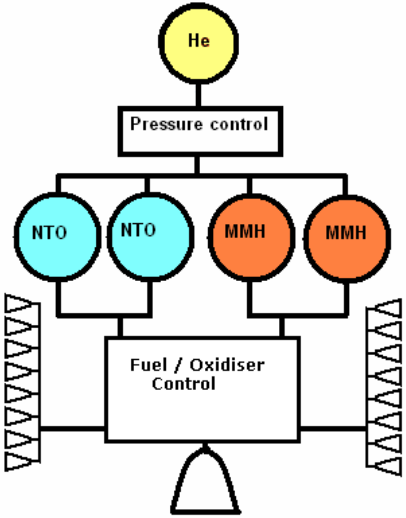
- Propulsion tanks + pressurant tanks
- Harness, piping

$$m_p = m_f\left[e^{(\Delta V / I_{sp}\,g)} - 1\right]$$

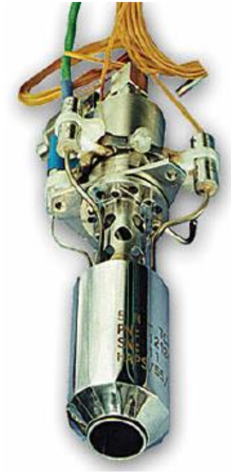
Rocket equation: m_f=dry mass, m_p=propellant
Isp=specific impulse, Δv=delta v

main engine

Propulsion Technology	Typical Steady State I_{sp} (s)
Cold Gas	30–70
Solid	280–300
Liquid	
Monopropellant	220–240
Bipropellant	305–310
Dual mode	313–322
Hybrid	250–340
Electric	300–3,000



Propulsion subsystem



RCS Thruster

Delta-v budget (example)

- Mission Analysis provides total delta-v (m/s) (dispersion, corrections, transfers, insertions, station keeping, orbit changes, wheel unloading, drag compensation,…)

⇨ selection of appropriate prop. system (main engine/thruster, chemical/electric/cold gas,…)

⇨ Use of rocket equation ⇨ propellant mass ⇨ sizing of tanks,…

⇨ Re-iteration when needed !

Manoeuvre	Delta-V	Margin	Total	Source	Notes
Launcher Dispersion	35.0	5%	36.8	Mission	
Orbital Transfer	4.0	5%	4.2	Mission	
Stationkeeping	12.0	5%	12.6	Mission	
Re- or De-Orbiting	0.0		0.0	Mission	
Trajectory Margin	0.0		0.0	Mission	
Cover Ejection Compensation	0.01	100%	0.02	AOCS	Compensate for 45 N force
RW Desaturation	4.9	100%	9.9	Propulsion	Cumulative over 6 years
Field Change Manoeuvre	0.0		0.0	AOCS	Use reaction wheels (no propellant)
Step-and-Stare Manoeuvres	0.0		0.0	AOCS	Use reaction wheels (no propellant)
Safe Mode Reserve	5.0	0%	5.0	Propulsion	
TOTAL			68.45 m/s		

$$m_p = m_f\left[e^{\left(\Delta V / I_{sp}\, g\right)} - 1\right]$$

(3) AOCS (attitude and orbit) / GNC (guidance and navigation control)

Stabilizes the spacecraft against external (and internal*) disturbances & Orbit control and maintenance

- 3-axis or spin stabilized (‘*gyroscopic stiffness*’)

- Analysis of pointing requirements
  (payload, s/c subsystems like antennae, solar panels, etc.)
  - re-pointing (⇨APE) , duration of starring (⇨RPE)
    safe modes, transfer phase,… ⇨ various modes need to be analysed
    see ESA pointing requirements Handbook (on server)
- Guidance & Navigation: e.g. change of orbit, interplanetary transfer, landing,….

