Introduction to Aerospace Engineering

Lecture slides

Introduction to Aerospace Engineering AE1102

Dept. Space Engineering

Astrodynamics & Space Missions (AS)

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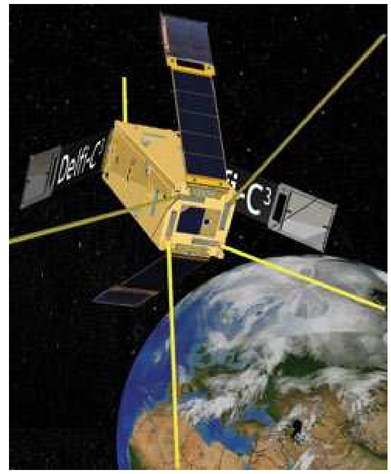

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Why do we go in Space?
What can we do there?
What are the challenges?

Historical highlights
Differences with Aeronautics
Characteristic conditions and numbers

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

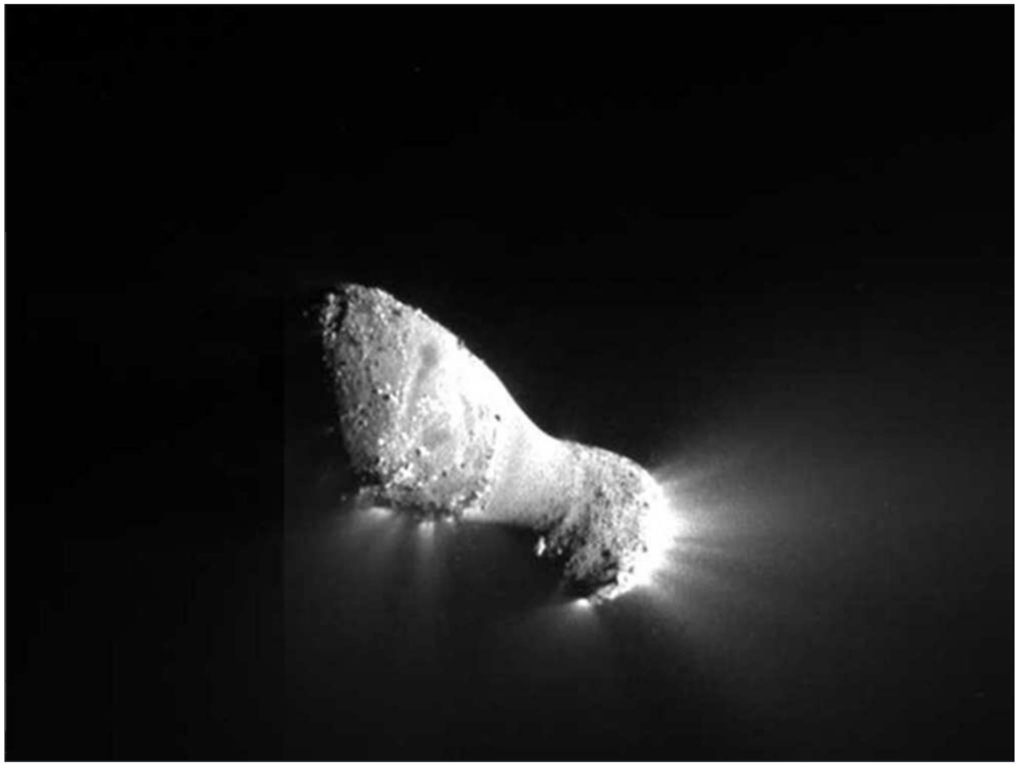
What is Space Flight (Astronautics) ?

- Learning goals
  - Get acquainted with concepts of space flight
  - Understand differences with aeronautics
  - Learn about historical perspective
  - Become aware of unique applications
  - Understand principles of satellite orbits
  - Understand principles of rockets
  - Get acquainted with unique aspects of "space technology"
  - Develop awareness of characteristic numbers and costs
  - Develop ability to make simple (back-of the-envelope) calculations
  - ???

Why do we go in Space?

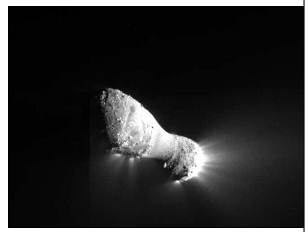
BECAUSE:

- we are curious
- it is challenging
- we have the necessary technology
- it stimulates technological innovations
- we can afford it
- it provides a unique environment (vantage point)
- It enables new applications
- we can do new business
- it provides access to new worlds
- Etc… ???
- it is there….



