Introduction to Aerospace Engineering

Lecture slides

Introduction to Aerospace Engineering AE1101

Dept. Space Engineering

Astrodynamics & Space Missions (AS)

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15 - 16

What is a spacecraft (S/C)?

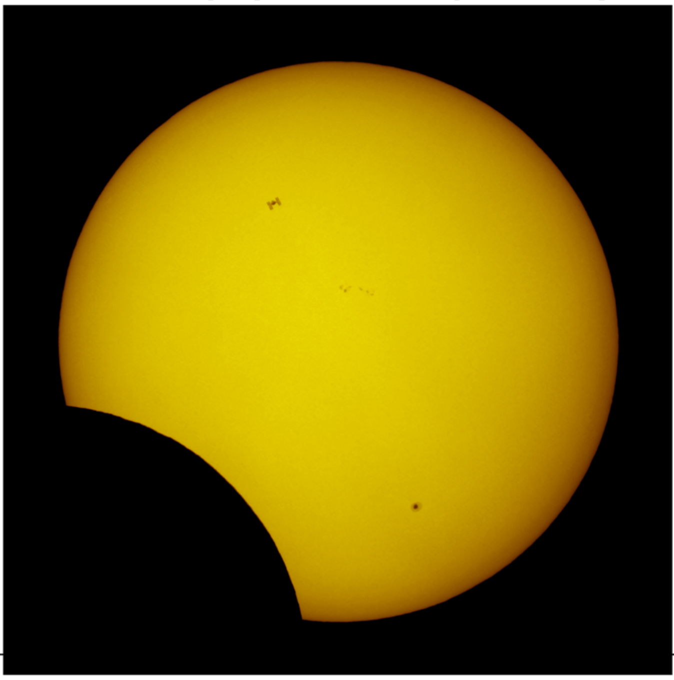
How spacecraft look (S/C configuration) and why

Categories of spacecraft

Initial sizing

Part of the contents of this presentation originates from the lecture "Space Engineering and Technology I, Part I" (ae1-801/1), by R. Hamann.

Picture of the day (4 January 2011)



Session 15 - 16

Learning goals

The student is able to ….

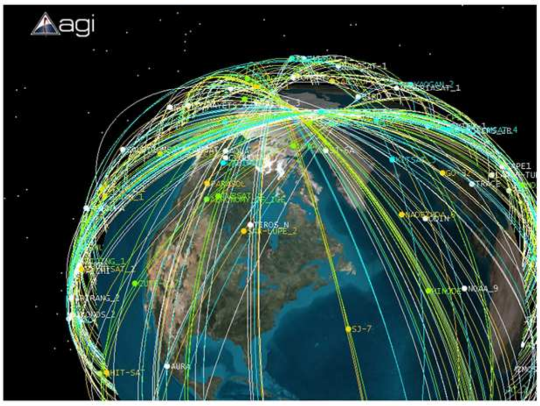
- … describe
  - What a spacecraft is
  - important spacecraft characteristics including mass, electrical power, size, life, pointing control and orbit determination accuracy, data rate, data storage capability, cost
- … describe and explain important configuration drivers
- … calculate first order estimate of spacecraft mass, volume, electrical power and cost based on payload mass, size and electrical power

Background

- At this moment ~ 800 active spacecraft (S/C) in space
- Each year about 80 spacecraft launched into space

  Jane's Space Directory →

  - 1994: 89 launches orbiting 121 spacecraft
  - 2008: 68 launches orbiting in total 91 spacecraft
  - Next 10 years: another 800 spacecraft



Spacecraft in LEO

Many spacecraft exist.

What is a spacecraft?

A spacecraft is a craft or machine designed for spaceflight (dictionary)

A typical telecommunication spacecraft

An assembly of structural, electronic an optical components that form a functional system to fulfill a specific mission (other)

Slide shows TDRSS satellite.

To be discussed:

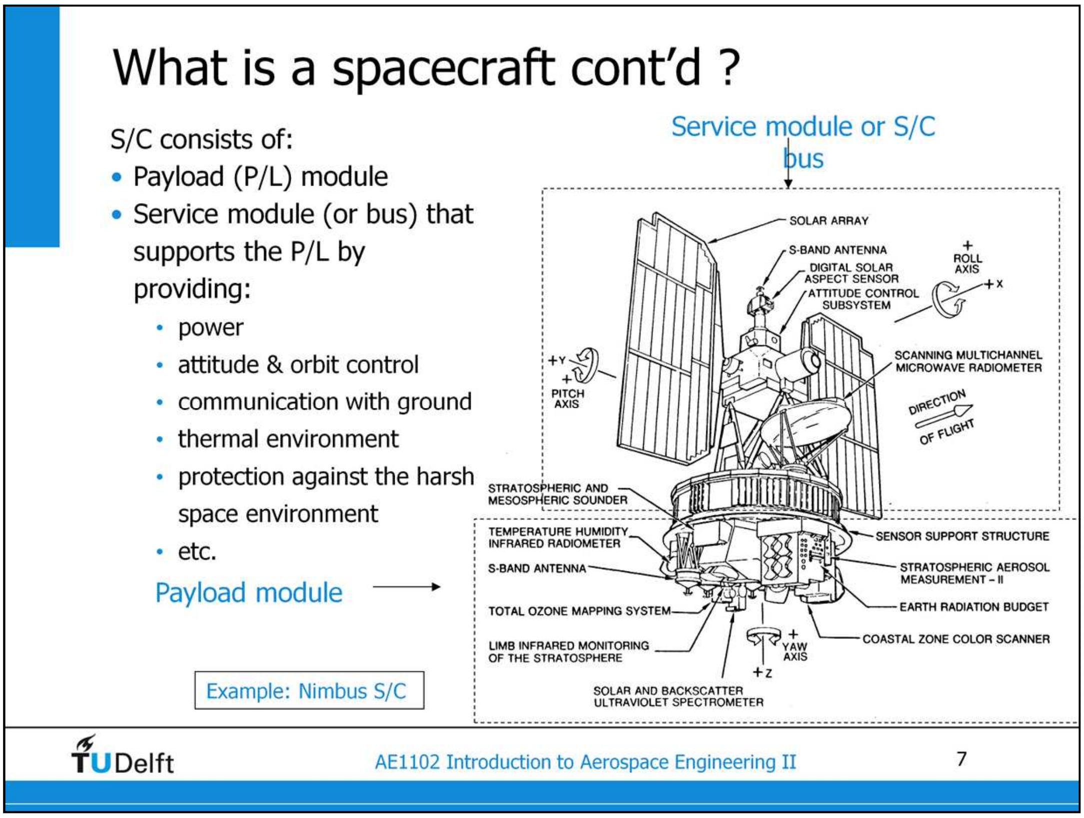
GEO

Antennas point to Earth

Communication requires high power

Long life

Photovoltaics used. Need to be pointed to the Sun



Nimbus spacecraft on slide.

A **spacecraft platform** or "bus" is the service module section of a satellite.

What is a spacecraft cont'd ?

Principal functions of the service module or spacecraft bus
Provide structural support for equipment
Determine & control attitude, point & manoeuver the S/C, manage angular momentum
Adjust orbit and attitude, dump angular momentum
Communicate with ground, support spacecraft tracking
Process commands, perform data processing/ formatting, provide computing power
Control equipment temperature
Generate and distribute power

Example of spacecraft technical data

Mars Express

Dimensions	1.5 x 1.8 x 1.4 m
Mass at launch overall	ca. 1160 Kg
of which Beagle	71 kg
Fuel	470 Kg
Payload	116 Kg

Propulsion:

- Thrust of the main engine: 400 N
- 8 manoeuvring thrusters with 10 N thrust each

Power Supply:

- Solar Panels, Area 11.4 m², output 660 W
- 3 Lithium-Ion Batteries with 22.5 Ah each.

Consumption of power:

- Observational phase: 270 W
- Manoeuvring phase: 310 W
- Data transfer phase: 445 W.

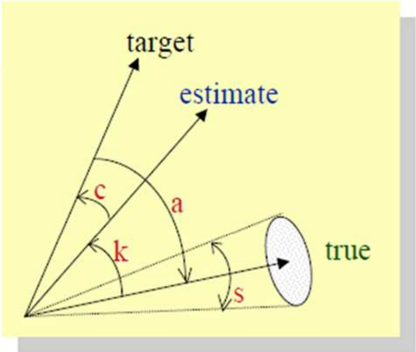
- Launcher: Soyuz/Fregat
- Launch Site: Baikonour/Kazakhstan.
- Launch Date: May/June 2003.

Spacecraft technical data cont'd

Function/characteristics	Capability (values are illustrative only)
Pointing Control	0.2°
Orbit determination accuracy	Within 100 m
Electrical Power	500 W
Design life	5 Years
Data memory storage	1.25 Gigabits
Downlink Data Rate	2 Mbit/sec
Mass available for P/L	200 kg

S/C technical data - Pointing Control

Pointing Control	0.2°



target	desired pointing direction
true	actual pointing direction (mean)
estimate	estimate of true (instantaneous)
a	pointing accuracy (long-term)
s	stability (peak-peak motion)
k	knowledge error
c	control error

a = pointing accuracy = attitude error
s = stability = attitude jitter

Source:
G. Mosier
NASA GSFC

Example

S/C technical data - Pointing Control (2)

Pointing Control	0.2°

This parameter is part of the Attitude Determination Control (ADC) S/C subsystem specification.

Example

The ADC accuracy of the S/C is within the angular cone < 0.2^0

1) What is meant by 0.2 degree pointing control?

Mind that 1^0 = 3600″ = 60′

2) What does this mean for the ground station and a satellite at 36000 km altitude?

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Question-1

0.2 degree = 720" = 12'

The answer is usually given in (degree) seconds so 720 (degree) seconds maximum long term pointing accuracy *a*

Question-2

pi/180x0.2x36000km = 125.6 km maximum deviation

This seems to be much, but only in case of laser communication → When considering RF Electro-Magnetic waves radiated by a High Gain S/C antenna the wavefront is broad enough to cover this spread.

S/C technical data - Pointing Control (2)

Orbit determination accuracy	Within 100 m

This is part of the Orbit Control System (OCS) specification.