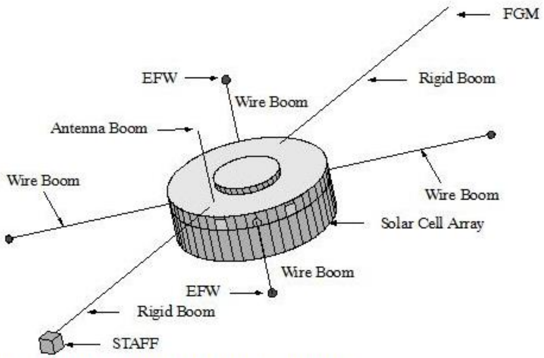


Figure 2: Illustration of the deployed Cluster spacecraft

Sensors:
Magnetometer, sun sensor, limb sensor, star tracker, accelerometer, payload, GPS (if available), gyroscopes , inertial measurement unit (IMU)

Actuators:
thruster (hot gas, cold gas, electric) ⇨ propulsion system
reaction or momentum wheels, control-moment gyros, magnetic-torquers, ‘natural’ perturbations, nutation dampers

* Internal disturbances: CoG uncertainty, thruster misalignment, thrust level mismatch, rotating mechanism (pumps, wheels,..), sloshing, dynamically flexible bodies, thermal shocks (eclipses)

(4) Thermal Control System (TCS)

Controls spacecraft thermal environment
(within operational, non-operational ranges) in various mission modes:

- TCS is driven by equipment and payload requirements
- Ground, launch, transfer, science mode, safe mode, eclipse, etc. must be considered
- Needs careful analysis of all mission modes (**internal dissipation** and **external input**) under various aspect angles and for all mission phases.

Sensors: temperature sensors

Control Components: Coatings, MLI, paint, radiators, sun shields, foam, heat pipes, optical reflectors, louvers, fillers, thermal insulators, cooler, cold plates, phase change devices, electrical heaters & thermostats, RHU's, ….

- Use of emission (ε), absorption (α) properties of materials to control temperature ⇨ paints, MLI, surface polish, …

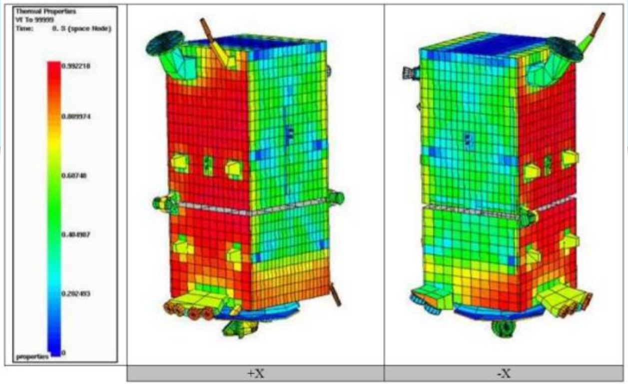
- Requires: Geometrical Mathematical Model (GMM) and Thermal Mathematical Model (TMM) – e.g. ESATAN
- Need to understand the characteristics and dissipation of all S/C equipment

⇨ **Attention (!) to: thermo-elastics (⇨co-alignment), outgasing**

⇨ **Analysis of cooling needs: passive/active cooling**

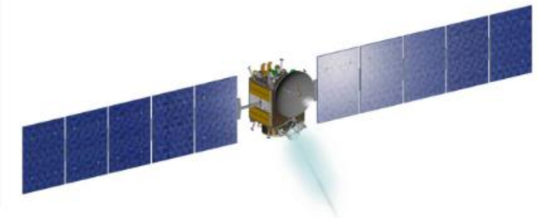
$$P = \epsilon \cdot \sigma \cdot A \cdot T^4$$

σ	Stefan-Boltzmann constant
A	Surface area
T	Absolute Temperature
ε	Emissivity factor



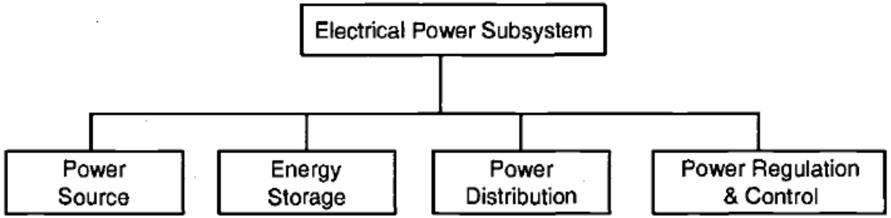
Sentinel-1 TAS

(5) Power



Provides: electrical power to S/C bus and payload

- **Solar Panel** (e.g. triple-junction cell ~28-32% eff.)
  - panels require pointing to the sun (cos (α) dependence)
    (dependent on orbit characteristics ⇨ pointing mechanism needed, with 1-2 DOF?)
  - body mounted (typ. spinner) or panel type (3-axis)
  - input at Earth: ~1370 W/m² solar flux (otherwise ~1/r² , r=distance from sun)
- **Batteries**
  - Primary (up to ~300 Wh/kg) and Secondary (re-chargeable, e.g. Li-Ion ~120 Wh/kg)
  - Energy storage
  - needed for emergency (safe mode), eclipses, or when panels cannot be pointed to sun,…
- **Alternative energy sources**
  - Nuclear Power (RTG, RHU's, ASRG's), … ⇨ very important e.g. for missions beyond Jupiter
- **Power Control and Distribution Unit (PCDU)**

