University of Southampton

Chapter 1

Systems Engineering

Professor Hugh Lewis

Chapter 1 overview

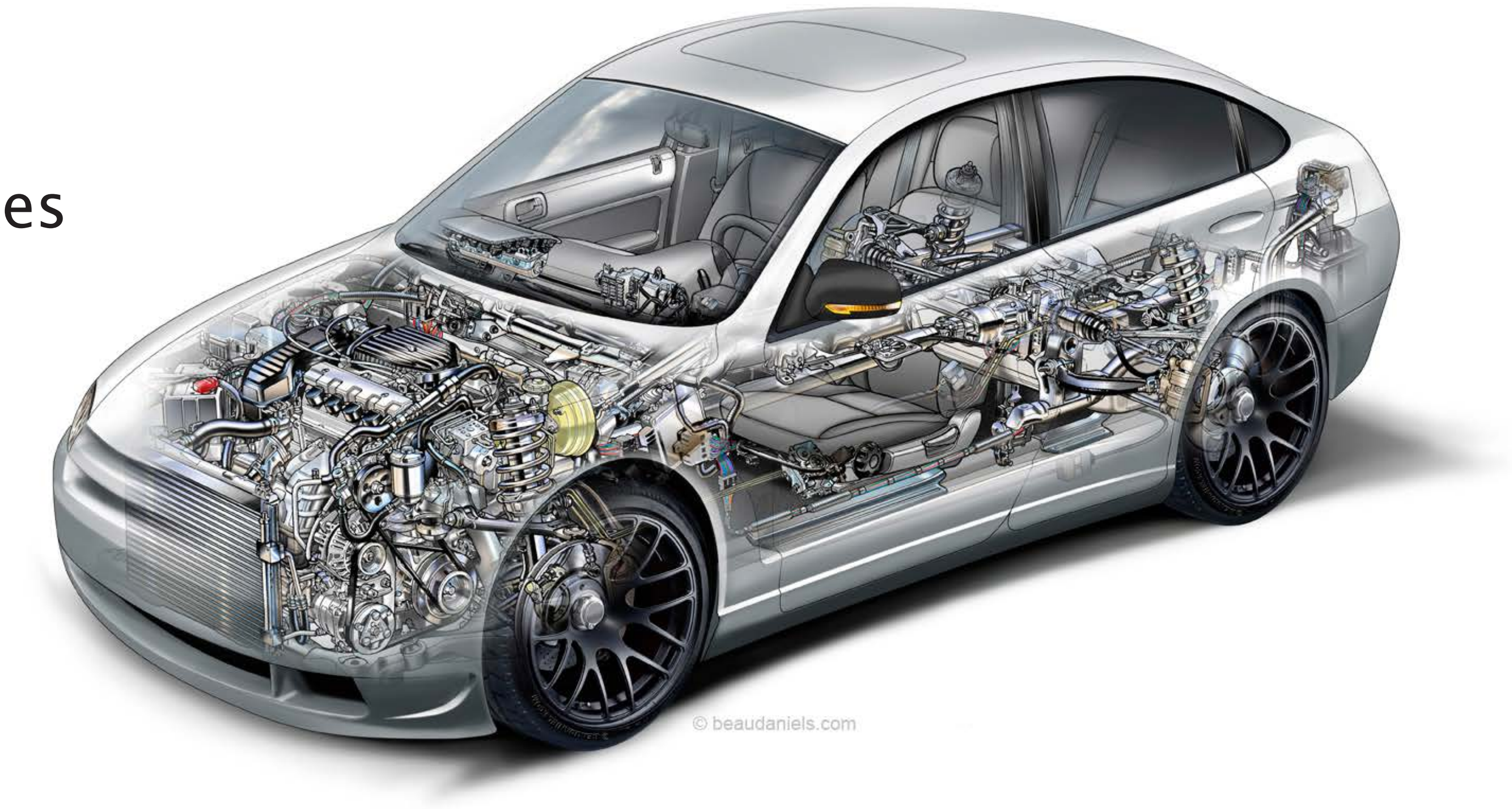
Chapter 1 – Systems Engineering – will be one lecture:

- Introduction
- Spacecraft subsystems
- Spacecraft design method and development
- Example
- Summary