The combination of ADC & OCS is mentioned:

AOCS = Attitude & Orbit Control System

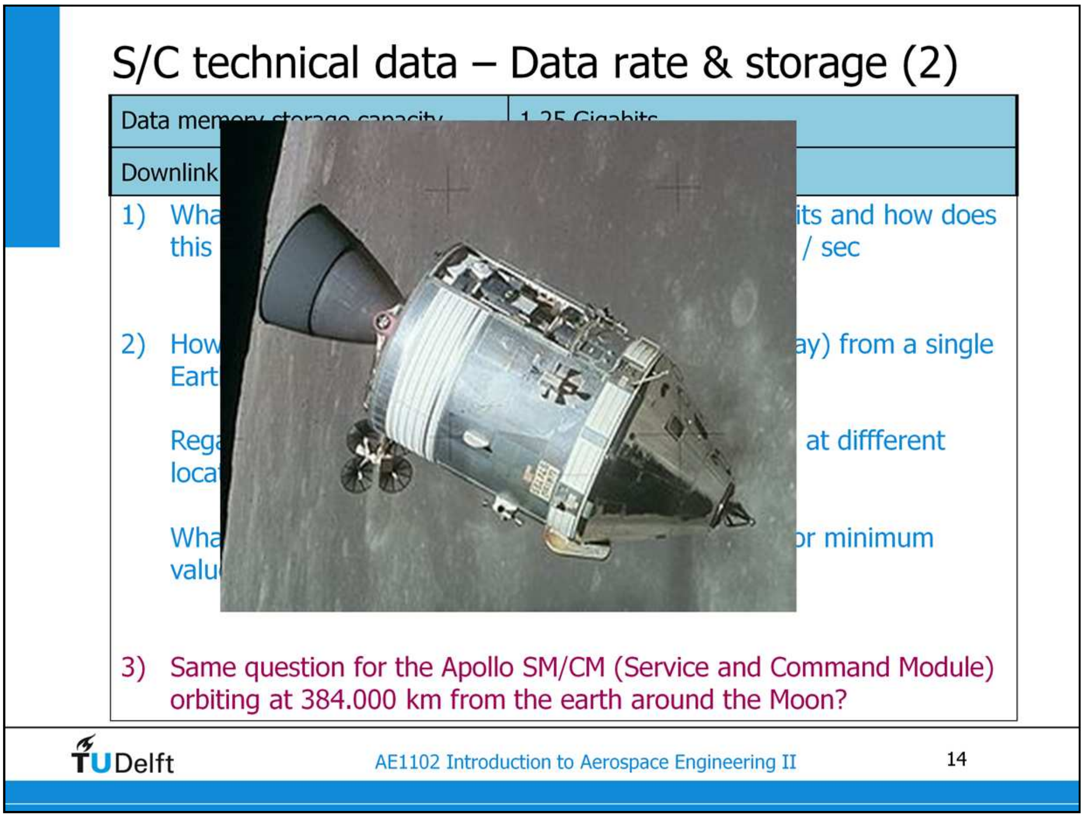
1) What is meant by an orbit determination accuracy of a satellite at 36000 km altitude within 100 meter in terms of

   a) Relative maximum radial deviation?
   b) Relative maximum tangential deviation?

Question-1

a) $\Delta h[km] / (R+h) = 0.1 / (6371+36000) = 2.36x10E-6$

b) $2\pi . \Delta h / (R+h) = 1.48E-5$



Question-1

This means that there is a solid state device in the S/C (taperecorders were used in the past) which supports the data storage of about

1.25E9 / 2E6 = 1250 / 2 = 625 seconds downlink time

Question-2

2x36000/300,000=240 msec (minimum)

This real value will be longer for an arbitrary location of the ground station.

The same holds taking different locations of the transmitting and receiving station on Earth.

Question-3

Average estimate 2x384.000/300,000=2.56 seconds !

No communication possible during eclipse

(Houston we’ve got a problem…)

Important spacecraft design aspects

For each spacecraft, the following aspects are key

Orbit

- determines distance to subject
  - with increasing distance less detail can be viewed and
  - more power is needed to communicate
- determines the spacecraft environment

Launcher performance

- limits the spacecraft mass

Payload characteristics and mission aspects

- determine the size of the spacecraft and the need for mechanisms

Electrical power

- determines the size of the power source

Mission duration in relation to reliability

- determines the amount of spare resources needed (propellant, over-sizing for degradation due to radiation and ageing, redundancy)

Important aspects cont'd

Attitude and orbit accuracy

- determines the quality of the scientific data, the quality of communications and the safety of the spacecraft

On-board computer power and data storage

- determines autonomy and amount of data to be down linked

Up- and Down-link data rate

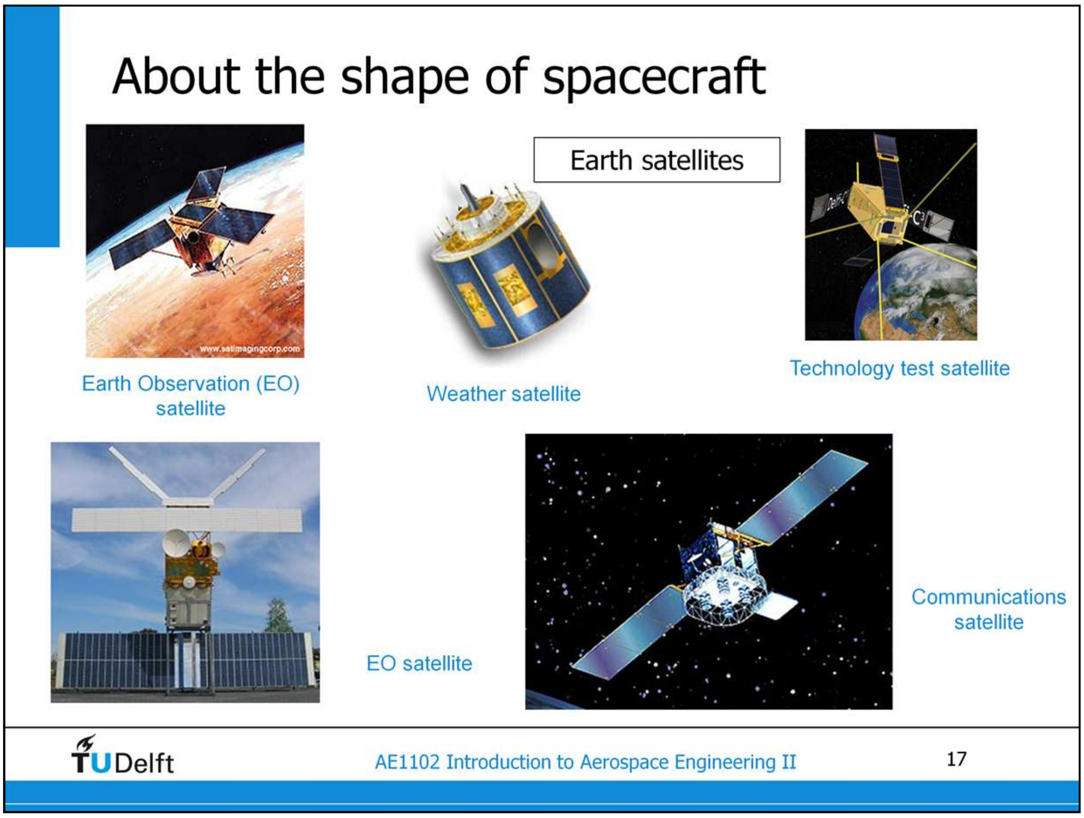
- determines the size of antennae, receiver and transmitter power

Manoeuvres to be performed

- determines amount of 'fuel' (propellant) to be carried on board

Operational temperature

- determines amount of thermal control to be performed

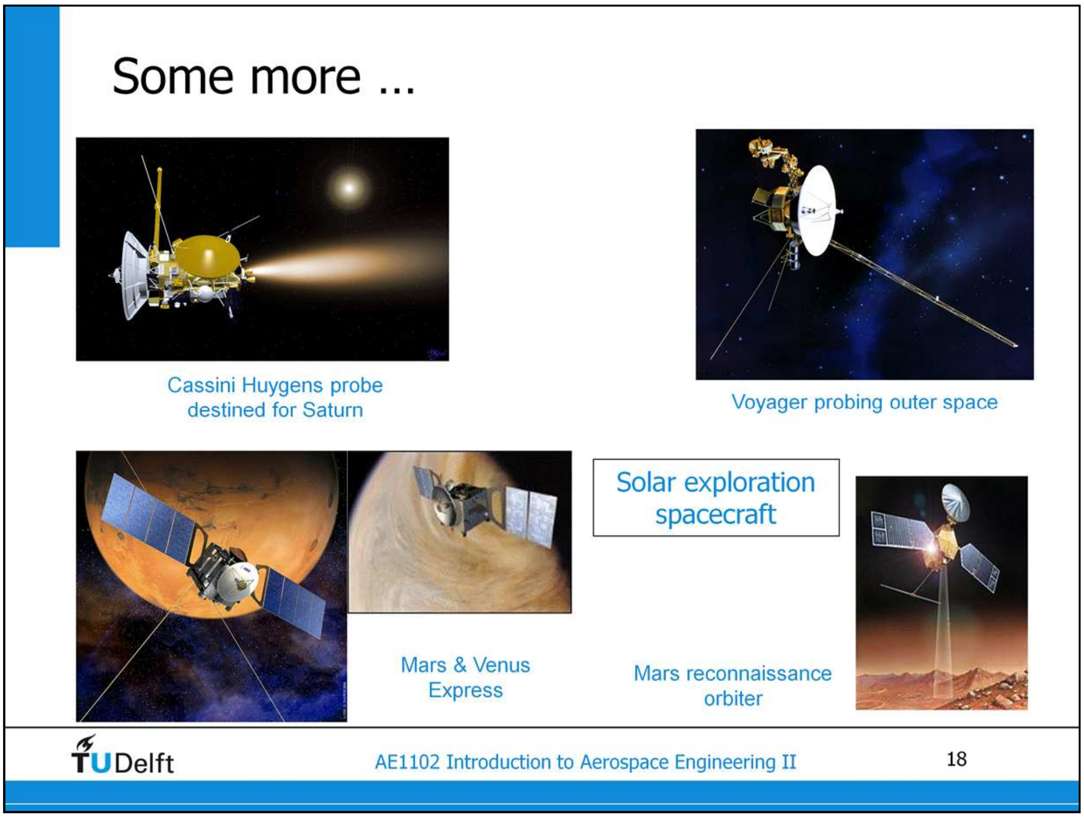


Spacecraft on slide include Ikonos (top left), Meteosat (top middle), Delfi C3 (top right), ERS (bottom left).

Spacecraft differ in performance, size, mass, shape, cost, reliability, development time, etc.

Spacecraft differ because of differences in:

- Payload
- Mission (mission duration)
- Operations
- Launcher
- Etc.



Spacecraft differ in performance, size, mass, shape, cost, reliability, development time, etc.

Spacecraft differ because of differences in:

- Payload
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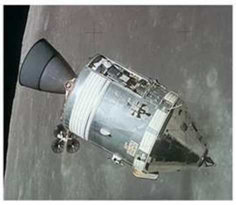
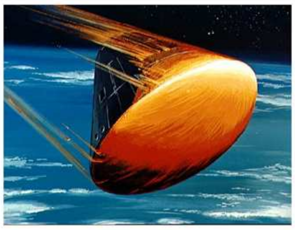
- Launcher
- Etc.

And some more ....