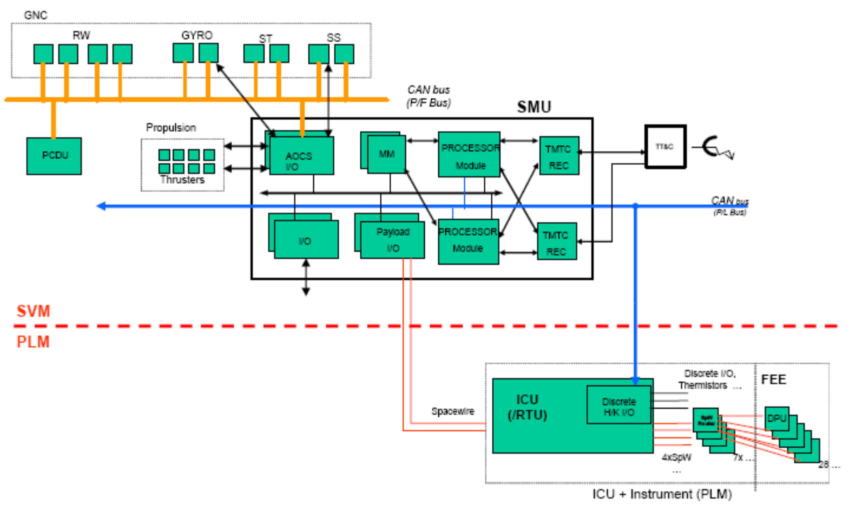


Simplified approach:
1) Define driving mission mode
2) Calculate power budget (all subsystems)
3) Sizing of panels, batteries and PCDU

(6) Data Handling & Control

Onboard Computer System and Mass Memory

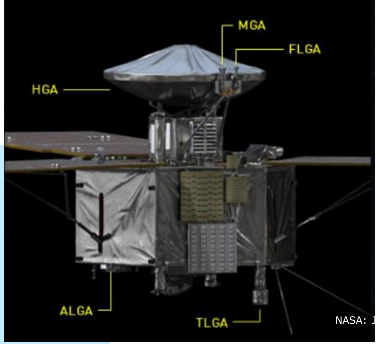
- Command interpretation and execution
- **Data Handling, Processing and Storage**
- Housekeeping handling
- AOCS control algorithm
- Control functions (power, thermal, payload)
- Failure Detection Isolation and Recovery (FDIR)
- …



Sizing:

- Processing need (MIPS, MFLOPS)
- Memory need
  (data production vs. download)
- Control complexity
- Redundancy concept
- Centralised/distributed concept

(7) Communication and Tracking



- Provides communication (RF-/optical link) for:
  - Commanding, housekeeping
  - Data download
  - Radio-Science
  - Tracking (location (range), velocity (doppler))
- Ground station to/from/between spacecraft
- For longer range: X- or Ka-band (others S, UHF)
- Understanding of required data rates
  ⇨ drives RF system (and memory)

– VHF:	30 - 225 MHz	
– UHF:	225 - 1000 MHz	
– L-Band:	1.0 - 2.0 GHz	
– S-Band:	2.0 - 4.0 GHz	
– C-Band:	4.0 - 8.0 GHz	
– X-Band:	8.0 - 12.4 GHz	
– Ku-Band:	12.4 - 18.0 GHz	
– K-Band:	18.0 - 26.5 GHz	
– Ka-Band:	26.5 - 40.0 GHz	
– Q-Band:	40.0 - 60.0 GHz	
– V-Band:	60.0 - 75.0 GHz	
– W-Band:	75.0 - 110 GHz	

Link budget:

$$\frac{E_b}{N_o} = \frac{P L_l G_t L_s L_a G_r}{k T_s R} = \frac{[EIRP] L_s L_a}{kR}\left(\frac{G_r}{T_s}\right)$$