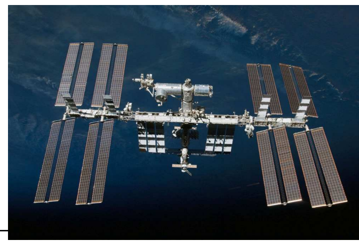
What can we do in Space?

- Observe the universe
- Observe and monitor the Earth
- Experience and exploit weightlessness (ISS)
- Perform in-situ science
- Travel to new worlds (solar system exploration)
- Space Tourism
- Make money…
- Etc…. ???



Comet Hartly 2010 (Deep Impact)

ISS (2010)

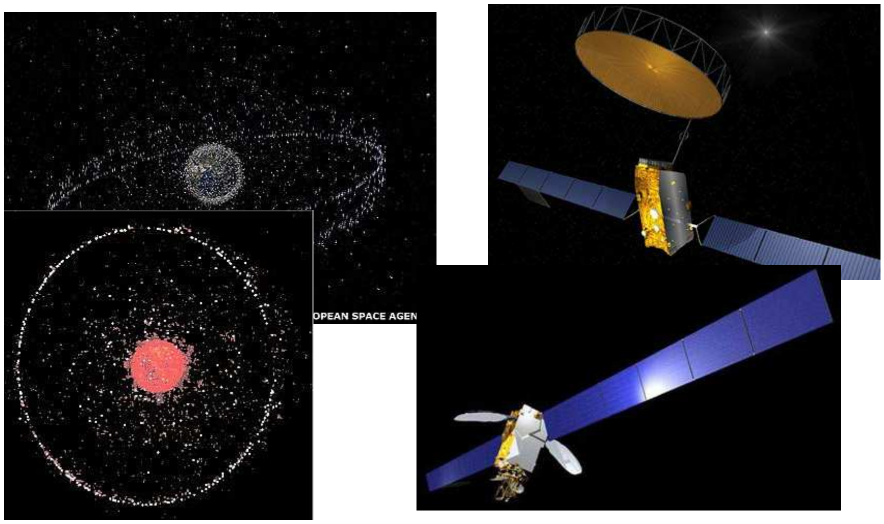


Virgin Galactic Spaceship-2

Important applications

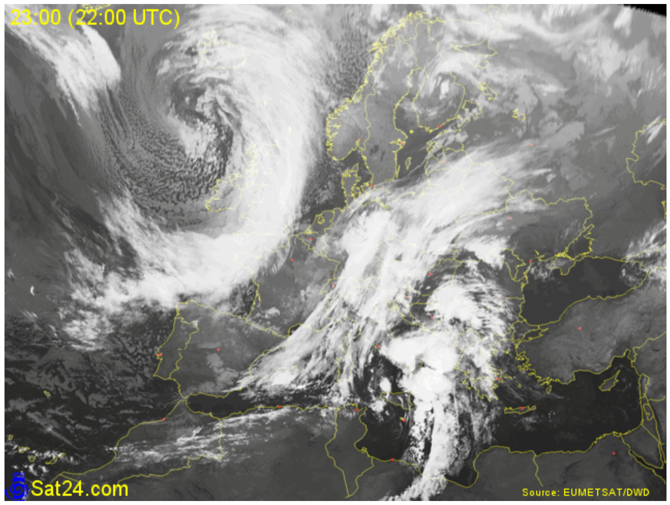
- Space physics
- Space astronomy
- Telecommunication
- Navigation
- Meteorology
- Disaster monitoring
- Global change
- Micro-gravity research
- Solar system exploration
- Espionage and surveillance
- Space tourism
- Etc… ???

Example of applications (Communication)



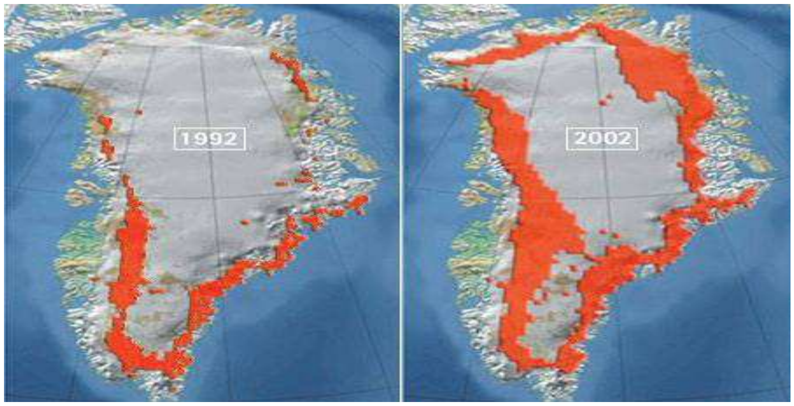
Satellites in geostationary orbit and sample missions (Inmarsat-4; Intelsat-10; ~6000 kg)