Space transportation spacecraft



Apollo CM/SM



Apollo CM

Moon buggy

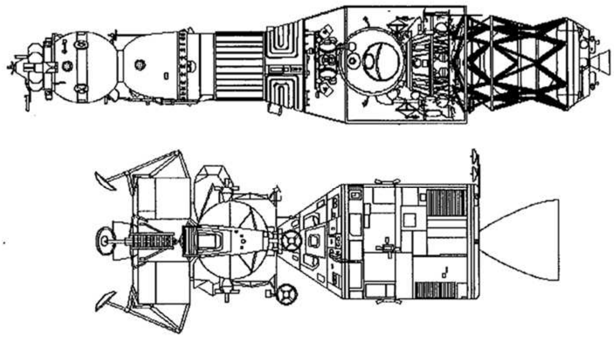
Lunar Lander & Ascender

Mars Lander & Ascender

Shape depends on mission payload

Spacecraft Mission Payloads

- Communications
- Weather
- Geodesy
- Environment
- Science
- Surveillance
- Navigation
- Military
- Search and Rescue
- Etc.



Other payloads:

- Moon dust, comet samples
- Space station supplies: Oxygen, water, food, fuel (propellants), medicine, etc.
- Other spacecraft (e.g. as payload for launchers and space tugs)
- People (crew or tourists)

Other aspects influencing the shape of S/C

In space transportation

- Launcher payload envelope
- Lander / rover
- Docking system

Manned/Unmanned

- Pressurized or not?

Power requirements

- Solar panels or not (size)?

Attitude control

- 3D
- Spinning
- Tumbling

Orbit

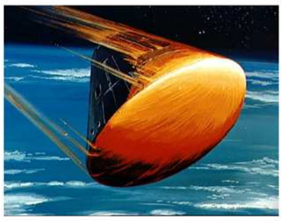
- LEO – Low Earth Orbit
- GEO – Geostationary Earth Orbit
- MEO – Middle (height) Earth Orbit
- HEO – High Earth Orbit
- Interplanetary/ Deep space probes
- …

Payload characteristics and config.

- Field of view
- Thermal conditions
- Atmospheric entry

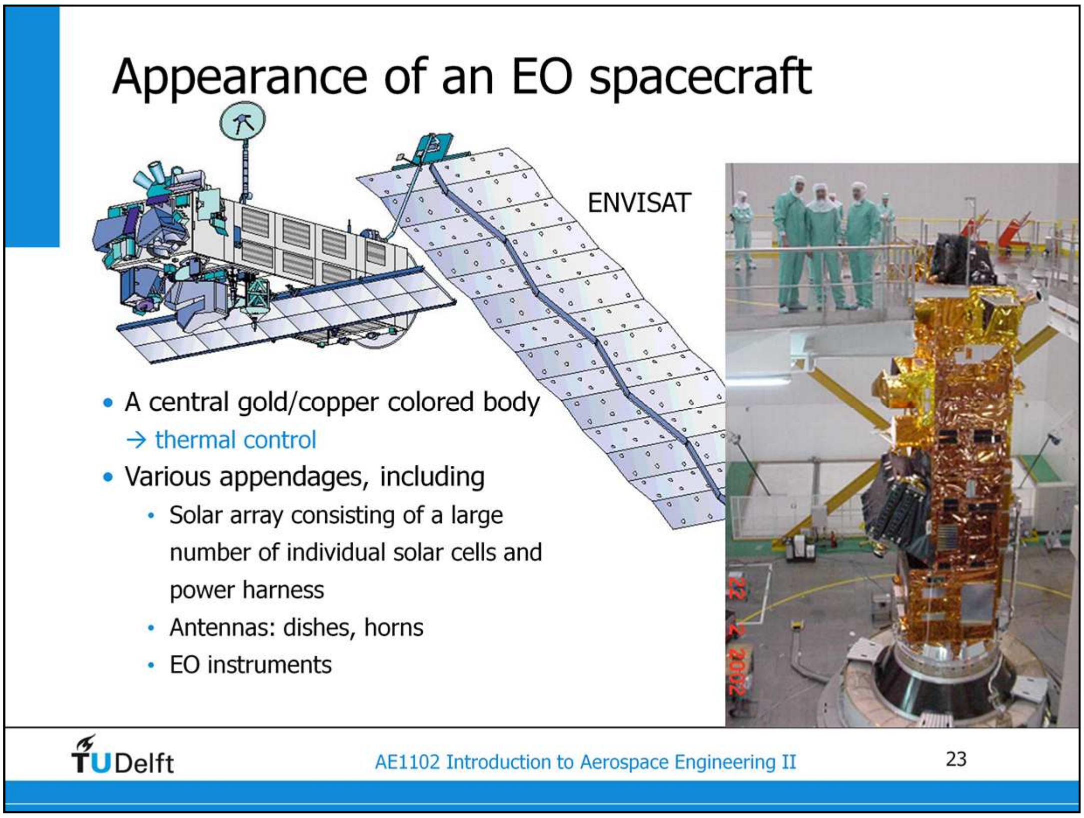
Etc.

Absence of aerodynamic shape ?



Absence of atmosphere!!!

Some exceptions, depending on extent of (planetary) atmosphere



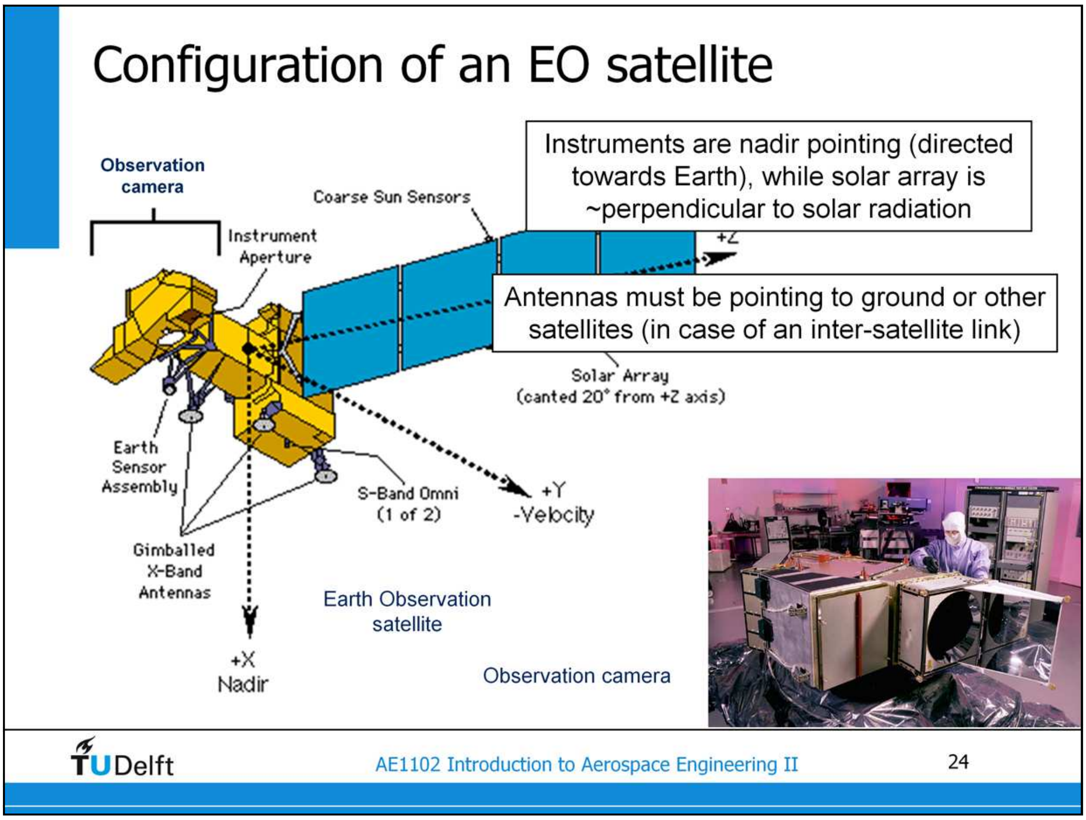
ENVISAT, ESA’s largest Scientific Satellite for Earth Observation

The solar cells look blue-ish since they mainly absorb the green part of the spectrum being the most energy intense part of the solar spectrum. Special coated coverglasses on the solar cells reflect the blue light and protect from radiation. Depending on the mission the coverglasses have a certain thickness.

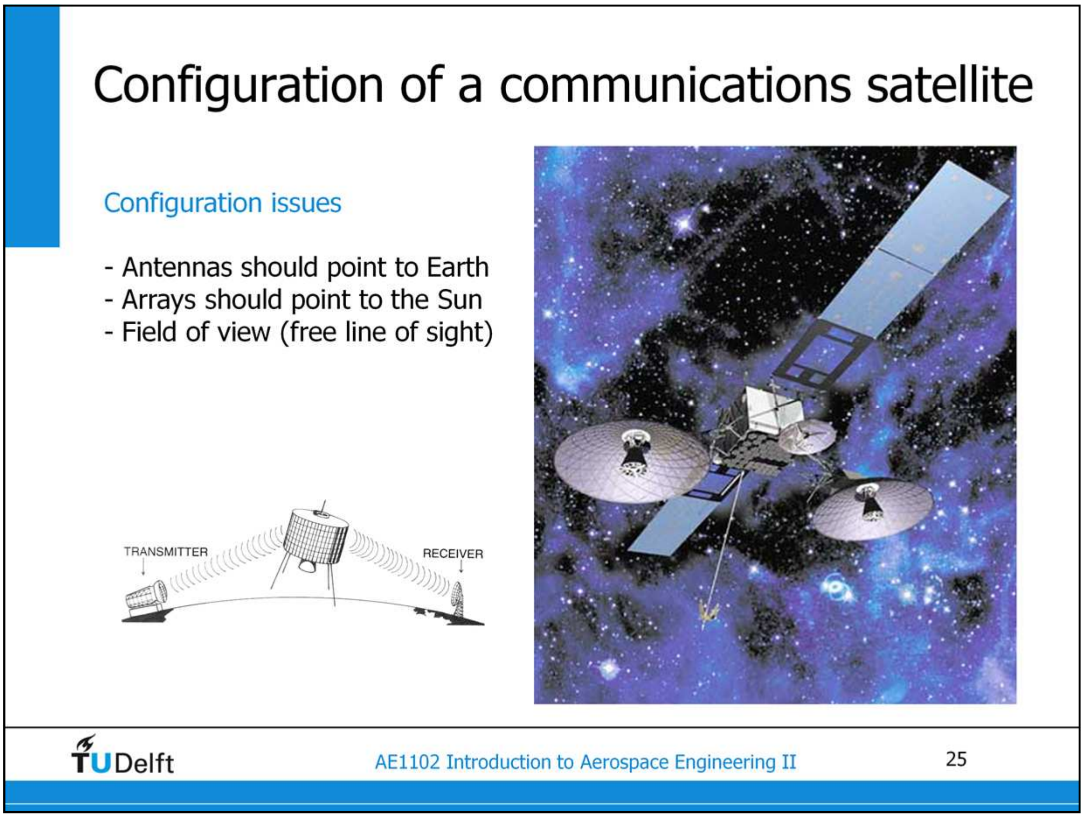
Space blanket -From Wikipedia, the free encyclopedia

A space blanket**,** is a blanket used in emergency situations to reduce heat losses in a person's body due to thermal radiation and convection. First developed by NASA in 1964 for the US space program, the material consists of a thin sheet of plastic (often PET film) that is coated with a metallic reflecting agent, making it metallized polyethylene terephthalate or MPET, usually gold or silver in color, which reflects up to 97% of radiated heat.