Energy per bit over noise >3 dB

P = transmitter power
L_l = Line loss
G_t =Antenna Gain Tx
L_s = space loss
L_a = transmission path loss
G_r = Gain receiver antenna
T_s = Receiver system noise temperature
k = Boltzmann constant
R = data Rate
λ = wave length
S = path length (distance)

$$G \cong \frac{\pi^2 D^2 \eta}{\lambda^2}$$

Antenna Gain

$$\theta = \frac{21}{f_{GHz} D} \qquad \theta \text{ in degrees}$$

3-dB beamwidth

$$\text{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2$$

Space loss L_S

⇨ You can use Peter's excel tool (server)

(8) Payload & Accommodation

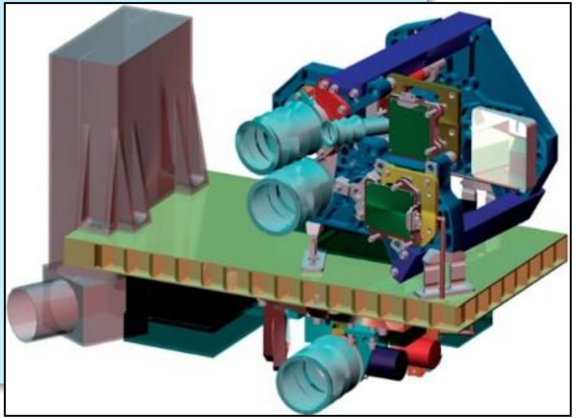
- Science & Measurement Requirements

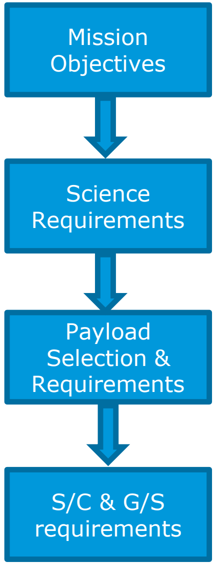
  ⇨ drive the instrument selection/design ⇨ drives S/C design **(!)**

- Accommodation (all S/C subsystems are affected):
  - Mass (Launcher, structure, propulsion system, etc…)
  - Power (power, cleanliness, etc.)
  - Data Rate (DHS, TT&C system, ground station, orbit)
  - Pointing requirements (AOCS and configuration, thermal)
  - Thermal ranges (op/non-op)
    - cooling required? Active/Passive
    - Thermoelastics -> deformations (e.g. optical systems)
  - Deployment needed (covers, baffles, sun shields…)?
  - Operation / commanding (complexity of modes, calibration)
  - EMC sensitivity and emission
  - Protection against heat, radiation, stray light etc.

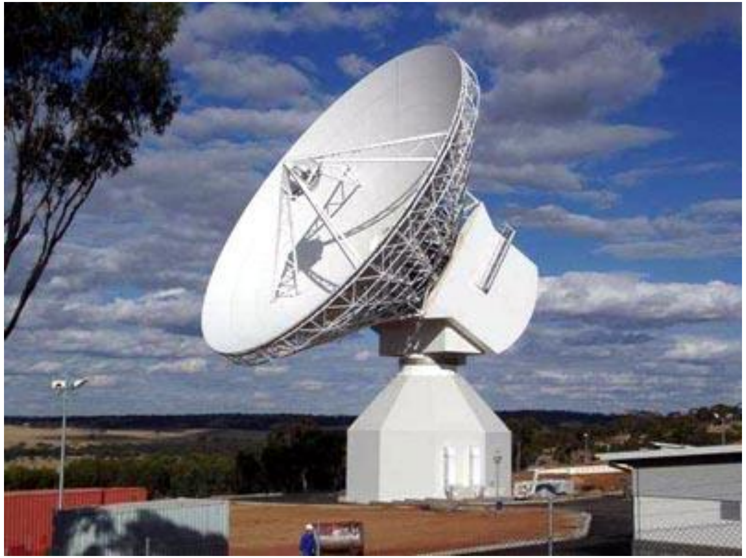
  Requires several iterations and trimming

  Understanding of underlying requirements is key !





