Nonlinear control and aerospace applications

Introduction to aerospace control systems

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Outline

Introduction

- The fields in which satellites are used are numerous:
  - telecommunications
  - scientific research
  - meteorology
  - Earth observation
  - etc.
- Satellite weight: from several kilos to tens of tons.
- Satellite life:
  - reaching transfer orbit
  - reaching mission orbit
  - checking of instrumentation
  - mission.

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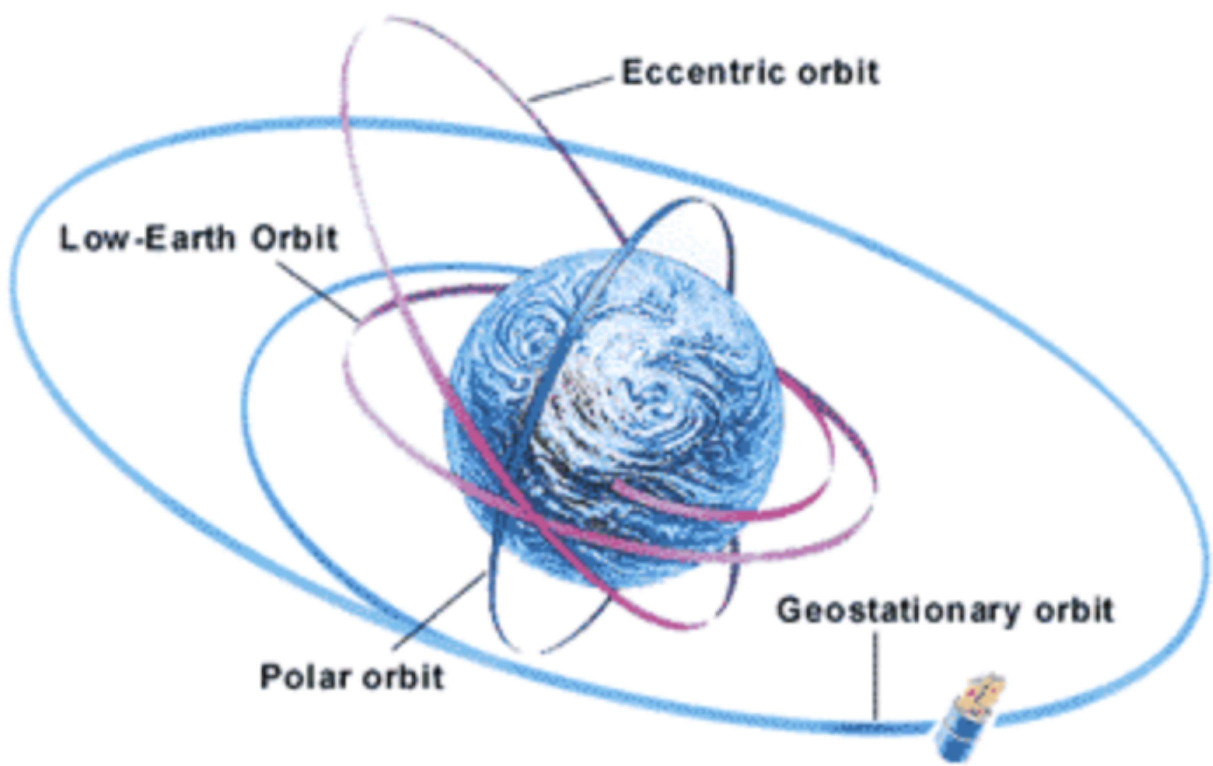
- Orbits:
  - LEO, low Earth orbit (180 to $2\,000$ km above the Earth surface)
  - MEO, mid Earth orbit ($2\,000$ to $35\,000$ km)
  - HEO, high Earth orbit ($\geq 35\,000$ km).



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Example: GEO, geostationary orbit

- The satellite travels on the orbit with a speed equal to the Earth rotation speed.
- The satellite is always above the same Earth zone.
- Equilibrium equation: $\overset{\text{Centrifugal force}}{m\omega^2 R} = G\frac{Mm}{R^2}$ gravity force
  - $\omega = 7.29\times10^{-5}$ rad/s = Earth rotational speed
  - $G = 6.67408 \times 10^{-11}$ m^{3}kg^{-1}s^{-2} = gravitational constant
  - $M = 5.972\times10^{24}$ kg = Earth mass
  - m = satellite mass not necessary
  - R = Earth-satellite distance.
- Letting $r = 6\,378$ km be the mean Earth radius, it follows that the distance of a geostationary satellite from the Earth surface is

$$R_g = R - r = \sqrt[3]{\frac{GM}{\omega^2}} - r = 35\,786 \text{ km}.$$

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Examples: Earth orbit satellites

- Examples of medium-sized satellites:
  - US Intelsat V (communication)
  - European Sentinel I (environment observation).