Wrapping the “silver” side towards the body supports the loss of excessive heat. This condition is seen above and with S/C in general. Wrapping the “gold” side towards the both contains the heat to the body in case of undercooling.



On slide we have Landsat-7 schematic + Landsat-7 Enhanced Thematic Mapper (ETM+)



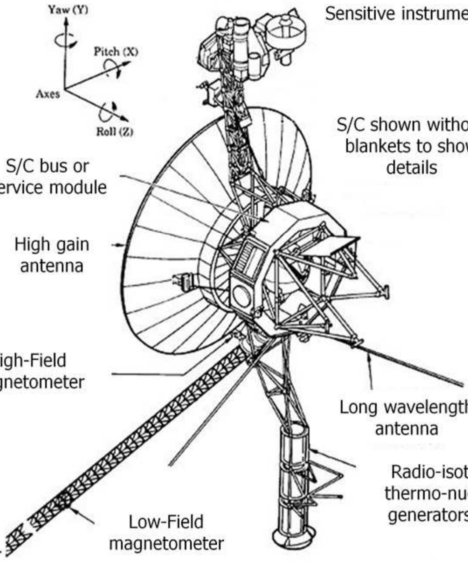
Slide shows TDRSS satellite.

To be discussed:

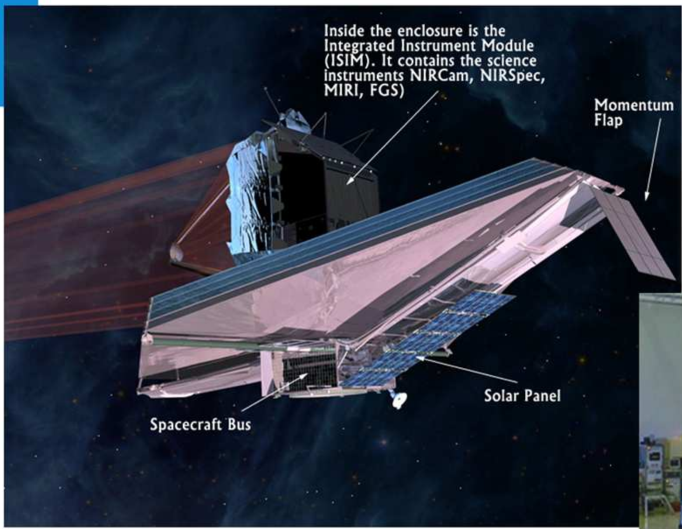
- GEO
- Need for antannae
- Antennas point to Earth
- Field of view (free line of sight)
- Communication requires high power
- Long life
- Photovoltaics used. Need to be pointed to the Sun

Configuration of a deep space probe

Voyager Mission
Deep space probe



Configuring for thermal control



JWST

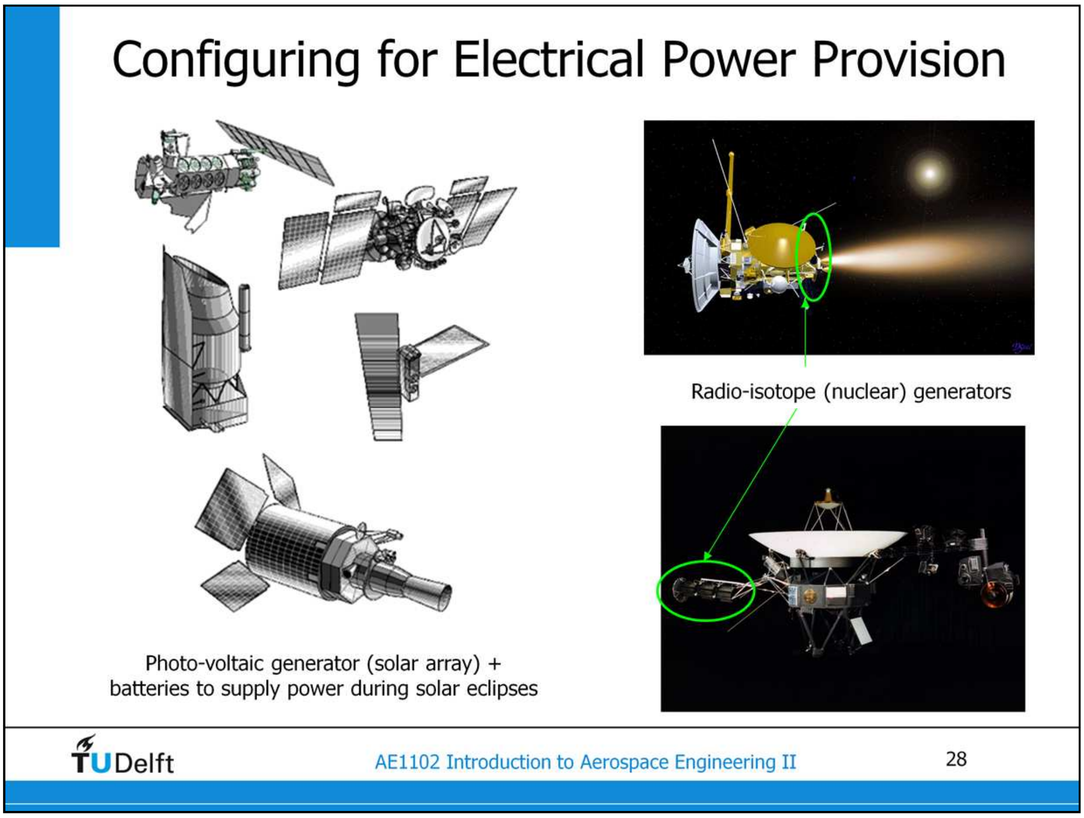
Large telecom sat

On slide we have James Web Space Telescope (right) and Spacebus 3000 spacecraft.

Spacebus is covered with MLI (gold/copper covered) to reflect the Sunlight.

For JWST, solar panel indicates direction of the Sun. On top we have the instrument, this instrument is to be kept really cool (a few K). To shield the instrument from the sunlight, a radiation shield is incorporated (the large layered structure seen in the figure.

(Show an emergency blanket or take some samples of MLI to class.



On slide (left) we have on top DMSP and Gorizont in the middle ISO and JERS and bottom DSP.

On slide (right) we have Cassini Huygens and Voyager. Both spacecraft are destined for deep space (outer planets) and hence are equiped with radio-isotope nuclear generators.

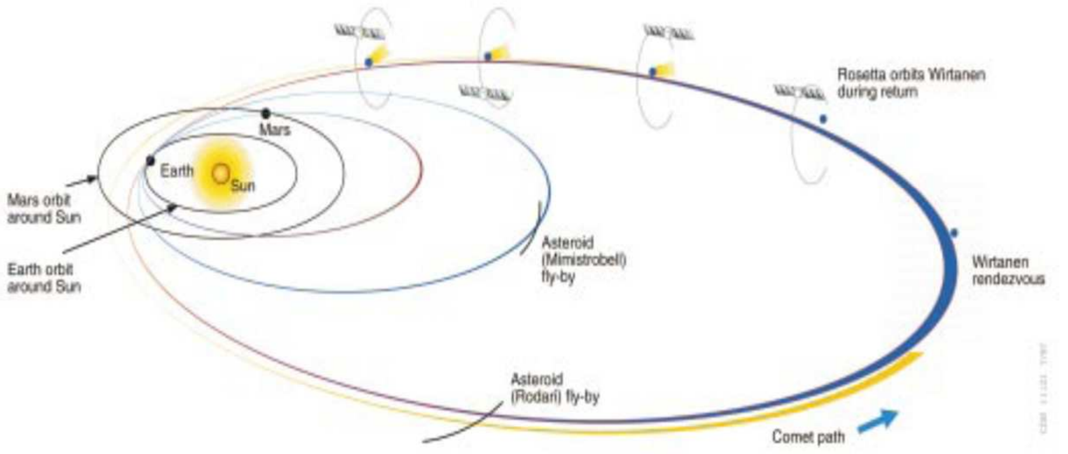
A radioisotope thermoelectric generator (RTG, RITEG) is an electrical generator which obtains its power from radioactive decay. In such a device, the heat released by the decay of a suitable radioactive material is converted into electricity.

Another mean for power generation is the use of heat engines. These convert mechanical energy in to electrical energy. The mechanical energy is obtained from a cyclic expansion of a gas between to extreme temperatures.

Deep space mission → Extreme reqts on SA

Rosetta mission requires extreme elliptical orbits

Launch March 2004 - Rendezvous May 2014 - End of Mission December 2015



Rosetta S/C = ESA's Comet Chaser [http://www.esa.int/SPECIALS/Operations/SEMC1VAMS7F_0.html]

Rosetta will be ESA's first spacecraft to undertake long-term exploration of a comet at close quarters. A deep-space hibernation is included before comet rendezvous.

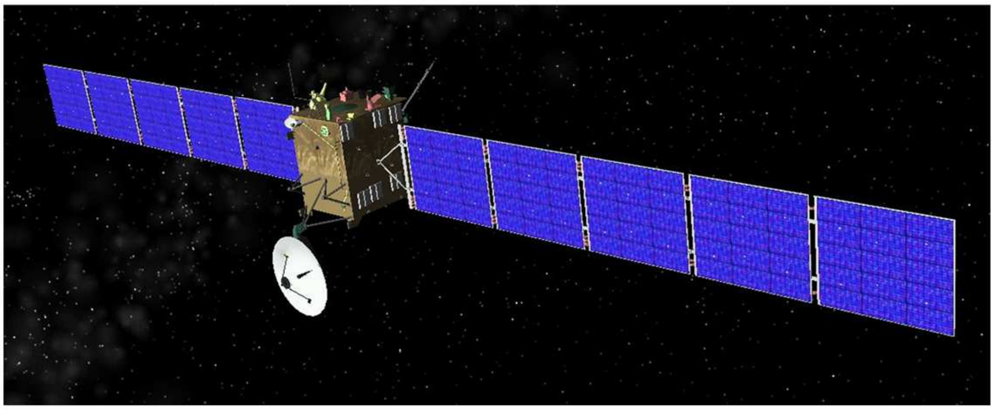
The mission consists of a large orbiter, designed to operate for a decade at large distances from the Sun, and a small lander, Philae. Each of these carries a large suite of scientific experiments designed to complete the most detailed study of a comet ever attempted. After entering orbit around Comet 67P/Churyumov-Gerasimenko in 2014, the spacecraft will release the lander onto the icy nucleus. It will then spend the next two years orbiting the comet as it heads toward the Sun. On the way to Comet Churyumov-Gerasimenko, Rosetta has received gravity assists from Earth and Mars, and will fly past two main-belt asteroids – Steins (September 2008) and Lutetia (July 2010).