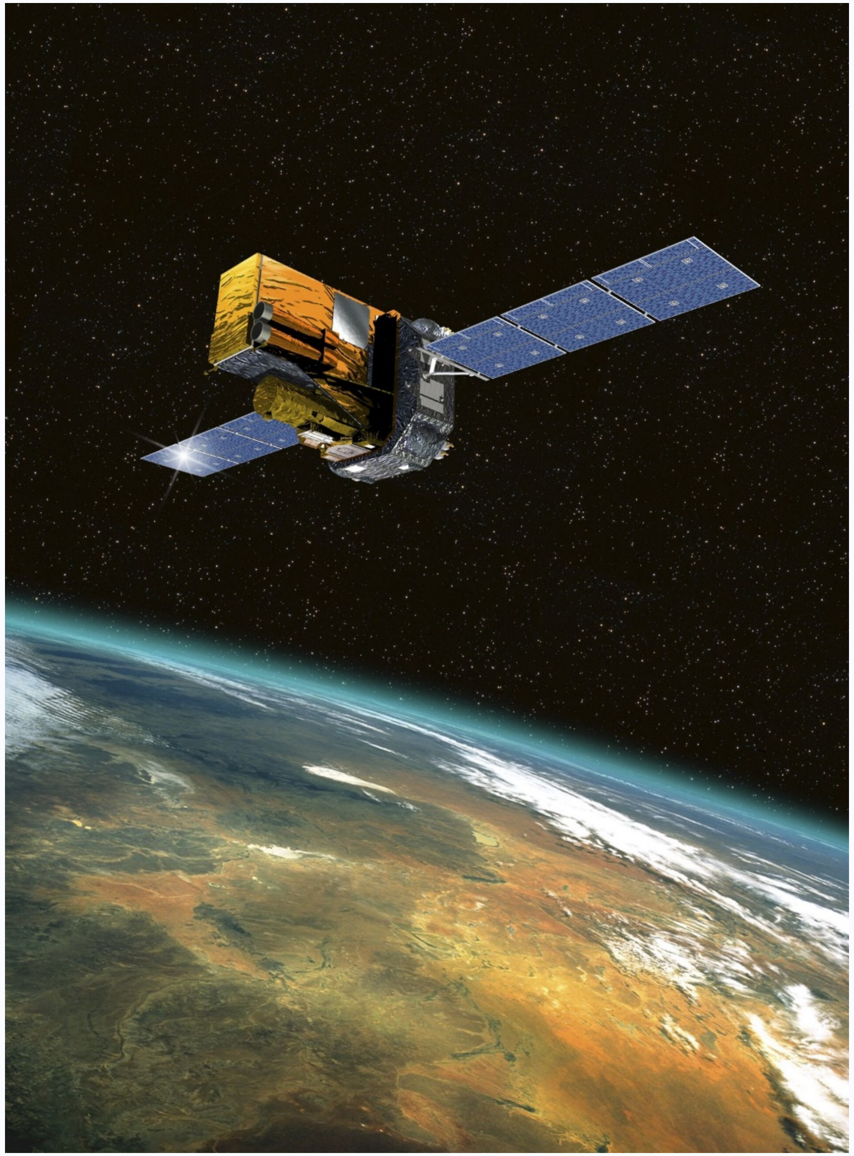
Introduction: systems engineering

Example – the car:

- Engine
- Transmission
- Suspension
- Wheels, tyres & brakes
- Steering
- Electrics
- Bodywork



Introduction: INTEGRAL spacecraft

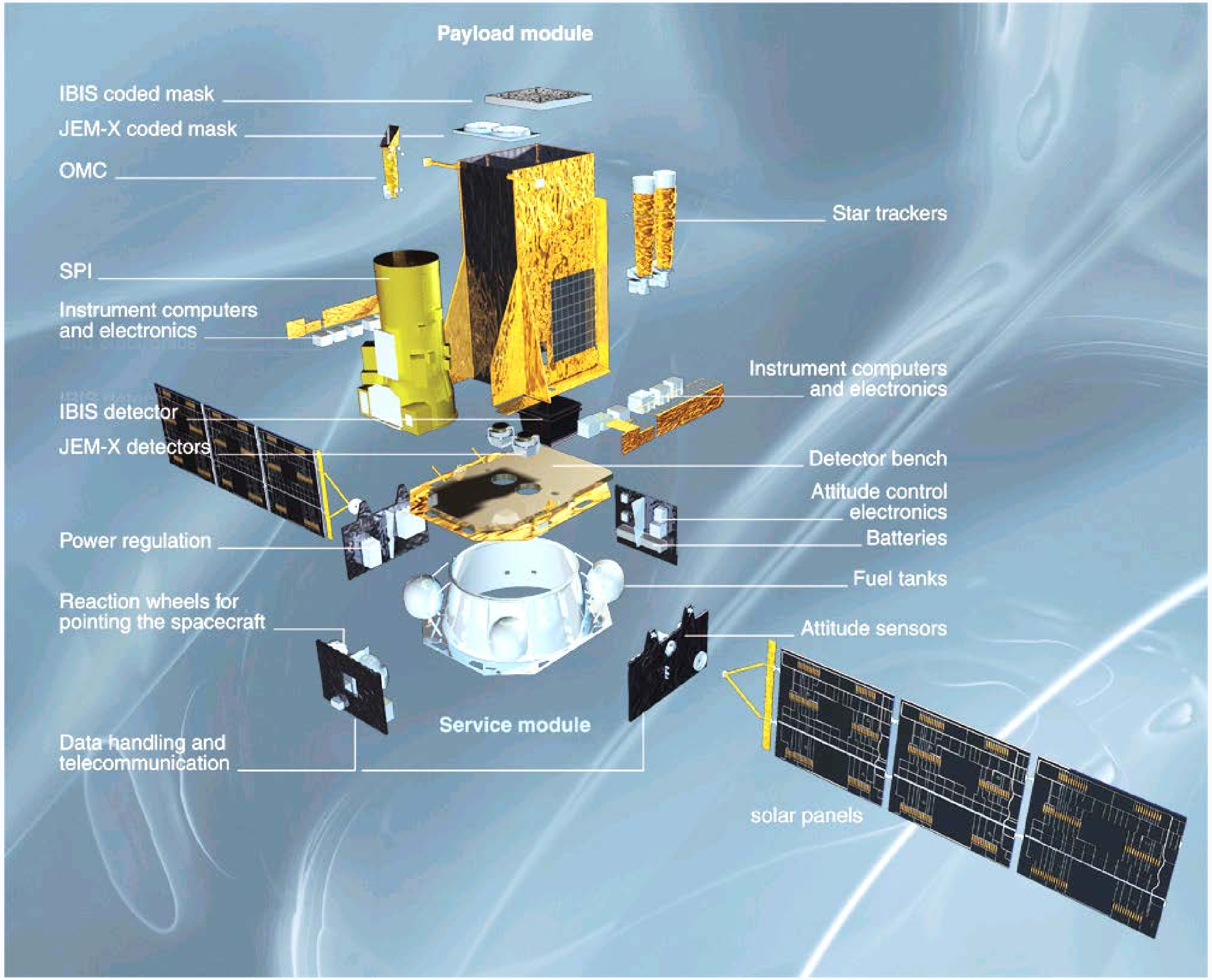


International Gamma Ray Astrophysics Laboratory

- The most sensitive gamma-ray observatory ever launched
- ESA mission in cooperation with Russia and the USA
- Launched October 2002 for a 2-3 year mission. It is still operational*
  - Mass ~4000 kg
  - Payload mass ~2000 kg
  - 5 m ‘high’
  - Highly elliptical orbit with a 3-day period