Intelsat V

Sentinel I

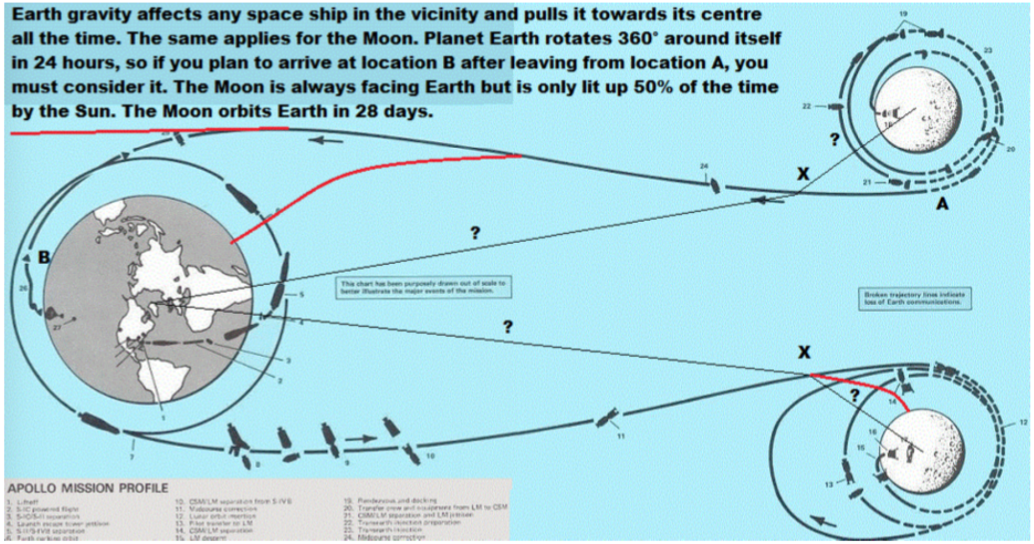
Introduction

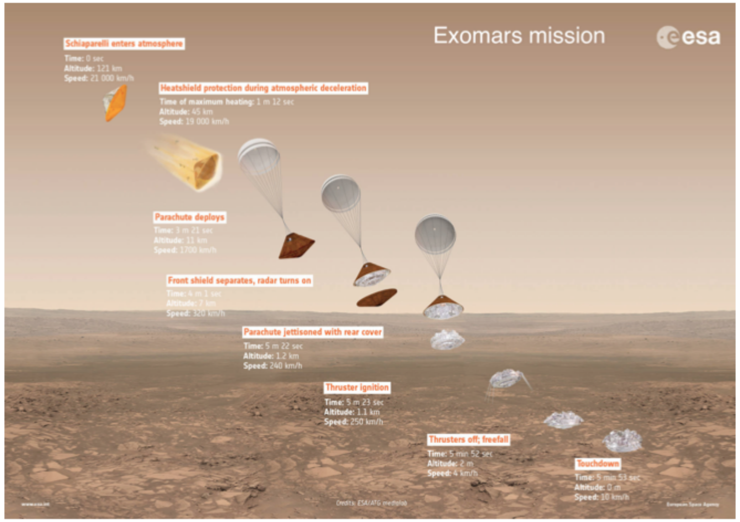
Examples: Earth orbit satellites

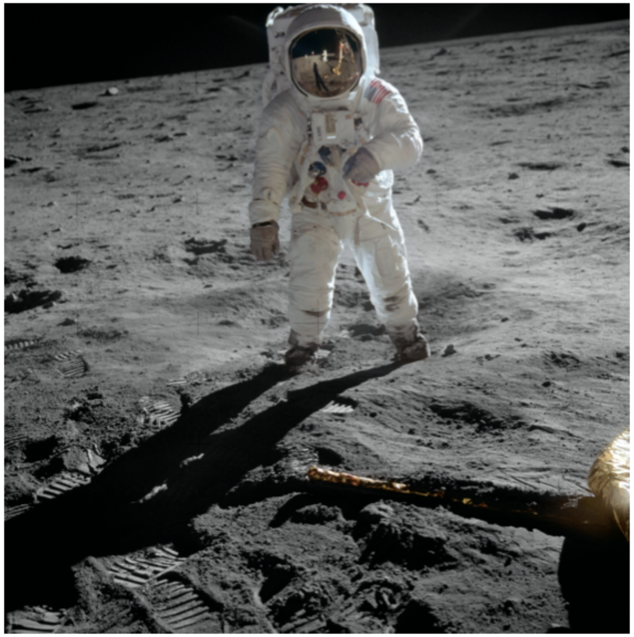
- Examples of medium-sized satellites are US Intelsat V and European Sentinel I.
  - Structural features:
    - central body with cubelike structure, $\sim 1.5 \times 1.5 \times 2\ \mathrm{m}^3$
    - solar arrays, $\sim 1 \times 7\ \mathrm{m}^2$
    - antenna directed toward the Earth
    - thrusters and attitude sensors located on the body and the solar panels
    - total mass $\sim 6\,000\ \mathrm{kg}$.
  - Attitude and orbit control system hardware:
    - thrust system
    - 2 momentum wheels
    - 2 infrared horizon sensors
    - 4 fine sun sensors
    - 12 coarse sun sensors
    - 2 three-axis coarse rate gyros
    - 2 three axis integrating gyros.