Deep space mission → Extreme reqts on SA

Rosetta mission → spacecraft as comet hunter

Low solar intensity 0.03 SC = 42 W/m^2
→ Large solar array
→ Low T= -130^{o}C

Solar Constant AMO 1 SC = 1400 W/m^2 at 1 AU
AMO = Atmospheric Mass Zero



For the Rosetta mission the solar array had extreme requirements due to the extreme elliptical orbits towards the comet 67P / Churimov-Gerasimenko. The large solar array is equipped with specific Silicon high efficiency solar cells which yield sufficient power in LILT (Low Intensity Low Temperature) conditions. In this case the required orbit proves to be the design driver for the solar array.

AM0 = Atmospheric Mass Zero – This refers to space conditions without or negligible amount of atmosphere. The 1400 W/m2 solar intensity is valid just outside the Earth atmosphere.

Methods of attitude control and sensors

Methods:

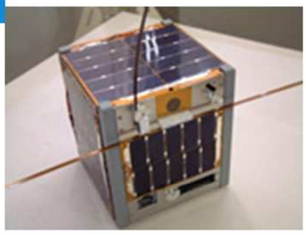
- Free tumbling
- Spinning / dual-spin
- Gravity gradient
- 3-D control
  - Thrusters
  - Reaction wheels
  - Control moment gyros
  - Magnetic torquers

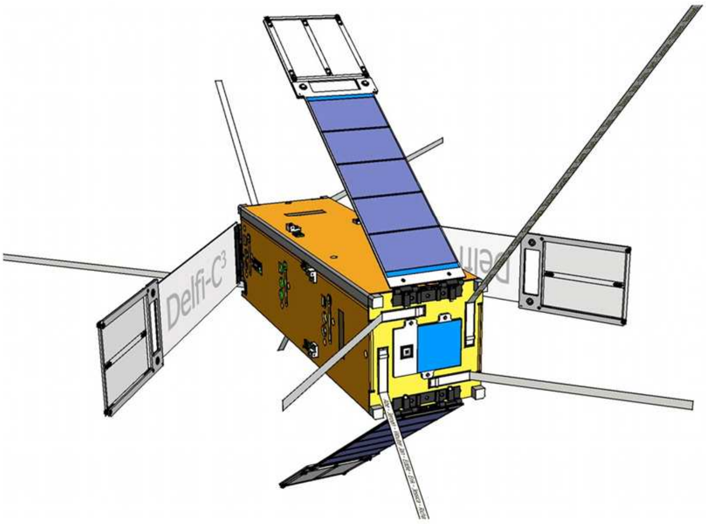
Sensors:

- Sun sensors
- Star trackers
- Limb sensors
- Inertial measurement unit
- GPS… !!!

Free tumbling spacecraft & SA design

CubeSats as a new trend in S/C design → **Delfi-C³**
Passive ADC requires an omni-directional solar array and antenna configuration





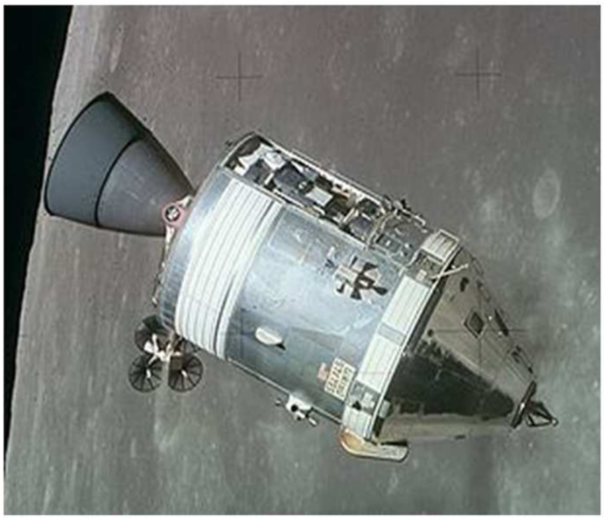
The TUD Delfi-C3 S/C (as large as a huge milk carton) is a member of the Cubesat series. A new trend in S/C design enabling cheaper and COTS (Comercial Of The Shelf) production of S/C. The ADCS is passive using magnetic torquers only. These magnetic rods stabilize the S/C by force interaction with the Earth magnetic field lines. The free (remnant) tumbling movements require an omni-directional solar array design. The same is valid for the antennas.

Elements of Attitude Determination & Control

ADCS = Attitude Determination & Control System

Active attitude control
3-axis stabilized

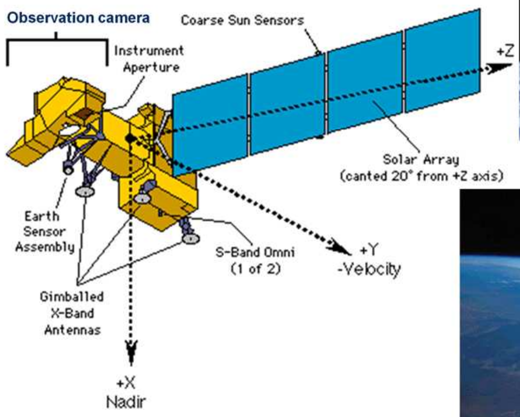
Passive attitude control
Magnetic torquers → Delfi-C3
Gravity gradient stabilized
Spin stability

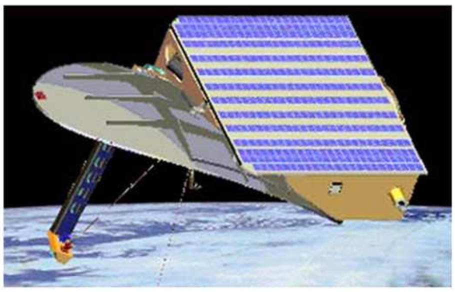


Appollo Command Module shows thrusters to provide six degrees of freedom in active ADC

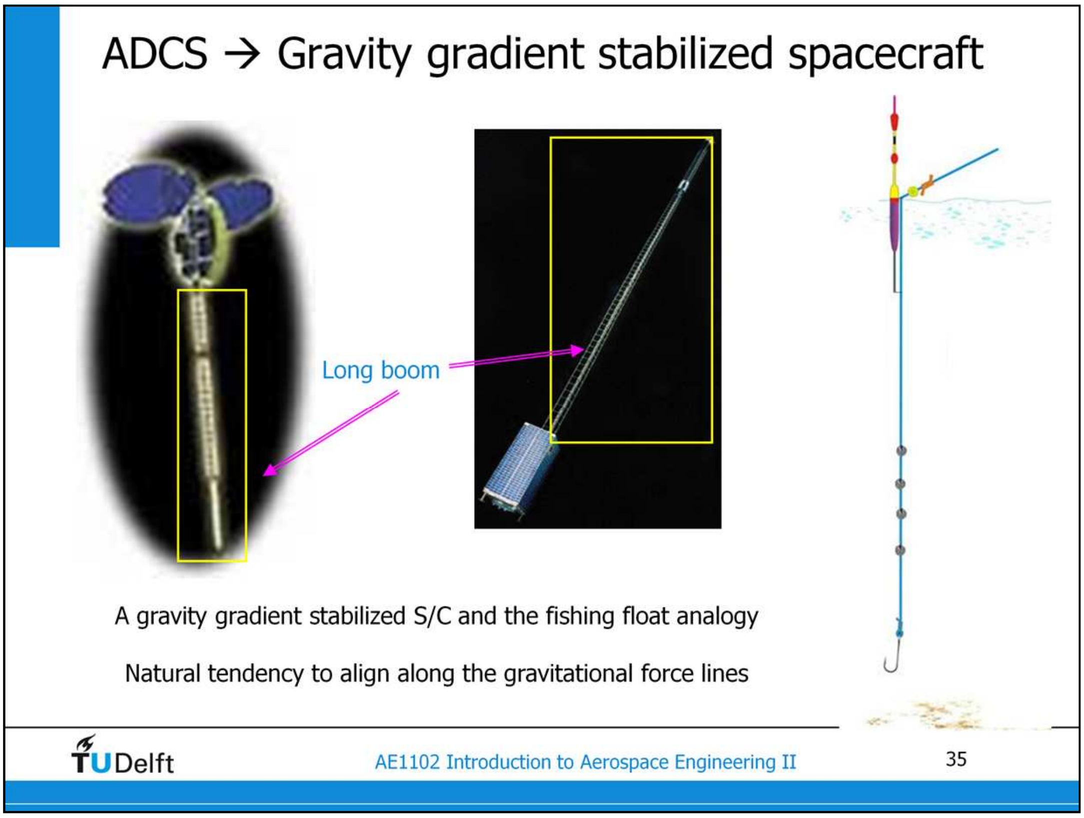
ADCS→ Active Attitude Control

Spacecraft utilising three-axis control





On slide we have Landsat-7 on right, SAR-LUPE at top right and envisat at bottom (middle)



Spacecraft on the left is an Orbcomm communications spacecraft

The fishing float analogy comprises

A) Floating on the water surface → equlibrium of centripetal force and gravitational force

B) Small leads attached to the fishing line → inertia added to the S/C yields vertical (along gravitational force lines) stability

Compare this condition to a massless rod with masses M1 and M2 at the ends at distances r1 and r2 from the Center-Off-Mass (COM) position along the rod. As long as the vertical attitude is not obtained a net torque (force x arm) about the COM results which is defined by the magnitude of M1 and M2 as well as R1 and R2. The equilibrium is defined by the (required) centripetal and gravitational forces on both masses. The COM position along the massless rod is found by (M1.r1+M2.r2)/ (M1+M2)

With

R1 the distance to the Earth COM of mass M1

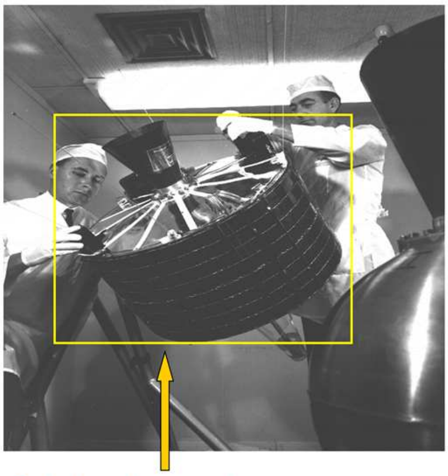
R2 the distance to the Earth COM of mass M2

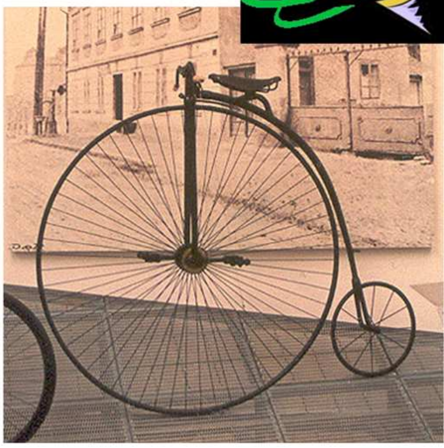
R the distance of the rod COM to the earth COM

The (detailed) analysis is part of later lectures and not part of this lecture sequence.