* Anomaly on 22 September 2021: https://www.cosmos.esa.int/web/integral

Introduction: INTEGRAL spacecraft



Spacecraft subsystems

Subsystem	Function	
Payload (p/l)	To fulfil mission objectives using a variety of sensors or communications hardware	Ch. 4
Structure	To provide structural support for p/l and subsystems in all predicted environments	
Attitude Control Subsystem (ACS)	To achieve mission pointing requirements (p/l, power, thermal, comms, etc)	Ch. 6
Propulsion	To provide orbital transfer capability, and to control mission orbit	Ch. 7

Spacecraft subsystems

Subsystem	Function	
Communications	To provide comms link with ground segment, for p/l data, telemetry and command	Ch. 9
Data Handling	To provide storage and processing of p/l, command and health monitoring data, and to facilitate exchange of data between subsystem elements	
Power	To provide a source of electrical power and to support p/l and subsystem operation	Ch. 8
Thermal	To provide a benign thermal environment for p/l and subsystem (reliability)	Ch. 10

Make a note of "bus" term with reference to payload

Spacecraft design method & development

Early stages: feasibility and preliminary design

- What is *systems engineering*?
  - "Space systems engineering is the science (and art) of developing an operable space system capable of meeting the mission objectives efficiently, within the imposed constraints (such as mass, cost, schedule, etc.)"
    - art → the application of human creative skill and imagination
- The *team*
  - Subsystem specialists
  - The team leader – the systems engineer

Spacecraft design method & development

Early stages: feasibility and preliminary design

- The *systems engineer*
  - ‘First-cut’ analysis in all areas
  - Appreciation of subsystem interactions
  - People skills → leadership
    - Maximise productivity
    - Foster team work, team spirit
    - Meeting skills
  - Success requires compromise

Spacecraft design method & development

Early stages: feasibility and preliminary design

Development of engineering *requirements*

Step 1: define mission objectives

- Performed by customer or user of proposed spacecraft (S/C)
- Example: 'fly-by Pluto and provide imaging and other data to characterise the Pluto/Charon system'

objectives are quantitative, detailed specification

Step 2: payload definition

- Performed by a working group of specialists in the field
- Detailed definition of mission objectives in terms of:
  - Specific observations
  - Types of instruments, sensors, etc.
- Examples: CCD imaging system, infra-red spectrometer, field detector

This part puts the origional objective in realistic terms according to current and realistic tech

Spacecraft design method & development

Early stages: feasibility and preliminary design

Development of engineering *requirements*

<u>Step 3: definition of top-level requirements (TLRs)</u>

- The system team has the responsibility to convert steps 1 & 2 into TLRs
- Example: trajectory, fly-by geometry, p/l operation plan, etc.

<u>Step 4: generation of design requirements (DRs)</u>

- The system team converts the TLRs into specific design requirements for the S/C subsystems

Top level requirements -> subsystem requirements, long quantitative list which the subsystem is designed with refrence to

- Examples: orbit parameters, ΔVs, fields of view, pointing accuracy, pointing stability, slew rates, data storage, communications link, etc.

In summary: payload operation + mission → design requirements

Spacecraft design method & development

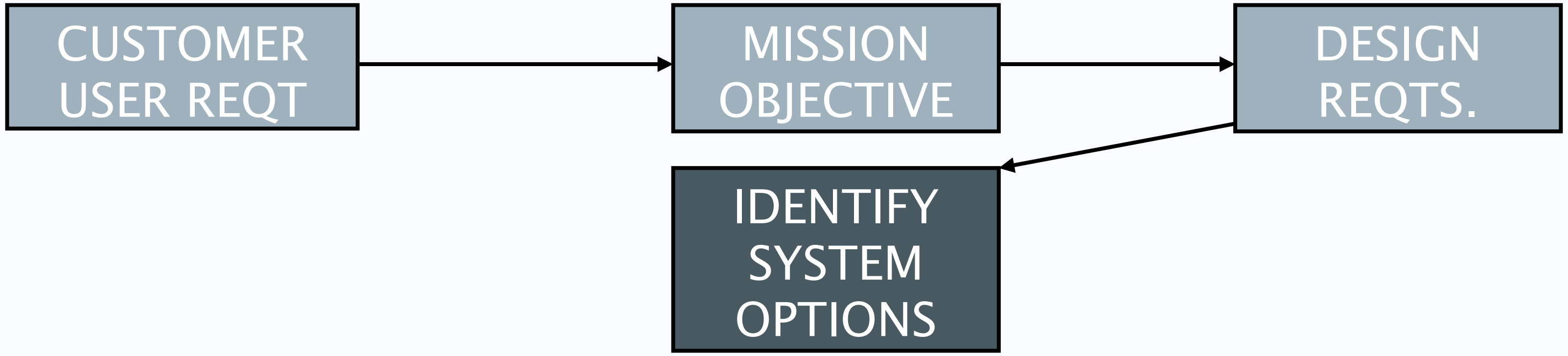
Design phases

- ECSS – European Cooperation for Space Standardization
  - ECSS-E-ST-10C System Engineering General Requirements
    https://ecss.nl/standard/ecss-e-st-10c-rev-1-system-engineering-general-requirements-15-february-2017/

Phase 0	Mission analysis-need identification
Phase A	Feasibility
Phase B	Preliminary definition