Ground Segment



ESA 35-m GS New Norcia, credits: ESA

Operations (Mission Control & Data Centre)

- Spacecraft and Instruments need to be controlled from Ground via Ground Stations (GS)
- Launcher authority takes control until successful launcher insertion orbit and separation from upper/transfer stage

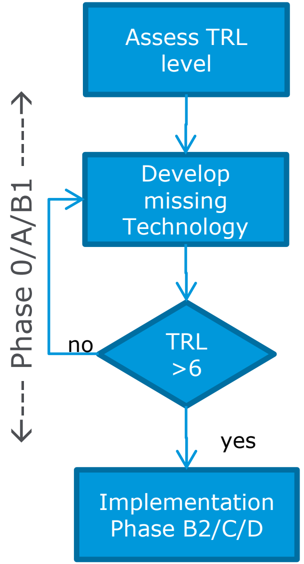
ESA Science missions:

- Mission Operations done by ESOC - Mission Operations Centre (MOC)
  - Navigation and tracking, commissioning, control of s/c, upload of commands, monitoring of health status, planning of manoeuvres etc.
  - Organise download of data for next passes
  - **Ground stations (GS)** to communicate with Spacecraft and download housekeeping & data
- Science Operations done by ESAC –> Science Operations Centre (SOC)
  - Instrument control, definition of instrument commands
- Science data distribution centres
  - Distribution of onboard data together with housekeeping to interested scientists
- Definition of observation cycles/modes

Technology Development

- Level of technology readiness is a **key schedule & cost driver**
- Assessment of efforts required to reach flight status is often difficult
- Assessment done according to the table below
- Non availability of technology can be detrimental to the schedule and cost

Technology Readiness Level
TRL 1: Basic principles observed and reported
TRL 2: Technology concept and/or application formulated
TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4: Component and/or breadboard functional verification in laboratory environment
TRL 5: Component and/or breadboard critical function verification in a relevant environment
TRL 6: Model demonstrating the critical functions of the element in a relevant environment
TRL 7: Model demonstrating the element performance for the operational environment
TRL 8: Actual system completed and accepted for flight ("flight qualified")
TRL 9: Actual system "flight proven" through successful mission operations



Cost, Risk and Schedule

Cost estimate is difficult !

- **3 basic methods**:
  1. bottom up approach
  2. parametric analysis
  3. by analogy with other missions (benchmarking)
- Need for cost model and data base with cost info (suppliers, manpower,…)
- Most difficult is the estimate on engineering, validation & verification cost, manpower etc. & cost of technology TRL upgrade
- Cost is driven by size and complexity of mission

Cost at Completion (CaC) comprises:

- Development cost
- Procurement cost of the space segment (industrial cost)
- Test facilities cost
- Launch cost
- Mission operation cost
- Science operations cost (Data analysis, distribution and archiving)
- Agency cost and margins
- Management costs
- Payload cost
- Contingency …

ROM … rough-order-magnitude

ESA science missions:
ESA: S/C, Launch, MOC,SOC, PM
M/S: Payload (+ESA)

ROM cost break down:

#	Item	percent
1	Project Team	20% (2+3+4)
2	Industrial Cost	~40-50% of total
3	Mission Operations (MOC)	5-10% of total
4	Science Operations (SOC)	5-10% of total
5	Launcher	see table
6	Contingeny (15%)	15% (1+2+3+4)
	total	sum (1-6)

Mission classes:

Ariane 5 (A64) ~ 1 B€ + P/L
SF (A62) ~ 600 M€ + P/L
Vega ~ 150 M€ + P/L

P/L ~ 20-100% of mission class

Risk Assessment

- Space missions are large investments
- Understanding and analysis of risk is important to avoid catastrophic events as much as possible
- Identification of risk followed by risk mitigation is the approach
- Make a risk Register with main risks
- Rated with likelihood (A-E) and severity (1-5)

Severity					
5	Low	MI01-payload funding Risk MI11 - PLM sun illum. Medium	MI01-payload funding Risk MI13–payload late fund. High	Very high	Very high
4	Low	MI02 – Noise & Photom. stability MI05 –Launcher availability Low	MI04- NeoCam detector Medium	~~MI05 –Launcher availability~~ High	Very high
3	Very low	Low	MI03 - Pointing Jitter MI06 - Eff. Area, QE MI07 - M2M MI08 - NeJT cooler MI12 - Dichroic Low	Medium	High
2	Very low	Very low	Low	Low	Medium
1	Very low	Very low	Very low	Low	MI10 - I/F SVM to PLM Low
	A (remote)	B (unlikely)	C (likely)	D (Highly likely)	E (near certain)
	Likelihood				

Score	Likelihood	Definition
E	Maximum	Certain to occur, will occur once or more times per project
D	High	Will occur frequently, about 1 in 10 projects
C	Medium	Will occur sometimes, about 1 in 100 projects
B	Low	Will occur seldom, about 1 in 1.000 projects
A	Minimum	Will occur almost never, about 1 in 10.000 projects