Example of applications (Earth observation; Meteorology)



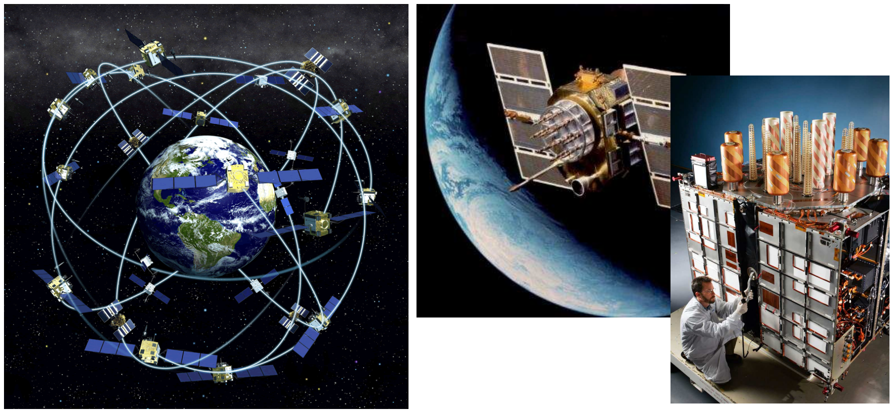
Infrared cloud picture taken by geostationary satellite (7 November 2010)

Example of applications (Earth observation; global change monitoring)



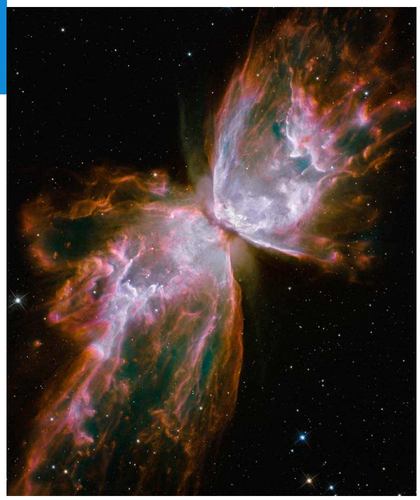
Decrease of Iceland ice cap due to global warming

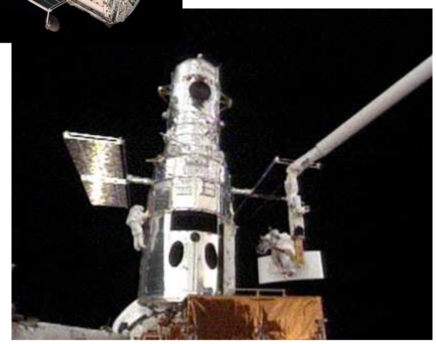
Example of applications (Global Navigation Satellite System; GNSS)



Constellation of GPS satellites and example of Block-I and Block-IIR-M satellites

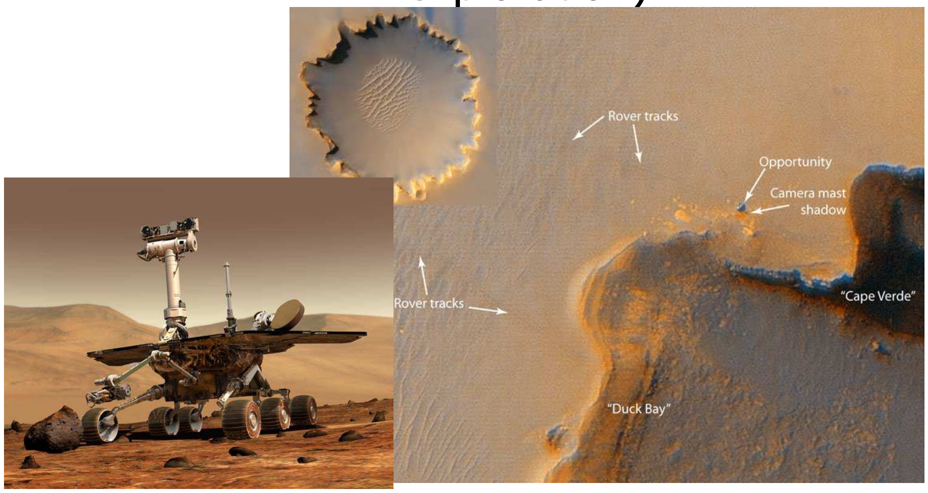
Example of applications (Space Astronomy)





The Hubble Space Telescope and one of the first pictures after the last repair mission

Example of applications (Solar system exploration)



The Spirit rover on the surface of Mars and pictured by the MRO orbiter

What are the challenges?