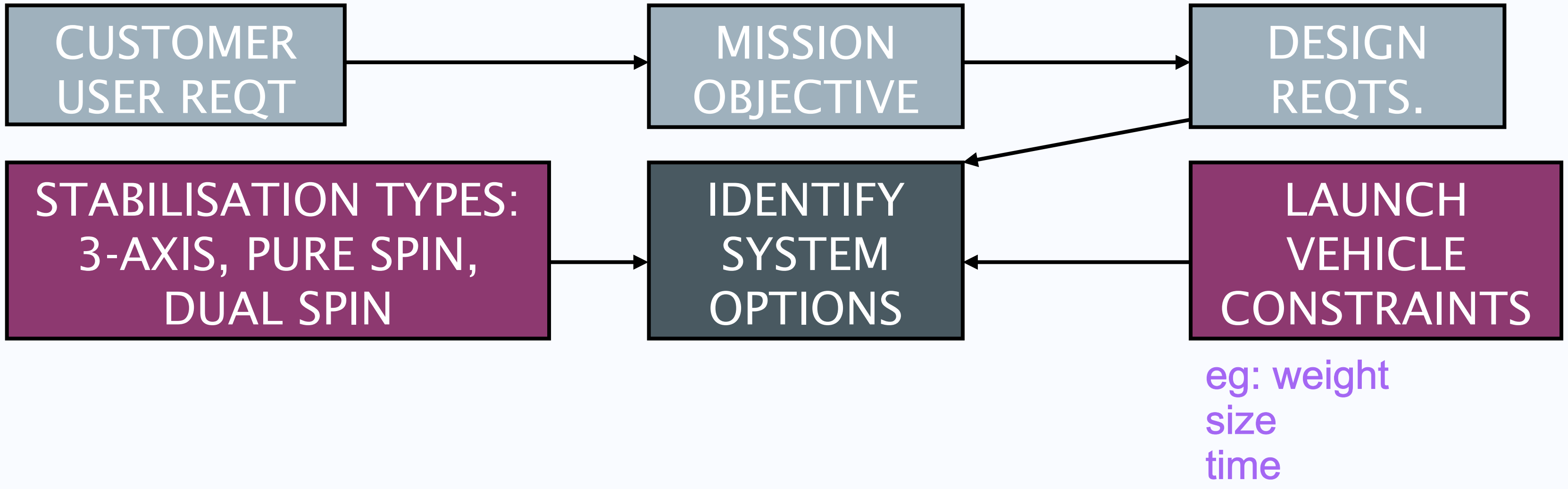
Spacecraft design method & development

Initial study logic – factors to be included



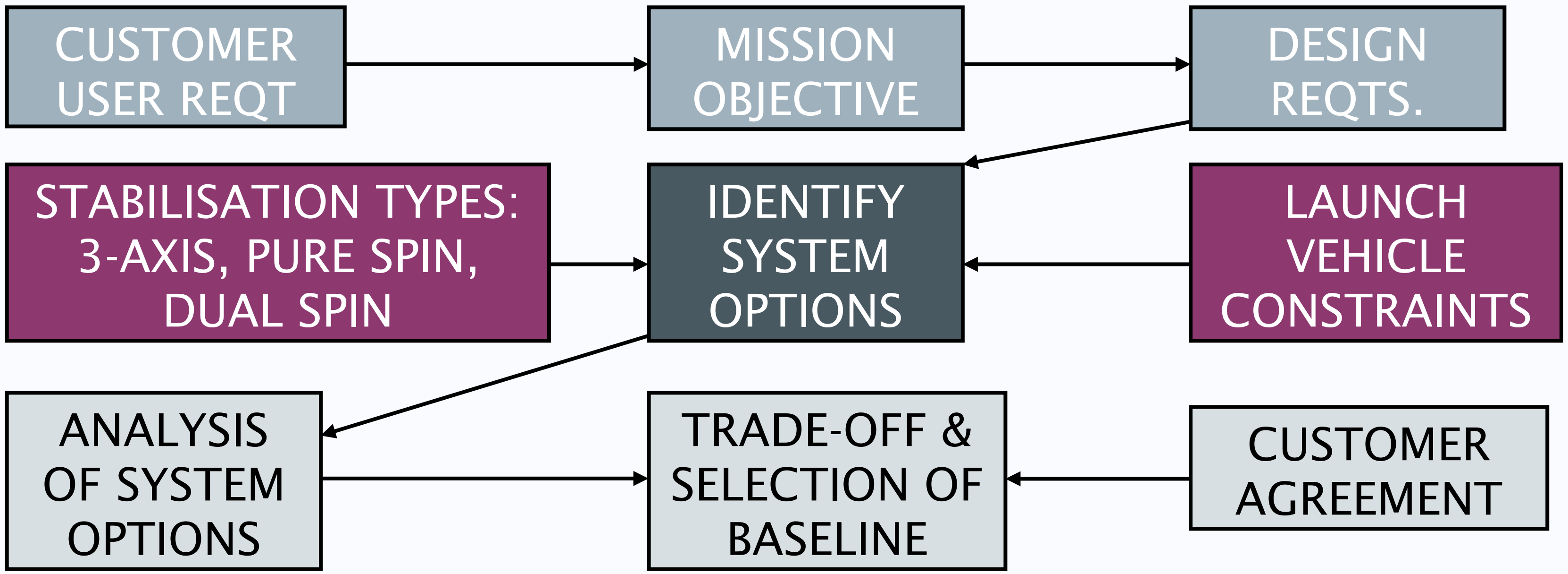