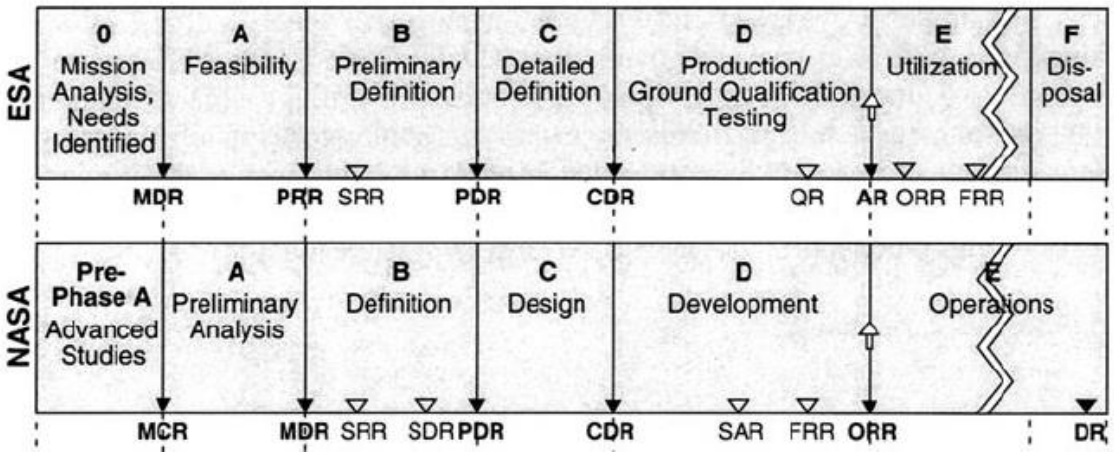
Risk Severity (1-5)

5

1

Severity	Schedule	Science	Technical (ECSS-Q-30 and ECSS-Q-40)	Cost
Catastrophic	Launch opportunity lost	Failure leading to the impossibility of fulfilling the mission's scientific objectives	Safety: Loss of system, launcher or launch facilities. Loss of life, life-threatening or permanently disabling injury or occupational illness; Severe detrimental environmental effects.	Cost increase result in project cancellation
Critical	Launch delayed (TBD) months	Failure results in a major reduction (70-90%) of mission's science return	Dependability: Loss of mission. Safety: Major damage to flight systems, major damage to ground facilities; Major damage to public or private property; Temporarily disabling but not life-threatening injury, or temporary occupational illness; Major detrimental environmental effects.	Critical increase in estimated cost
Major	Launch delayed (TBD) months	Failure results in an important reduction (30-70%) of the mission's science return	Dependability: Major degradation of the system. Safety: Minor injury, minor disability, minor occupational illness. Minor system or environmental damage.	Major increase in estimated cost
Significant	Launch delayed (TBD) months	Failure results in a substantial reduction (<30%) of the mission's science return	Dependability: Minor degradation of system (e.g.: system is still able to control the consequences) Safety: Impact less than minor	Significant increase in estimated cost
Minimum	No/ minimal consequences	No/ minimal consequences.	No/ minimal consequences.	No/ minimal consequences.

Project Phases



◇	DoD Milestone
▼	Major Review (Control Gate)
▽	Review
⇧	Launch
AR	Acceptance Review
CDR	Critical Design Review
DR	Decommissioning Review
FRR	Flight Readiness Review
MCR	Mission Concept Review
MDR	Mission Definition Review
ORR	Operational Readiness Review
PDR	Preliminary Design Review
PRR	Preliminary Requirements Review
QR	Qualification Review
SAR	System Acceptance Review
SDR	System Definition Review
SRR	System Requirements Review