- To get there, stay there and return
- To do this in an affordable, efficient way
- To deal with a harsh and hostile environment
- To develop the technology
- To invent innovative applications
- To (remotely) operate the systems
- To automate and autonomate the systems
- To deal with the unexpected…..

Enabling technologies

- Miniaturization of electronics
- Radio communication and radar technology
- Capability to build large light-weight structures
- Advanced heat resistant materials
- Light-weight, powerful gas turbines and pumps
- Liquid propellant rocket engines
- Active guidance using gyroscopes
- Solar cells
- Heat engines (Stirling principle)
- Digital computers
- Life support systems
- Etc… ???

Example of energy supply in Space

Envisat solar panel
- Power: 6.55 kW
- Dimension: 5x14 m^2
- Silicium solar cells

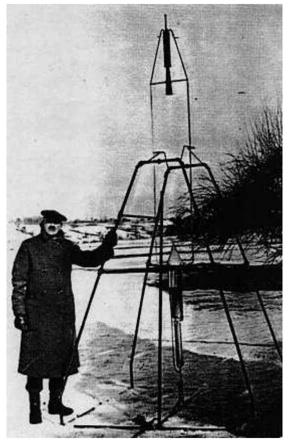
Vanguard-1 (1958)
- First solar cells in space (invented in 1954 by Bell Telephone Lab)
- Power: 10 mW
- Dimension: 6x25 cm^2
- Satellite mass: 1.5 kg

Important dates and people - The theory

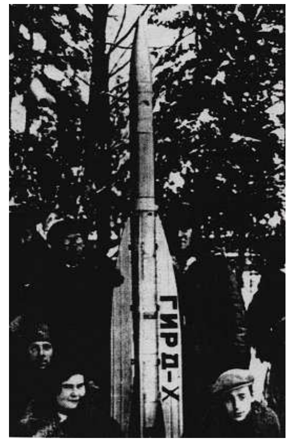
- 1571 - 1630
  - Kepler solves the mystery of celestial mechanics
- 1642 – 1727
  - Newton defines the physical principles of force, motion and gravitational attraction
- 1865
  - Jules Verne describes a virtual trip to the Moon
- 1903
  - Tsiolkowski publishes his theoretical study on rocket propulsion and multi-stage rocket motion
- 1920's
  - Oberth pioneers the theoretical fundamentals of space flight
- 1925
  - Hohmann analyzes the method to perform interplanetary flight

Important dates and events - The hardware

- 1920-1940
  - Goddard launches first liquid propellant rocket in the US
  - Koroljev does the same in Russia
- 1940-1945
  - Von Braun develops the first operational short-range missile (V2 rocket)
- 1950-1960
  - Russia and the US develop Inter-mediate range and Inter-continental range Ballistic Missiles (IRBM's & ICBM's)



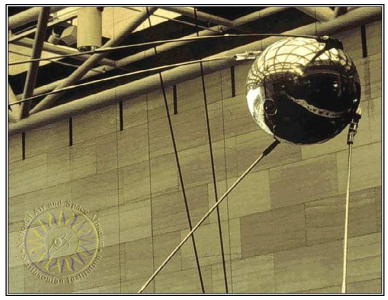
R.H. Goddard 1926



Koroljev 1933

Important dates and events - Spaceflight

- 1957
  - Launch of Sputnik I
- 1958
  - Launch of Explorer I
- 1959
  - Luna 2 makes a hard landing on the moon
- 1961
  - First manned satellite flight (Gagarin; Vostok I)
- 1962
  - First US manned satellite flight (Glenn; Mercury)