ADCS → Spin stability

Whole body spins





Rotational symmetry

Mass distribution→ rotational inertia

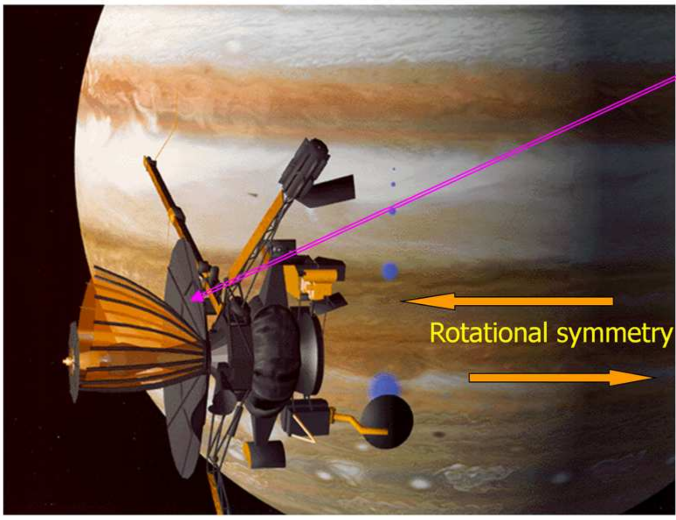
Spin stabilization as is seen with bycicle wheels. A rotating body tends to keep its rotation axis fixed in space. Enlarging the wheel more stability is obtained. The Earth is another example. Deviations in orientation as seen with a childrens toy → the spinning top (shown on top)

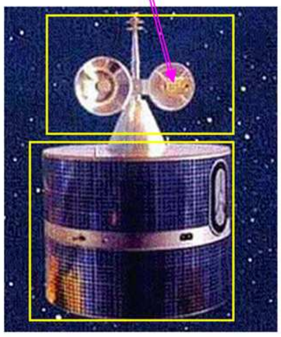
The rotational inertia is given by $I=MR^2$

This is best understood looking at the right picture. Assume that all mass M is located at the outer radius R for this formula.

ADCS → Dual-Spin Spacecraft

Galileo was the first dual-spin planetary spacecraft

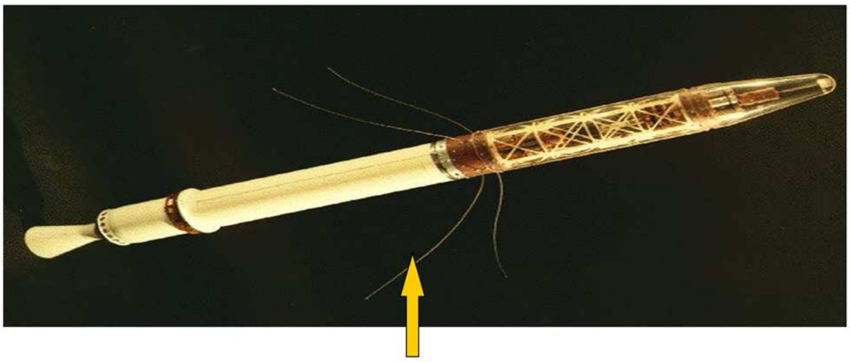




Dual-spin stabilized S/C

Galileo was the first dual-spin planetary spacecraft: a spinning section rotates at about 3 rpm, and a "despun" section is counter-rotated to provide a fixed orientation for cameras and other remote sensors

ADCS → Spin stability



Explorer-1 spacecraft (1957)
- Spin stabilized about its longitudinal axis @ 750rpm
- Four flexible wire antennas for communication

What can go wrong?

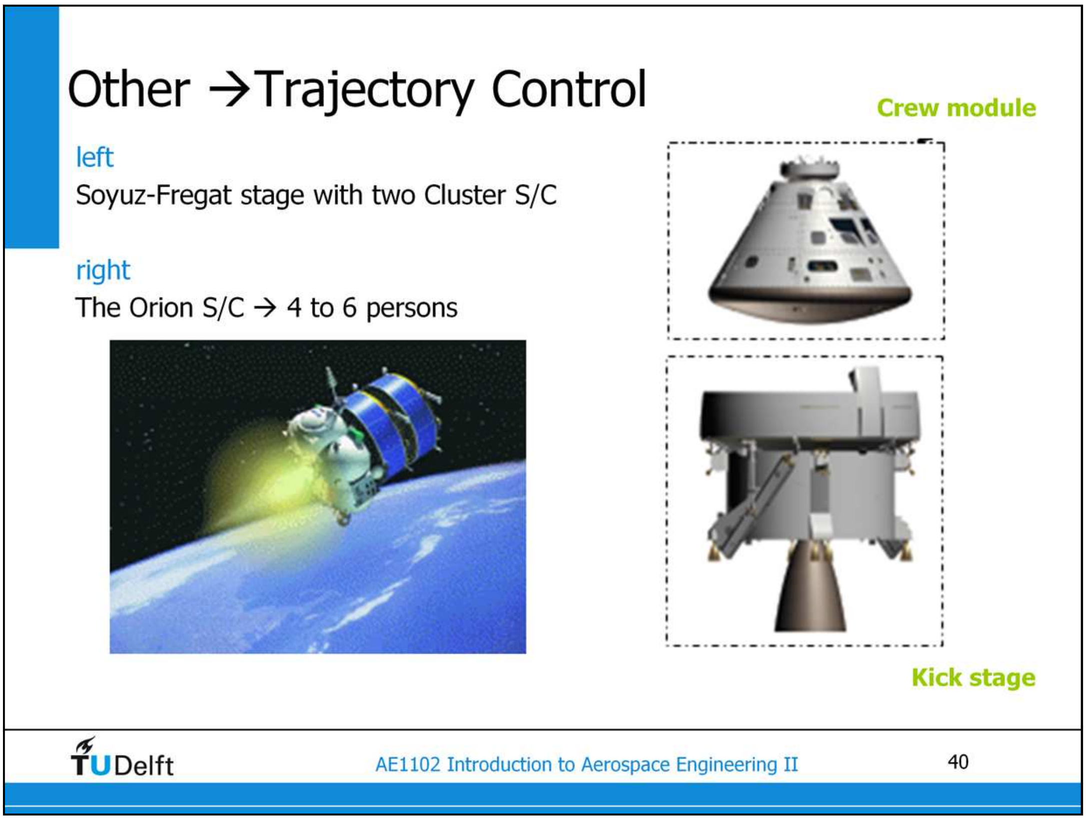
To the surprise of mission experts, satellite Explorer 1 changed rotation axis after launch. The elongated body of the spacecraft had been supposed to spin about its long (least-inertia) axis but refused to do so, and instead started pre-cessing due to energy dissipation from flexible structural elements. This motivated the first further development of the Eulerian theory of rigid body dynamics (after nearly 200 years) to address dissipation.

ADCS → Spin stability: what can go wrong?

The Ulysses mission
34 years later

Spin stability better understood but..

Still instability resulting from design



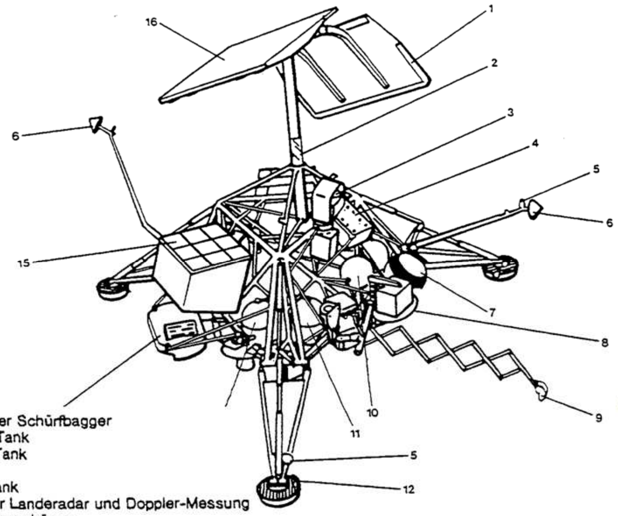
On slide we have left a Soyuz-Fregat stage transporting 2 Cluster satellites.

Dry S/C mass is S/C mass excluding propellant mass. Empty mass is dry mass including residual propellant mass. Launch mass is total mass launched. It includes loaded S/C mass (sum of S/C dry mass and propellant mass), (apogee) kick stage and launch adapter.

On the slide right we have the Orion S/C

Orion is a spacecraft design currently under development by the United States space agency NASA. Each Orion spacecraft will carry a crew of four to six astronauts. The spacecraft is designed to be launched by the Ares I, a launch vehicle, also currently under development. Both Orion and Ares I are elements of NASA's Project Constellation, which plans to send human explorers back to the Moon by 2020, and then onward to Mars and other destinations in the Solar System.

Other → Surveyor Lander configuration

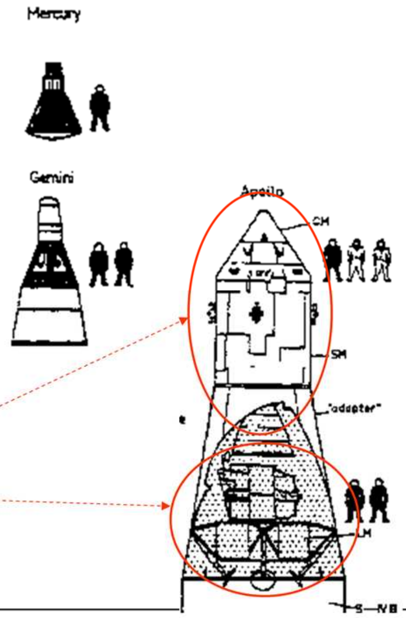


1 Solarzellenausleger
2 Stereo-Spiegel
3 Fernsehkamera
4 Elektronik des Alpha-Experiments
5 Eichmarke für Fernsehkamera
6 Rundstrahlantenne
7 Helium-Tank
8 Alpha-Experiment
9 Ausfahrbarer Schürfbagger
10 Stickstoff-Tank
11 Oxydator-Tank
12 Landefuß
13 Treibstofftank
14 Antenne für Landeradar und Doppler-Messung
15 Instrumentengehäuse
16 Hochgewinn-Planarantenne

On slide we have Surveyor. This is an unmanned Moon Lander that transmitted TV pictures to Earth and conducted a local study of the Moon surface.