Spacecraft design method & development

Initial study logic – factors to be included



Spacecraft design method & development

Initial study logic – factors to be included



Spacecraft design method & development

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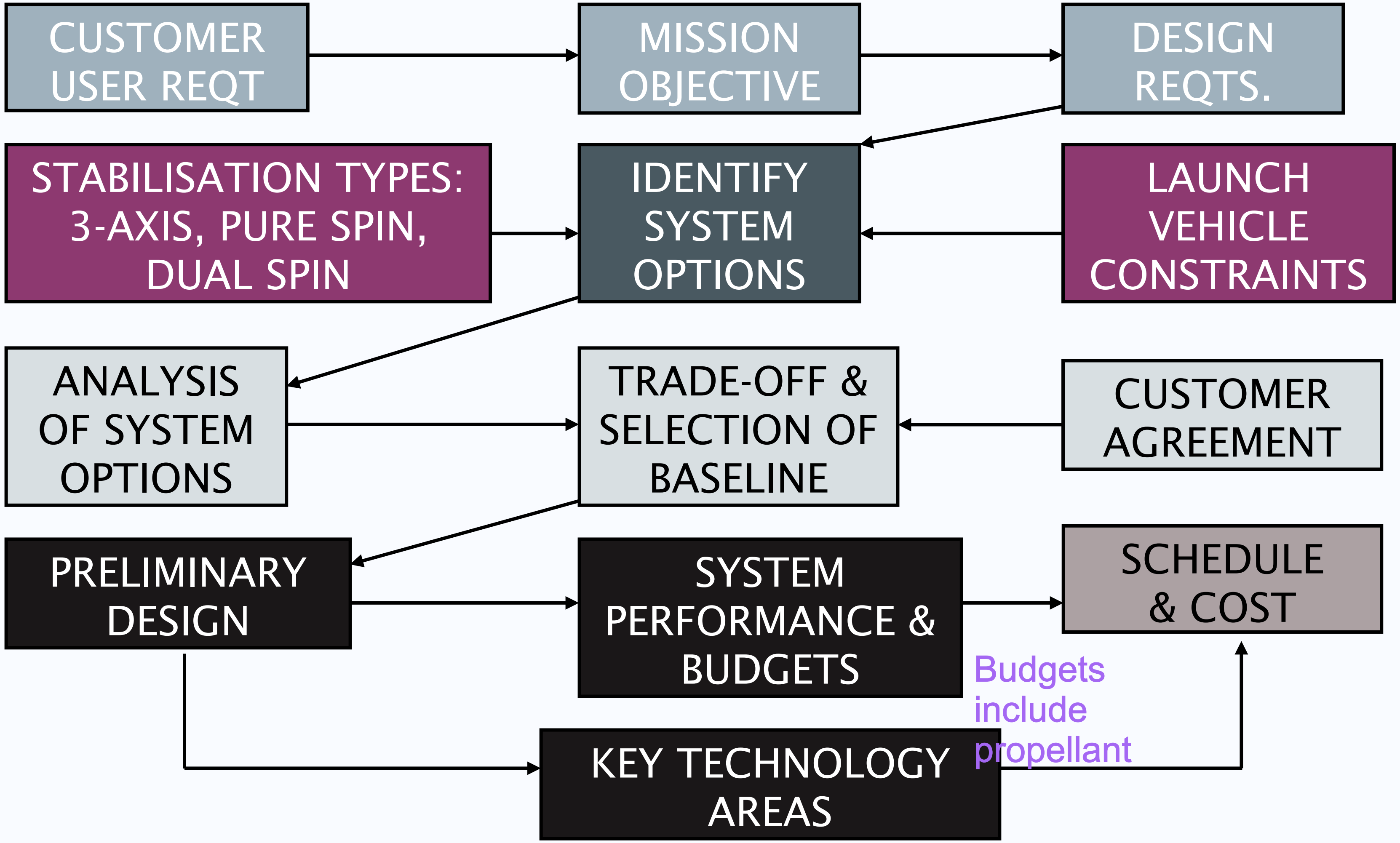
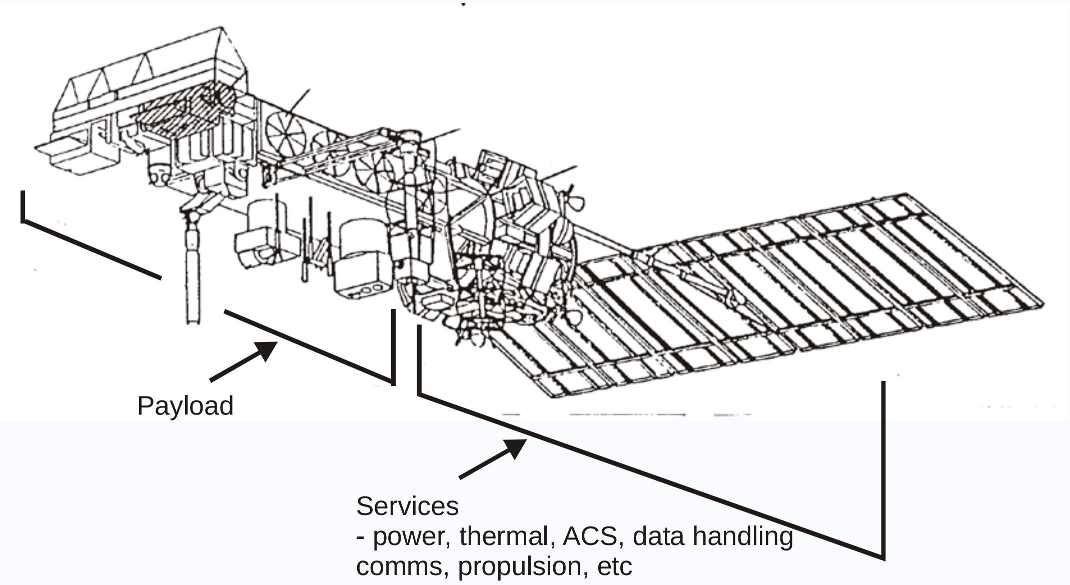
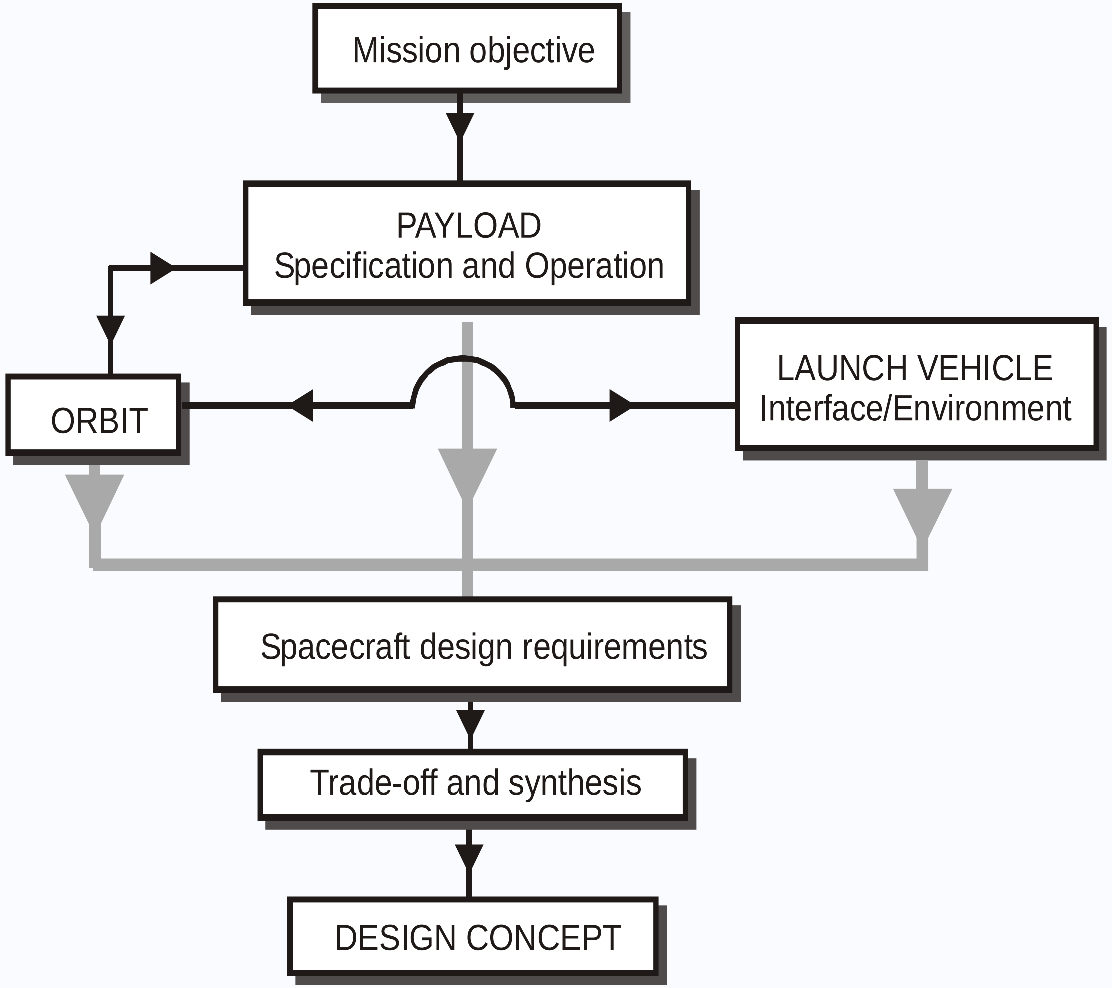