Launch: 4 oktober 1957

Shape: sphere

Radius: 0.58 m

Mass: 83.6 kg

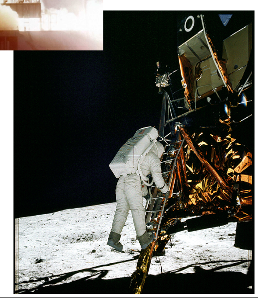
Radio frequencies: 20 and 40 MHz

Low earth orbit: 227 x 941 km

Inclination: 65.1º

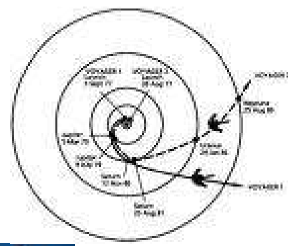
Important dates and events – Spaceflight (cnt'd)

- 1962
  - Mariner II to Venus
- 1965
  - First EVA (Extra Vehicular Activity) by Leonov; Voskhod 2
- 1967
  - First launch of largest rocket ever (Saturn-V)
- 1968
  - First European scientific satellite (ESRO II)
- 1969
  - First men on the moon (Amstrong & Aldrin; Apollo 11)
- 1974
  - First Dutch satellite (ANS)
- 1976
  - First soft landing on Mars (Viking 1/2)



Important dates and events – Spaceflight (cnt'd)

- 1977
  - Voyager-2 to Jupiter, Saturn, Uranus and Neptune
- 1979
  - First successful flight of the European Ariane launcher
- 1981
  - First flight of the Space Shuttle
- 1986
  - First launch of MIR, the permanent Russian Space Station
- 1990
  - Launch of Hubble Space Telescope
- 1998
  - Launch of the first element of the ISS, the Russian Zarya module



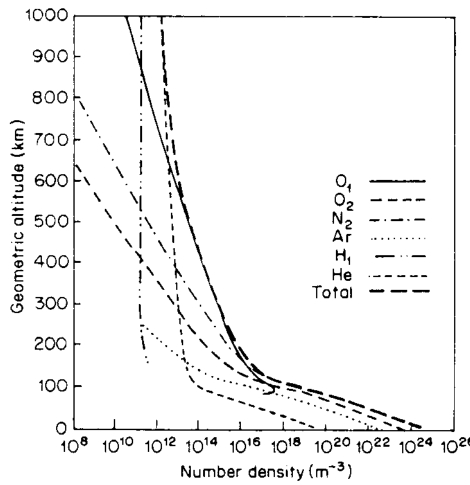
Differences with aeronautics

- Short-duration powered flight
- Free flight after launch
- Extremely high velocities
- Limited “steering” capability after launch
- No physical access to hardware after launch
- Vacuum environment
- Weightlessness
- Expendable propulsion
- High vantage point for observations
- Fast global coverage
- Tailored design for each mission
- Expensive !!??
- Etc… ???

What is Space?

Vacuum

- Where does it start (> 120km)
- No (small) lift and drag
- No "breathing" atmosphere
- No oxygen for propulsion
- Fluids "evaporate" (lubrication problems)
- Aggressive environment (atomic oxygen erodes plastics)
- Outgassing of materials



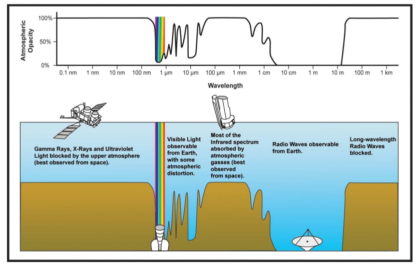
Source: Fortescue

What is Space? (Cnt'd)

Thermal Environment

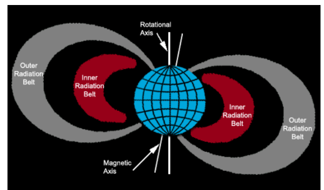
- Extremely hot and cold
- Without special measures material temperatures may vary between -270 and +120 C (near Earth)
- Solar flux at Earth surface 400 to 600 W/m^2 (depending on cloud cover, latitude and time of day), in space 1400 W/m^2
- Earth surface temperature ~293 K
- Deep space temperature 4 K
- **No convection** (because no air and no gravity) but…
  - Radiation (internally and to environment) and
  - Conduction (internally)

What is Space? (Cnt'd)



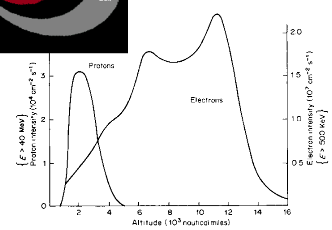
Radiation

- no atmosphere to shield from dangerous and destructive electro-magnetic radiation (e.g. UV, X-rays)
- destroys living tissue, electronics, plastics
- Full EM spectrum observable!