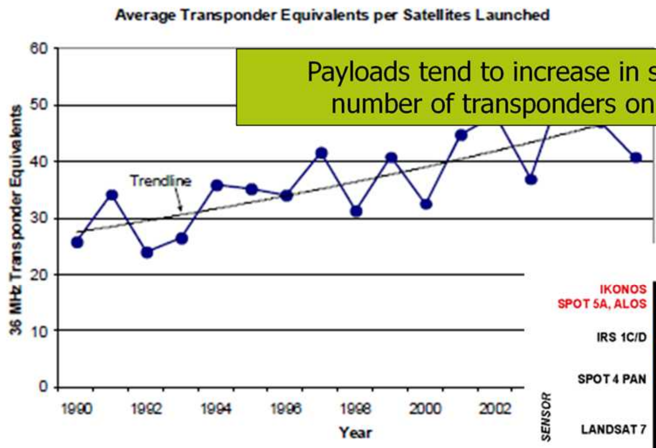
Other → Life support

- Mercury
  - manned Earth orbiter
    - weightlessness
    - reentry
- Gemini
  - manned Earth orbiter
    - rendez-vous and coupling
    - space walk
- Apollo
  - manned Moon orbiter
  - manned Moon lander
  - and return to Earth

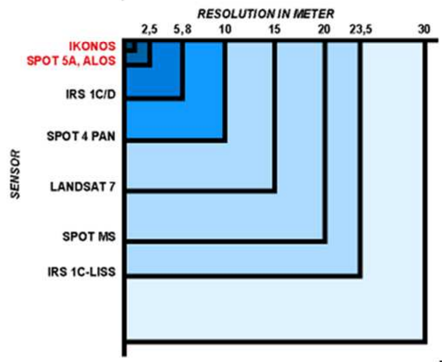


Moon program 1960-1972

Evolution in time of payload capability



Payloads tend to increase in size and number number of transponders on a telecom S/C



Resolution increases with size of lens

- The larger the lens diameter the higher the resolution -

Transponder = combination of transmitter and receiver.

Evolution in time Intelsat telecom S/C

Satellite	First launch (total number)	Launcher	Communication capacity	# of transpon-ders (-)	Electrical power (Watt)	Mass at orbit insertion (kg)	Satellite body Diam (m)	Satellite body Height (total) (m)	Attitude control	Design life year	Cost satellite 10^6 \$	Cost launch 10^6 \$
IntelSat I	1965 (1)	Thor-Delta	240 telephone circuits or 1 TV channel	2	40	68/39	0.72	0.60	Spin stabilisation	1.5	7	4.7
IntelSat II	1966 (3)	Improved Delta	Idem	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Spin stabilisation	3	3.6	4.6
IntelSat III	1968 (5)	Improved Delta	1200 telephone circuits and 2 TV channels	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Spin stabilisation with despun antennae	5	6.25	5.75
Intelsat IV	1971 (7)	Atlas-Centaur	4000 telephone circuits and 2 TV channels	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Spin stabilisation with despun antennae	7	18.5	32.5
IntelSat IVA	1975 (6)	Atlas-Centaur	6000 telephone circuits and 2 TV channels	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Spin stabilisation with despun antennae	7	21.5	32.5
IntelSat V	1980 (7)	Atlas-Centaur	12000 telephone circuits and 2 TV channels	27	1200	1870/ 1012	20	15.7	Three axes stabilized	7	28.0	32.0

Trends:
- Increasing # of transponders
- Increasing electrical power
- Increasing mass
- Increasing size
- Increasing life
- Increasing cost

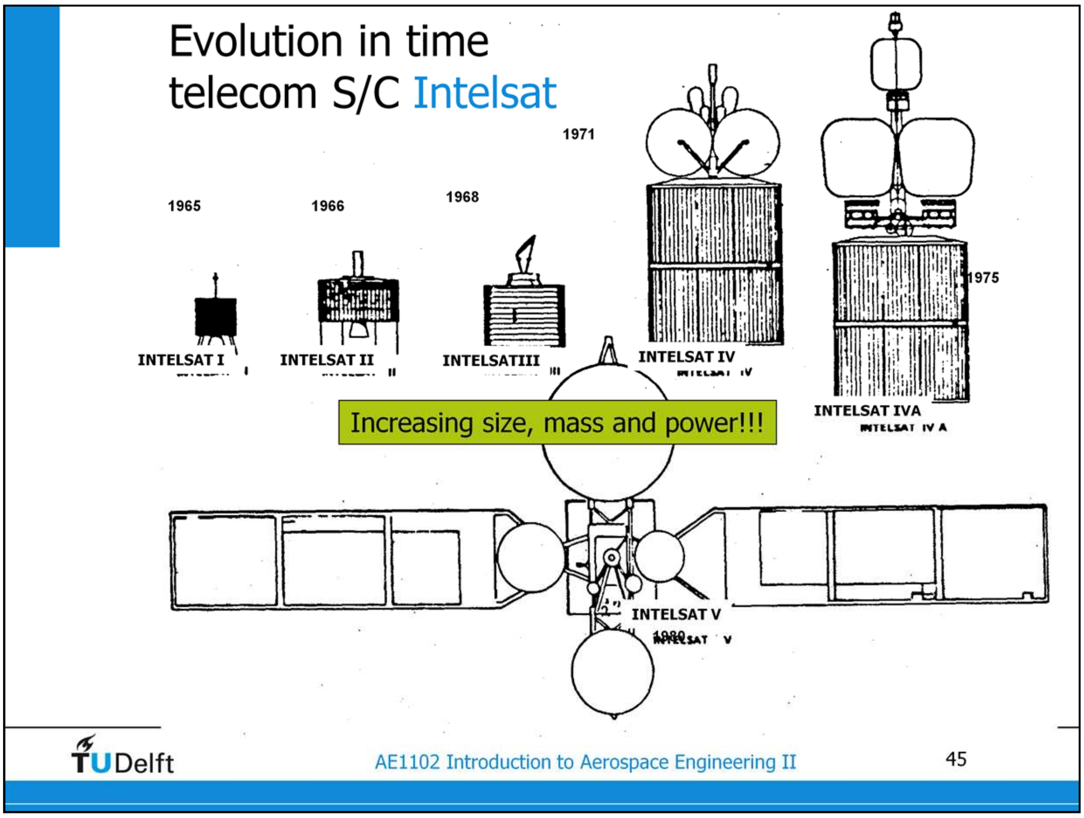


Figure shows satellites have increased in size. In addition, it shows:

-introduction of parabolic reflectors allowing for more directed power

-Larger solar arrays

ACCENT HERSCHEL-TELESCOOP

Nederlands duurste ruimte-instrument stuk

AMERSFOORT De HIFI-spectrometer aan boord van de Europese ruimtetelescoop Herschel heeft een defect. Herschel werd op 14 mei gelanceerd en bevindt zich inmiddels – onbereikbaar – op 1,5 miljoen kilometer afstand van de aarde.

Met een prijskaartje van zo'n 200 miljoen euro is de HIFI (Heterodyne Instrument for the Far Infrared) het duurste en meest complexe ruimte-instrument dat ooit in Nederland is ontwikkeld en gebouwd. Er is vijftien jaar aan gewerkt, onder leiding van het SRON Netherlands Institute for Space Research in Groningen.

Op zondag 9 augustus bleek dat een elektronische transformator in een regelmodule van HIFI het begeven had. Hoe dat precies kon gebeuren is niet bekend; de 'zwarte doos'-gegevens van de betreffende periode zijn ook verloren gegaan. Er is echter wel een reserve-exemplaar van de 'Local Control Unit' aan boord.

'Ik ga nog steeds uit van een externe oorzaak', zegt HIFI-hoofdonderzoeker Frank Helmich van SRON. Ruimte-elektronica kan ontregeld raken door energierijke kosmische straling.

De afgelopen weken zijn er volgens Helmich 'tot in den treure' allerlei tests uitgevoerd op een identieke kopie van HIFI in het Groningse SRON-laboratorium. Tot nu toe lijkt niets erop te wijzen dat er iets mis is met het ontwerp van de in Polen gebouwde regelmodule.

De Europese ruimtevaartorganisatie ESA heeft een onderzoeksteam in het leven geroepen. Binnen twee weken hoopt men te weten of het veilig is om het reserve-exemplaar van de regelmodule in bedrijf te nemen. Helmich verwacht dat HIFI dan weer gewoon functioneert.

Volgens Thijs de Graauw, directeur van het ALMA-observatorium in Chili en geestelijk vader van Herschel en HIFI, zijn tijdens de test- en kalibratiefase van het instrument al indrukwekkende resultaten verkregen. HIFI richt zich voornamelijk op het onderzoek van water in gebieden waar nieuwe sterren en planeten ontstaan. De Graauw: 'Ik ga nog steeds uit van een rijke wetenschappelijke oogst.'

Govert Schilling

Text taken from Volkskrant, Saturday 5, September 2009.

Reliability & failure data

Some failure data

- Out of 456 small satellite missions flown between 1956 and 1996 310 spacecraft launched successfully
  - 69% orbit insertion reliability → insertion failure rate 0.32/insertion
- Launches are historically 85% to 90% reliable
- C… nd of life

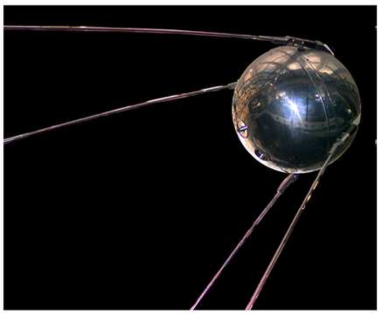
Reliabi… uccessfully unde…

Typica…

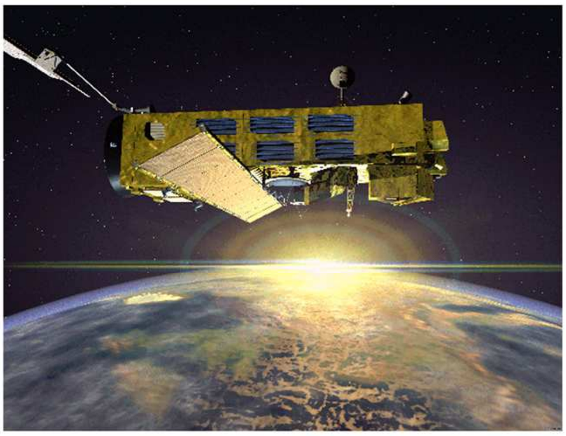
Include reliability data in text lecture notes, see part B.