Spacecraft design method & development

Initial study logic – factors to be included





Spacecraft design method & development

Design phases

- ECSS – European Cooperation for Space Standardization
  - ECSS-E-ST-10C System Engineering General Requirements

Phase 0	Mission analysis-need identification
Phase A	Feasibility
Phase B	Preliminary definition
Phase C	Detailed definition
Phase D	Qualification and production
Phase E	Operations/utilisation
Phase F	Disposal

  - System level activities during phases C/D/E can be very expensive

Spacecraft design method & development

Principle system level trade-offs:

<u>Mission Analysis</u>

- Launch vehicle; orbit type; orbit acquisition
  - Major influence on all subsystem design requirements

<u>Attitude Control System (ACS)</u>

- Stability types – 3-axis, pure spin, dual spin
  - Major influence on all subsystem design requirements

<u>Propulsion</u>

- Solid propellant; liquid (monoprop, biprop); electric

<u>Communications</u>

- Power versus gain

Spacecraft design method & development

Principle system level trade-offs:

<u>Power</u>

Solar arrays; radio-isotope thermal generators; batteries, fuel cells

<u>Thermal</u>

Passive versus active

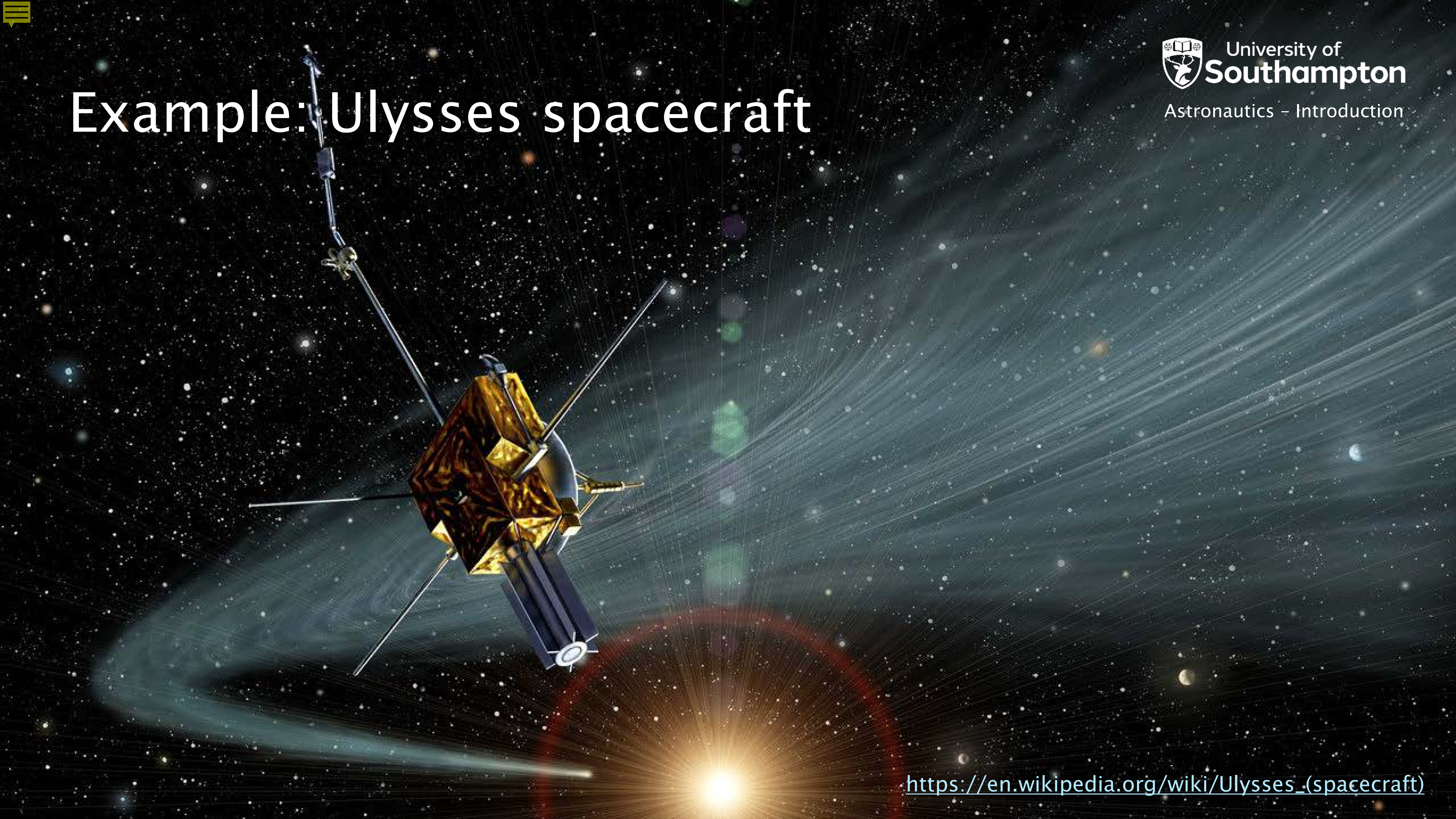
<u>Technology</u>

New versus old

- Conservative: minimise cost; minimise schedule; minimise uncertainty
- Innovative: subsystem specialists

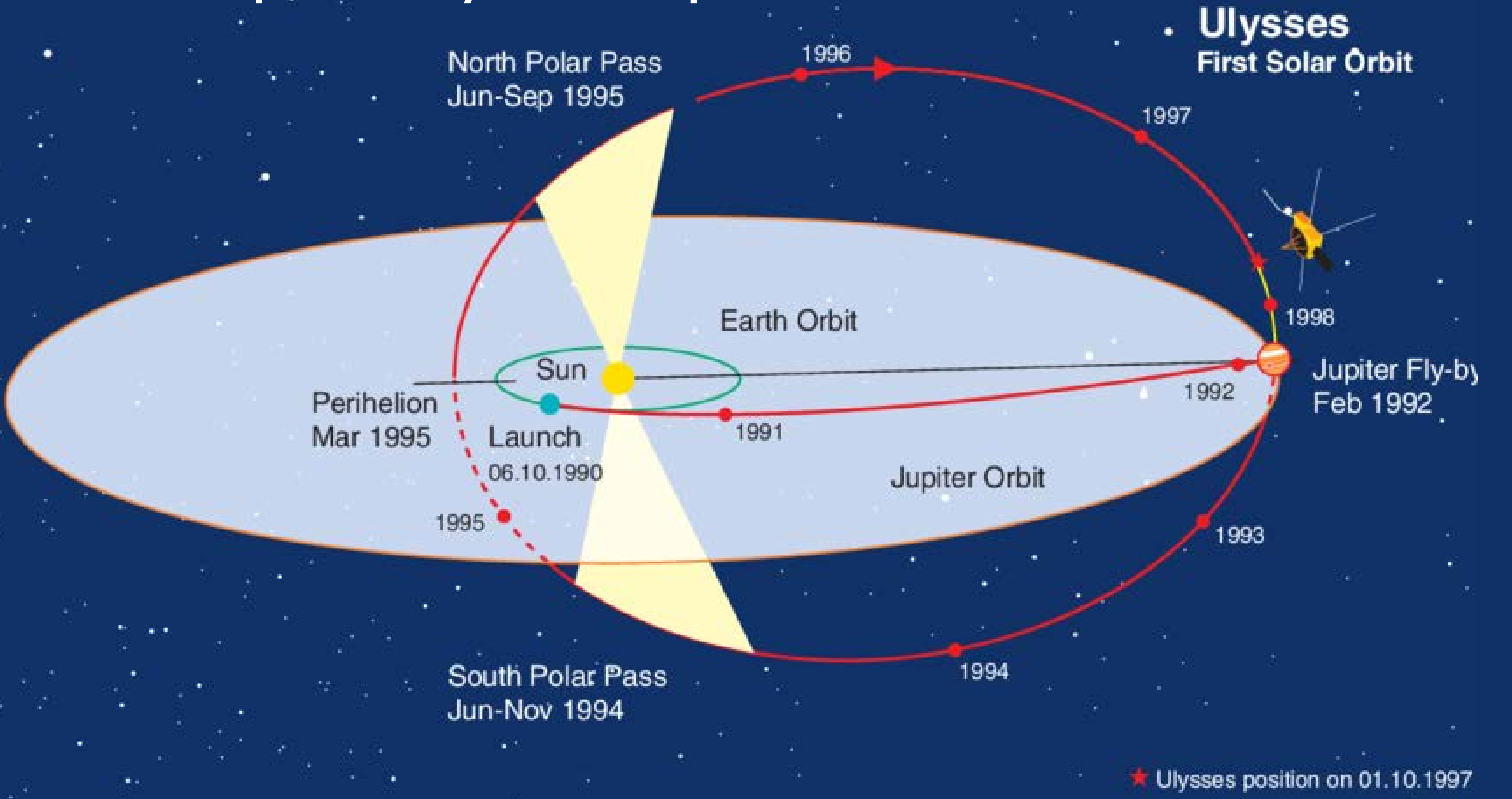
<u>Political, regulatory and commercial influences</u>