High energy particles

- High-energy protons and electrons
- Van Allen radiation belts
- South-Atlantic anomaly
- Solar flares / eruptions (even noticeable on Earth)



Source: Fortescue

Movie of the day (17-11-2011)

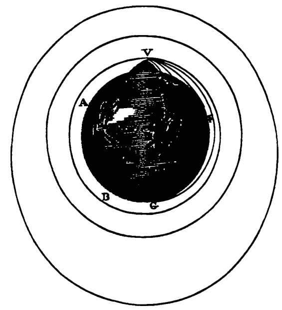
- http://www.space.com/13627-time-lapse-video-earth-auroras-iss.html

What is space ? (Cnt'd)

Weightlessness!!

After launch the satellite and its contents are in a state of:

CONTINUOUS FREE FALL



Why? (Basics of astrodynamics: Newton's laws)

- Conservation of momentum (mass times velocity = constant)
- Force equals mass times acceleration (F=Ma)
- Reactive force = - Action force ("Action equals reaction")
- Gravitational force: proportional to the masses of the attracting bodies and inversely proportional to the square of the distance to the center of the bodies

What is Space (Cnt'd)

Earth gravity force on a S/C in circular orbit at height h_{orbit} (assume S/C is a point-mass)

Newton's 4th law

Newton's 2nd law

$$F_g = G\frac{M_{S/C}M_E}{(R_E + h_{orbit})^2} = M_{S/C} \cdot g$$

$$g = G\frac{M_E}{(R_E + h_{orbit})^2} = \frac{\mu}{(R_E + h_{orbit})^2}$$

$$g_0 = G\frac{M_E}{R_E^2} = \frac{\mu}{R_E^2} \quad (N.B.\ h_{orbit} = 0) \implies g = g_0\frac{R_E^2}{(R_E + h_{orbit})^2}$$

UNIVERSAL gravitational constant: $G = 6.673 * 10^{-11}$ ($m^3\ kg^{-1}\ s^{-2}$)

g / g_0 = Gravitational acceleration at S/C altitude and Earth surface, resp.
R_E = Earth radius (assuming spherical Earth)
h_{orbit} = Height of the S/C above the Earth's surface
N.B. In a circular orbit F_g acts normal to the velocity vector → V_{orbit} = constant

What is Space (Cnt'd)

How does a satellite (S/C) stay in a (circular) orbit?

Equilibrium between gravity force and centrifugal force

- Gravity force $F_g = M_{S/C} \cdot g = M_{S/C} \cdot g_0 \cdot \frac{R_E{}^2}{(R_E + h_{orbit})^2}$
- "Apparent " centrifugal force (circular orbit) $F_c = M_{S/C} \cdot \frac{V_{orbit}{}^2}{R_E + h_{orbit}}$
- Equilibrium $F_g = F_c \Rightarrow \quad V_{orbit} = V(h_{orbit}) = \mathrm{R}_E \sqrt{\frac{g_0}{\mathrm{R}_E + h_{orbit}}}$
- Orbital period $T = \frac{2\pi(R_E + h_{orbit})}{V_{orbit}}$

See example in notes below

GENERAL NOTE:

All expressions can also be used INVERSELY !!!

Example:

If the orbital period T, the Earth radius Re and the height of the orbit h_{orbit} are given, you can calculate the velocity of the S/C using the formula for the orbital period.

Assume T = 90 minutes, Re = 6378 km and h_{orbit} = 275 km

Compute V_{orbit}

Answer: 7.74 km/s

N.B. Always be careful with the "units". Make sure you are always consistent. So don't mix up km and m, or min, hrs and seconds

Example problems

Velocity and orbital period of a satellite in a circular Earth orbit

- Compute the value of g_0 at the Earth's surface
  (GM_{Earth} = 398601.3 km^3/s^2; Re = 6378 km)
- Compute the velocity of a satellite at 800 km altitude (Envisat)
- Compute the velocity of the Moon around the Earth
  (Average Earth-Moon distance = 384000 km)
- Compute the orbital height of a geostationary satellite
  (Orbital period = 23 hr 56 min)

Answers:

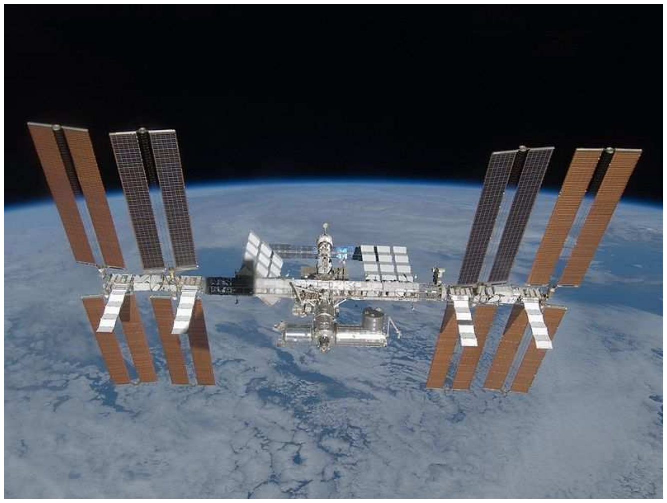
g_0 = 9.80 m/s2

$V_{envisat}$ = 7.4519 km/s

V_{moon} = 1.0118 km/s

$H_{geo\text{-}sat}$ = 35785 km

Weightlessness



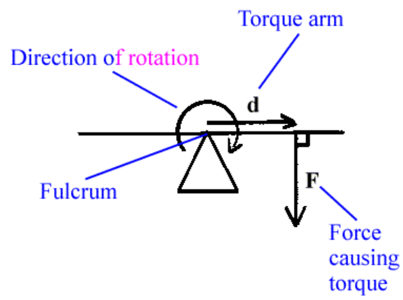
The International Space Station (ISS)

Weightlessness (Cnt'd)

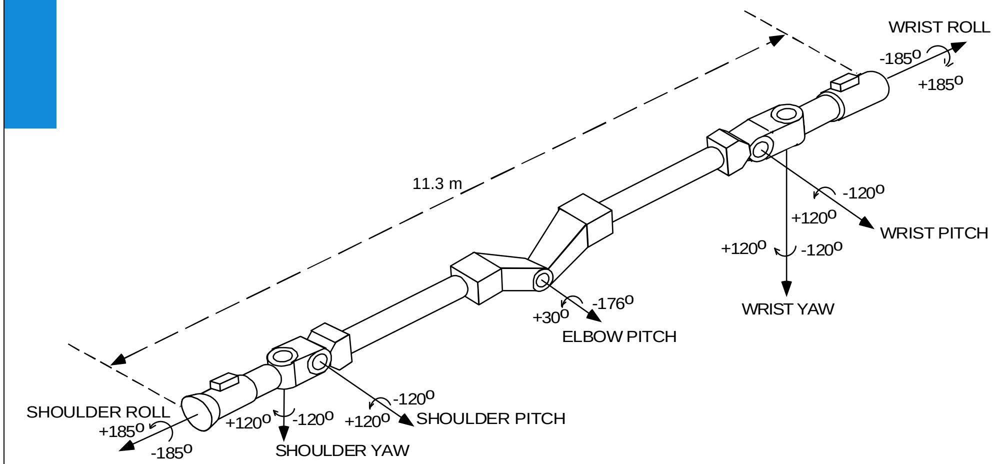
How do we move (heavy) objects in space? (robot arms exerting torque)

What is "torque" (in Dutch: "koppel of "moment")?

- Torque is also called "moment" or "moment of force"
- It is the product of "force" (N) times "arm" (m)
- It acts like a lever which causes a rotational motion about a "fulcrum" or "pivot point"
- Examples: wrench or electrical screw driver



Weightlessness (Cnt'd)



The European Robot Arm (ERA); Courtesy Dutch Space

Weightlessness (Cnt'd)

- **Example**
  - A robot arm of 10 m length (*l*) has to move a payload of 6000 kg mass. The actuator at the root of the arm exercises 300 Nm torque. What time does it take to move the payload over 180 degrees?
    - Force ***F***, acceleration ***a*** and displacement ***s*** at the end of the arm:

$$F = \frac{\text{Torque}}{l} = \frac{300}{10} = 30N$$

$$a = \frac{F}{\text{payload mass}} = \frac{30}{6000} = 0.005\, m/s^2$$

$$s = \alpha R = \frac{\pi}{2}.10 \text{ (NB. s equals distance traveled for } \alpha = 90 \text{ degrees)}$$

    - 90 degree arc with full acceleration/deceleration covered in $t = \sqrt{(2\,s/a)} = \sqrt{(2\,l\,(\pi/2)/a)} = \sqrt{(10\,\pi/0.005)} = 79.3\text{ s}$
    - 180 degrees covered in less than 160 seconds
    - What is the velocity of the payload at 90 degrees?