SMAD, p. 8

Some (Science) Mission examples

see https://eoportal.org/

Mission	Launch	Operational orbit	Launch mass [PL mass]	Total power	Propulsion	Downlink	Pointing
Smart-1	2003 Shared Ariane 5 with ASAP	Polar elliptical Moon orbit (transfer from GTO)	367 kg [19 kg]	1765 W cruise mode 225 W science mode	3.9 km/s 82 kg Xe Solar Electric Propulsion	65 kbit/s S band + X/Ka band demonstration	APE = 15′
MEX (same platform as VEX)	2003 Soyuz 2-1b with Fregat upper stage	Mars (330 km x 10.530 km i=86.9°)	1223 kg [116 kg]	650 W	457 kg Bi-propellant	38-230 kbit/s X band	APE = 0.15°
Lisa Pathfinder	2015 Vega with propulsion module	Sun-Earth L1	1910 kg Includes 214 kg prop. module dry mass + 1250 kg propellant. [178 kg]	650 W	Propulsion module + Bi-propellant + cold gas	52 kbit/s X band	APE = 0.05°
Corot	2006 Soyuz 2-1b	LEO 896 km 90°	668 kg [300 kg]	530 W	90 m/s Mono-propellant	1.5 Gbit/day S band (722 kbit/s)	APE = 0.5″ (telescope used as a FGS)
CHEOPS	2017 Shared launch (compatible with passenger to Soyuz, Vega, and other launchers)	LEO SSO, dusk-dawn (650-800 km)	280 kg [60 kg]	200 W nominal 60 W allocated to the instrument	Mono-propellant 30 L tank	1.2 Gbit/day S band	APE 4″ rms (telescope used as a FGS)

Table 9: Examples of European science missions, completed or under development. Data rates for orbits beyond L1/L2 are typically achieved with a ground station contact of 6 to 8 hours per day.

Margin

- **Margins are important in early phases due to uncertainty, low level of definition and unknown/unknowns**
- ⇨ **Always keep appropriate margins adopted to the level of definition**

- **Equipment level margin** according to maturity
  - 5% for off-the-shelf items (no changes)
  - 10% for off-the-shelf items with minor modifications
  - 20% for new designs, new developments, major modifications

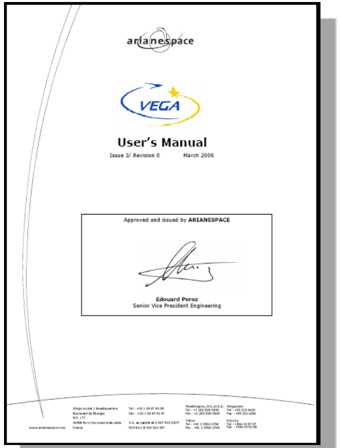
- **System margin** (at least 20%)
  - On top of and in addition to equipment margins; applied after summing best estimates + margin
  - Two options for the propellant calculation +10% margin + 2% residuals
    - Margin on total dry mass and margin on launcher: typically used during early study phases +10% margin
    - Margin on maximum separated mass: typically used later, when mission analysis and launcher analysis become available

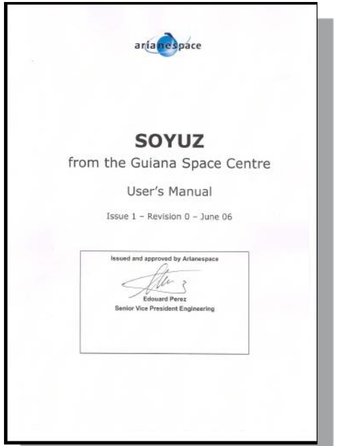
⇨ "Margin philosophy for Science Assessment Studies" (on server)

Recommended Literature

https://directory.eoportal.org/web/eoportal/home

- Space Mission Analysis and Design (SMAD) – microcosm (library)
- Spacecraft System Engineering P. Fortescue – Whiley (library)
- ESA track Groundstation handbook (server/Peter Falkner)
- ESA pointing requirements handbook (server/Peter Falkner)
- Launcher: VEGA, SF-2B, Ariane 5 user manuals (>web or server)
- ESA M5 call technical Annex (on server under PF)


arianespace
VEGA
User's Manual
Issue 3/ Revision 0 March 2006
Approved and issued by ARIANESPACE
Edouard Perez
Senior Vice President Engineering


arianespace
SOYUZ
from the Guiana Space Centre
User's Manual
Issue 1 – Revision 0 – June 06
Issued and approved by Arianespace
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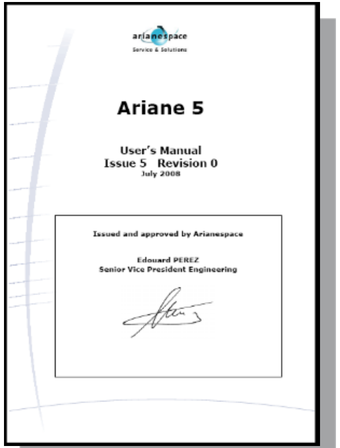
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July 2008
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Questions ?