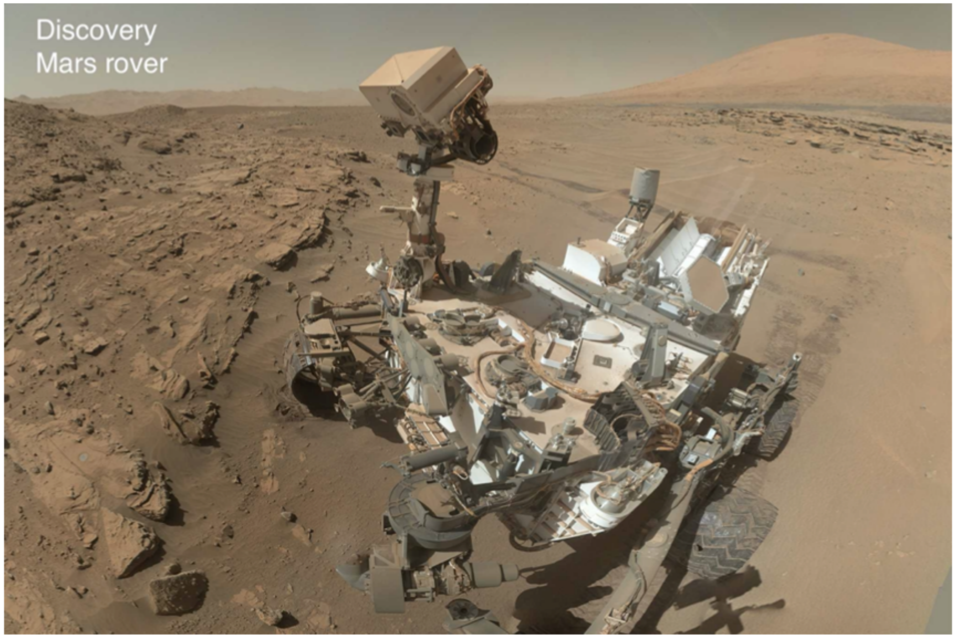
Introduction

Examples: Moon and Mars missions









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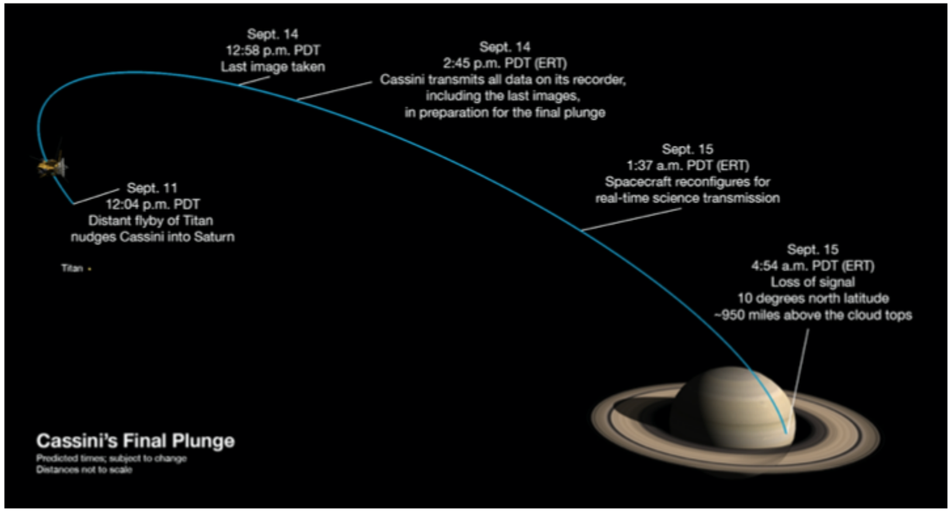
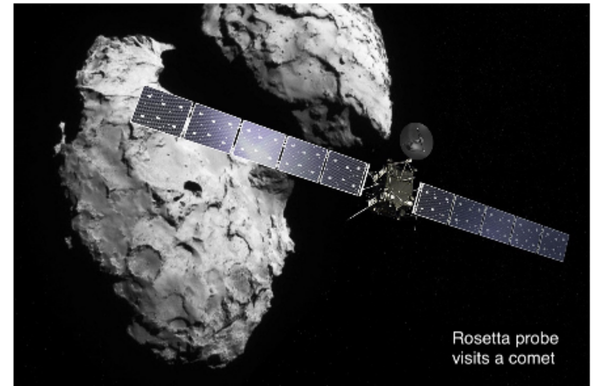
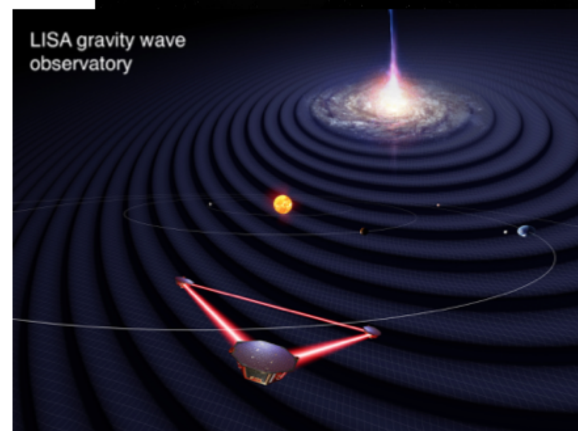
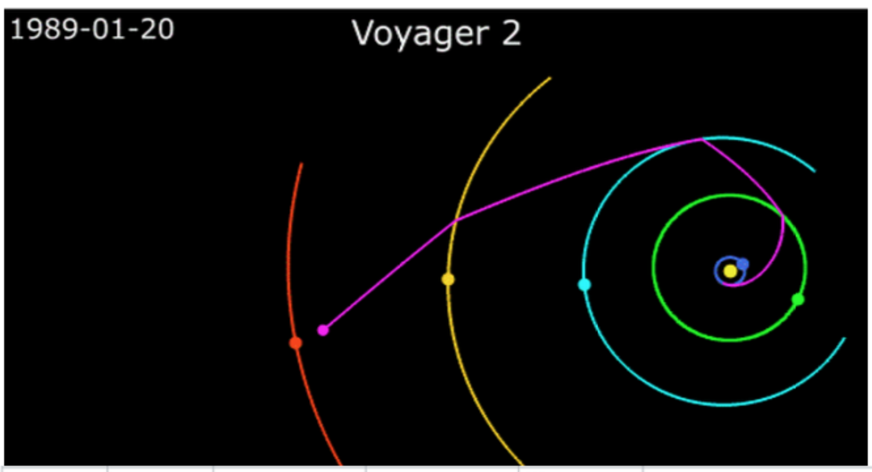
Examples: Other interplanetary missions

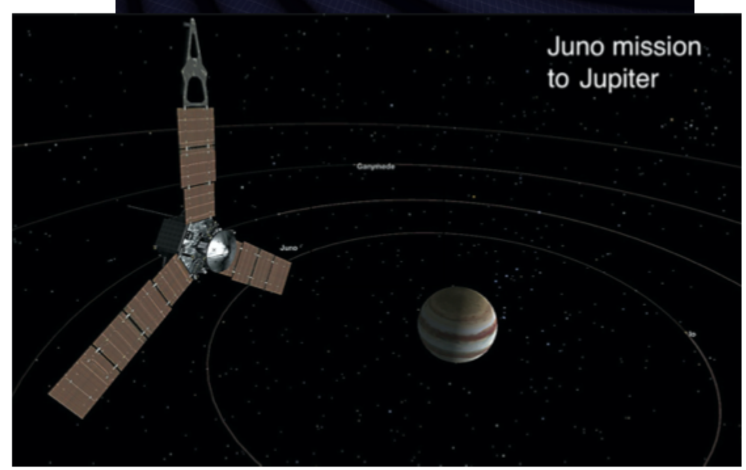








Voyager 2	Jupiter	20 August 1977	9 July 1979	689 days (1 yr, 10 mo, 20 d)	Voyager 2 flew by Jupiter.
	Saturn		5 August 1981	1447 days (3 yr, 11 mo, 17 d)	Voyager 2 flew by Saturn.
	Uranus		24 January 1986	3080 days (8 yr, 5 mo, 5 d)	Voyager 2 flew by Uranus and was the first spacecraft to visit it.
	Neptune		25 August 1989	4389 days (12 yr, 6 days)	Voyager 2 flew by Neptune and was the first spacecraft to visit it.



Overview

- Topics are organized in two main parts:
  1. Attitude dynamics and control:
     - rotations, attitude kinematics and dynamics
     - attitude control.
  2. Orbital dynamics and control:
     - orbital dynamics
     - orbit/trajectory control.

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