Data on slide taken from http://www.engin.brown.edu/courses/en176/2003%20Lectures/meeting%209/9_3_19_02.ppt#328,7,Weakest Link? Small Satellite Historical Survey results: 1956 - 1996

Reliability of a S/C - Simple versus complex



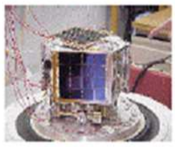
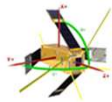
Single payload



Multiple (10) payloads

The Sputnik only had a single transmitter whilst the Envisat has 10 dedicated scientific instruments.

Mass and size - Spacecraft Categories

Designation	Mass (kg)	Power (W)	Dimension (m)	Comment/Picture
Micro-spacecraft	10-100	10-100	0.3-1	
Class I micro-spacecraft	5-20	5-20	0.2-0.4	
Class II micro-spacecraft	1-5	1-5	0.1-0.2	 Delfi –c3
Class III micro-spacecraft	<1	<1	<0.1	

Small spacecraft in more detail

Definition taken from Surrey.

Some mass definitions

Launch mass: Total spacecraft mass at launch. Besides the spacecraft itself, it may include mass of kick stage, and launch vehicle adapter

Total spacecraft mass: Gross or loaded spacecraft mass

BOL spacecraft mass: Mass of spacecraft at Begin Of Life (BOL), also referred to as on-station mass

Spacecraft dry mass: Total spacecraft mass minus the mass of expendables

EOL spacecraft mass: Mass of vehicle at End of Life (EOL)

Spacecraft dry mass (VDM): Net or final vehicle mass: Dry vehicle mass plus residuals and gases at cut-off (burnout)

S/C Mass Estimation

How? ⇒ By using historical data on payload to vehicle mass ratio + averaging

Spacecraft	Payload mass	Vehicle mass	Payload to vehicle mass ratio
	(kg)	(kg)	(%)
Monitor M	420	750	56
EROS-A	36	250	14.4
Average			35.2%

Minimum 5-10 spacecraft data needed to allow for a reasonable estimate !!

Example:
Payload mass is 300 kg

⇒ Using the average ratio of 35.2% it follows:
S/C mass = 300/0.352 = 852 kg

Can we apply this method also to estimate other parameters, like electrical power, of the spacecraft ??

Why do we take an average percentage and not say an average of the total mass of the vehicles in our table?

Spacecraft Body Size Estimation

Dimensions can be estimated from spacecraft mass - M_{SC}

Spacecraft body volume $V = M_{SC} / \rho$

Spacecraft density - ρ

Large spacecraft [SMAD]

- 75 S/C → 136 kg < total mass < 3625 kg
- 20-179 kg/m^3 → average is 79 kg/m^3

Smallsats

- 18 S/C - dry mass < 300 kg 200-1000 kg/m^3 → average is 338 kg/m^3

Large spacecraft [SMAD]: $V = 0.01\ M_{SC}$

Smallsats [TU-Delft]: $V = 0.003\ M_{SC}$

Spacecraft body size depends on basic shape of body (box, cylinder, etc.)

Large spacecraft [SMAD, section 10.5.1], 75 S/C, 136 kg < total mass < 3625 kg): 20-179 kg/m^3, average is 79 kg/m^3

Question to students:

For a number of spacecraft collect mass and size data and determine spacecraft mass density and plot mass density versus spacecraft mass.

When designing a satellite, it is advised to select a number of comparable satellites and use these satellites to determine typical densities. When doing so, you must give care to appendices (antenna's, solar panels, etc.) and propellant tanks. The latter take up

(based on empty mass ar

Studied 75 U.S. spacecra
'84)

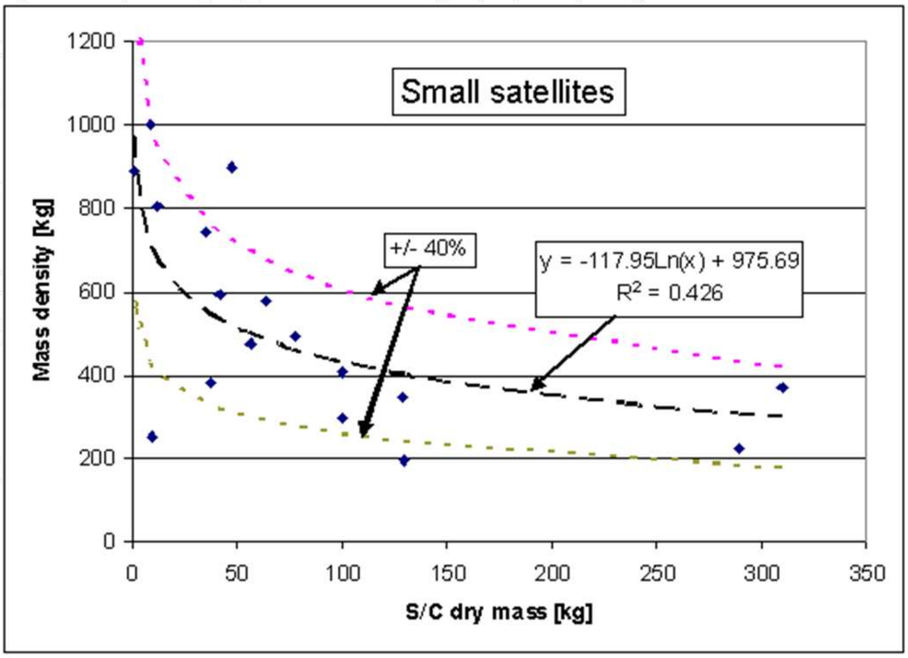
• Various Earth-orbiting

• Mass ranged from 135

• Density ranged from 20

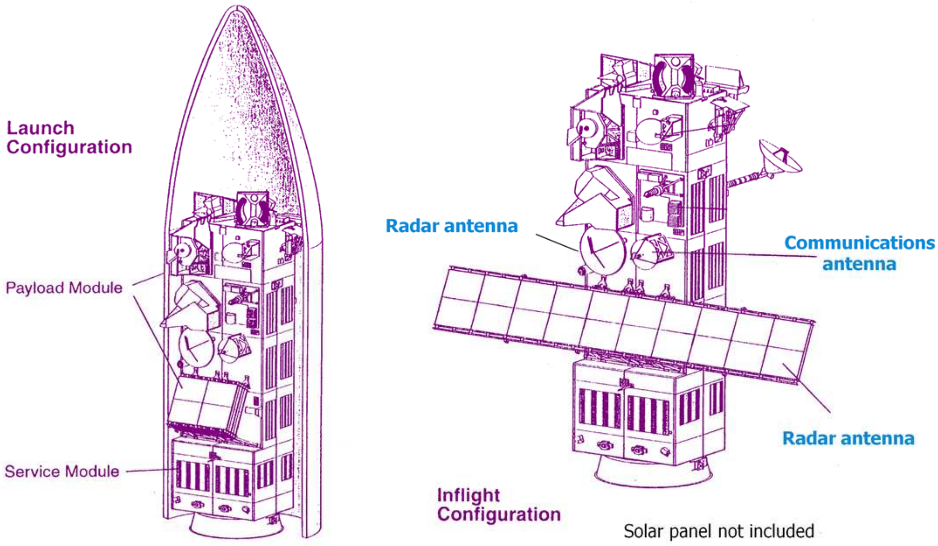
• All spacecraft were cyli
rectangular to circular

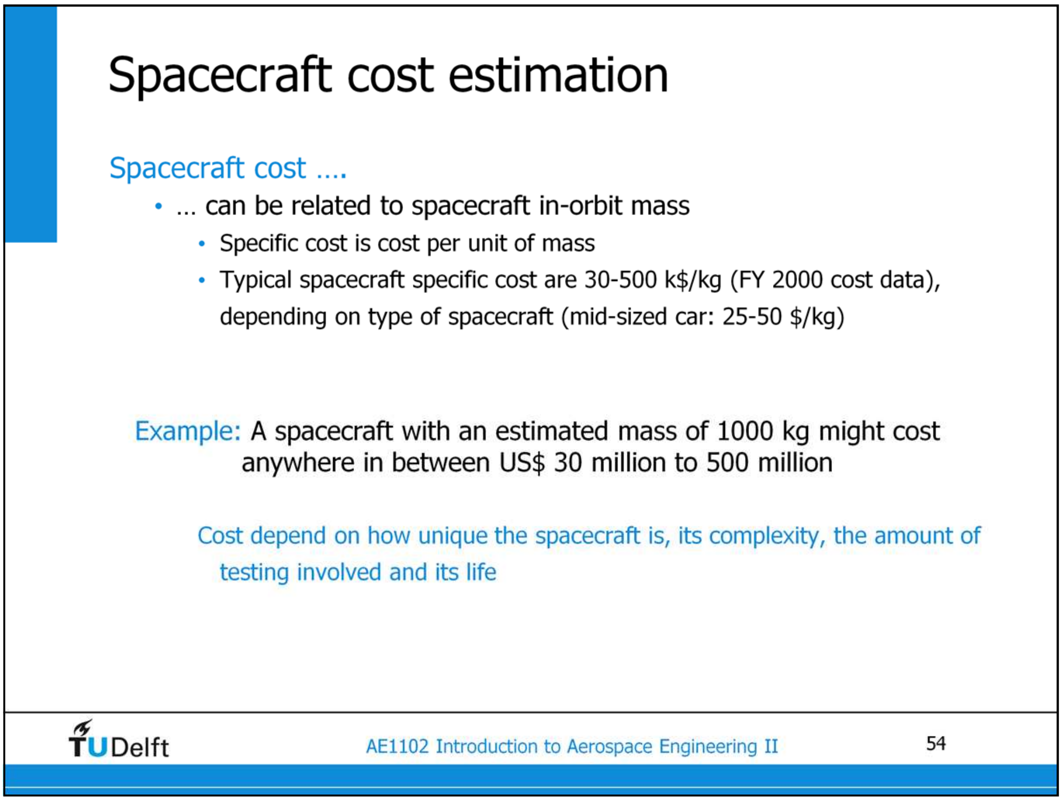
Volume of satellite is not



boxes. All boxes need space to get rid of excess heat.

Mass and size – The ENVISAT launch and in-flight configuration





Earlier in this presentation some data are given on the costs of INTELSAT communications satellites indicating a specific cost for development and launch of 50.000-300.000 $/kg (based on in-orbit mass). For the International Space Station this is about 450.000 $/kg and for Globalstar about 50.000 $/kg (based on a mass for each satellite of 450 kg and 1300 M$ investment costs for the space segment including launch. Source: Jane’s Space Directory, 2000). For comparison, the specific cost of a mid-sized car is less than about 25 $/kg.

Other indications of the complexity of space systems are the high number of personnel involved in the development, and the total time required from the initial conception of a space mission to its launch and operation (typically several years).

Questions?

- Thank you for your attention !!!