Answer: The velocity equals time times acceleration, giving ~ 0.4 m/s

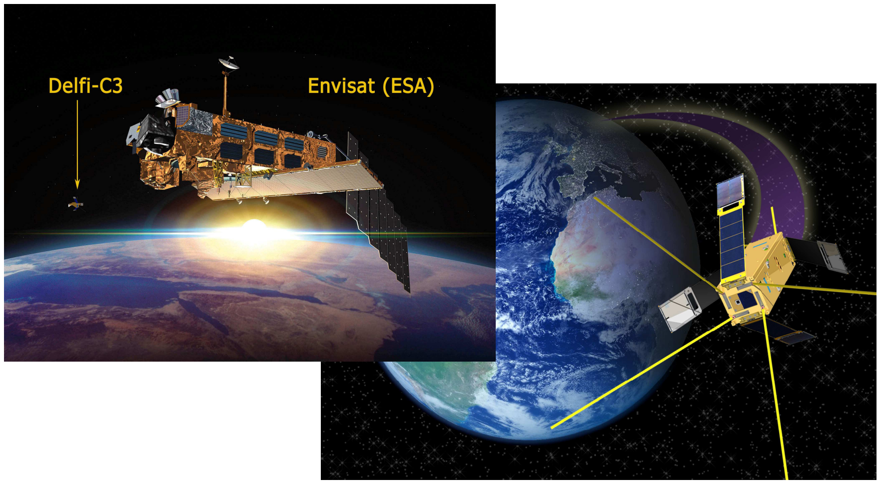
Example questions (weightlessness)

- Is the orbital velocity of a spacecraft dependent of its mass or not? (motivate your answer)
- What happens to a free-floating astronaut, when he swings a hammer and hits the nail?
- What happens to a free-floating astronaut when he torques a bolt?
- What is the motion of an object within the ISS if it remains untouched?
- Why is it possible to move heavy objects near the ISS with small force?
- Why is it possible to dock a 120 ton Space Shuttle with a 330 ton ISS?

Characteristic numbers

- Payload mass (3kg – 100,000kg)
  - Large aircraft (70,000kg)
- Launch mass (20,000kg – 3,000,000kg)
  - Large aircraft (250,000kg)
- Minimal orbital velocity (7.8 km/s = 28,000km/hr)
  - Aircraft (900km/hr – 3000km/hr)
- Minimal orbital height (250km)
  - Aircraft (10km – 20km)
- Typical satellite lifetime (3yr – 15yr)
  - Aircraft (25yr)

Example of spacecraft size and mass



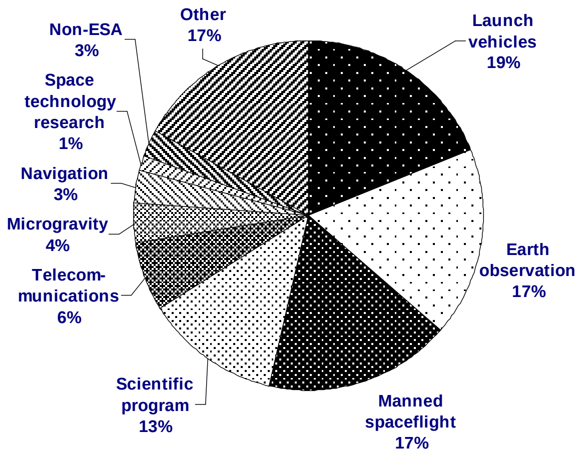
ENVISAT (ESA; 2002; size: school bus; mass: 3000kg)

Delfi-C3 (DUT; 2008; size: milk pack; mass: 3kg)

Characteristic numbers (Cnt'd)

- Cost of a Space Shuttle launch (500 MEuro)
  - Long-range aircraft (~0.5 MEuro)
- Cost of a large communications satellite (250 MEuro)
  - Inter-continental glass fiber cable (??? MEuro)
- Cost of Galileo navigation system (4,000 MEuro)
- Annual ESA budget (3,500 MEuro)
- Annual NASA budget (22,000 MUS$)
- Etc… ???

Characteristic numbers (Cnt'd)



ESA budget (2000)

Source: Space News, January 24, 2000

Budget growth

- 2710 M€ (2000)
- 2903 M€ (2006)
- 3500 M€ (2009)