Example: Ulysses spacecraft

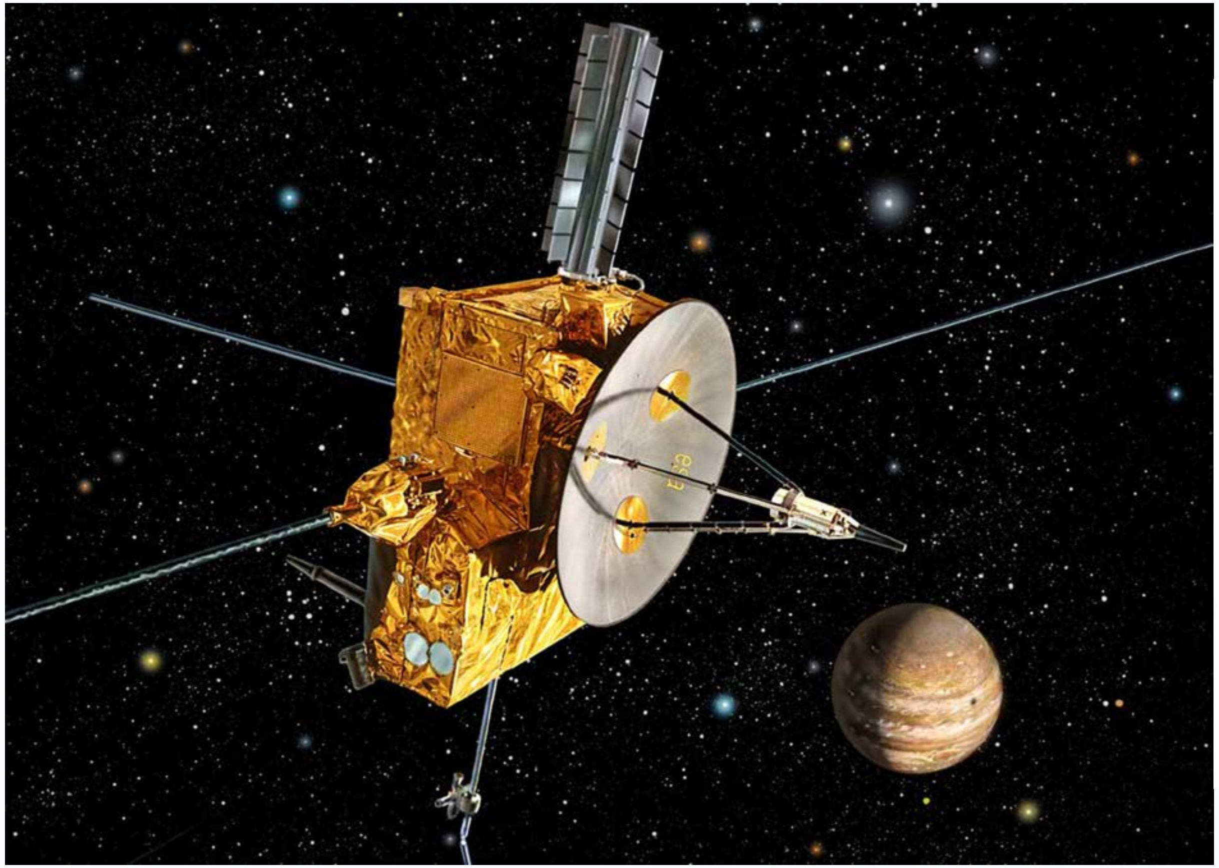


https://en.wikipedia.org/wiki/Ulysses_(spacecraft)

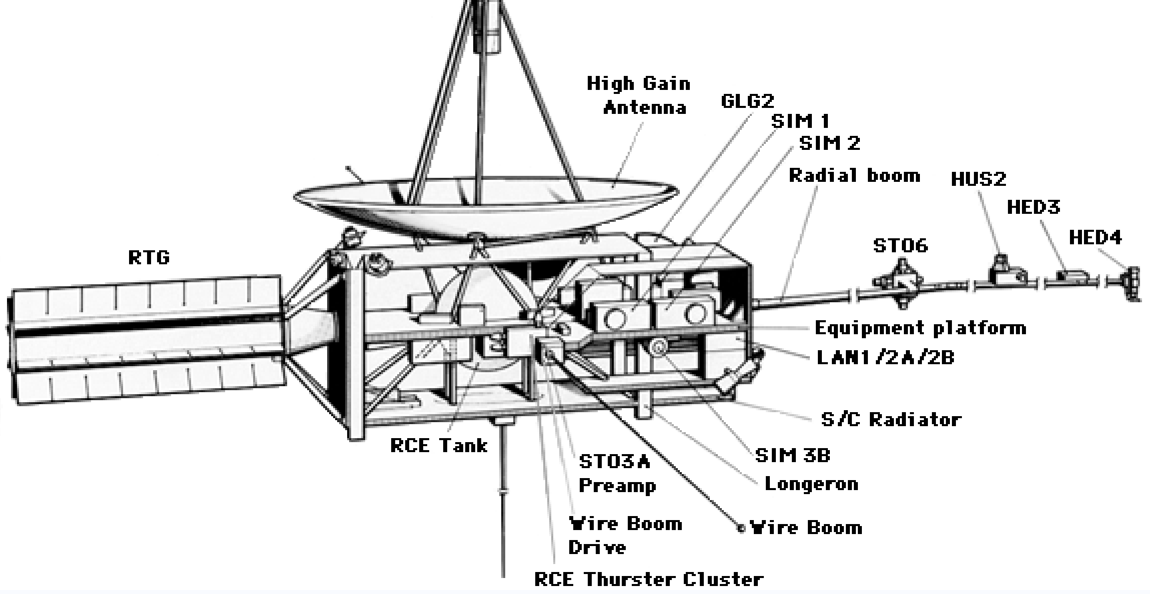
Example: Ulysses spacecraft

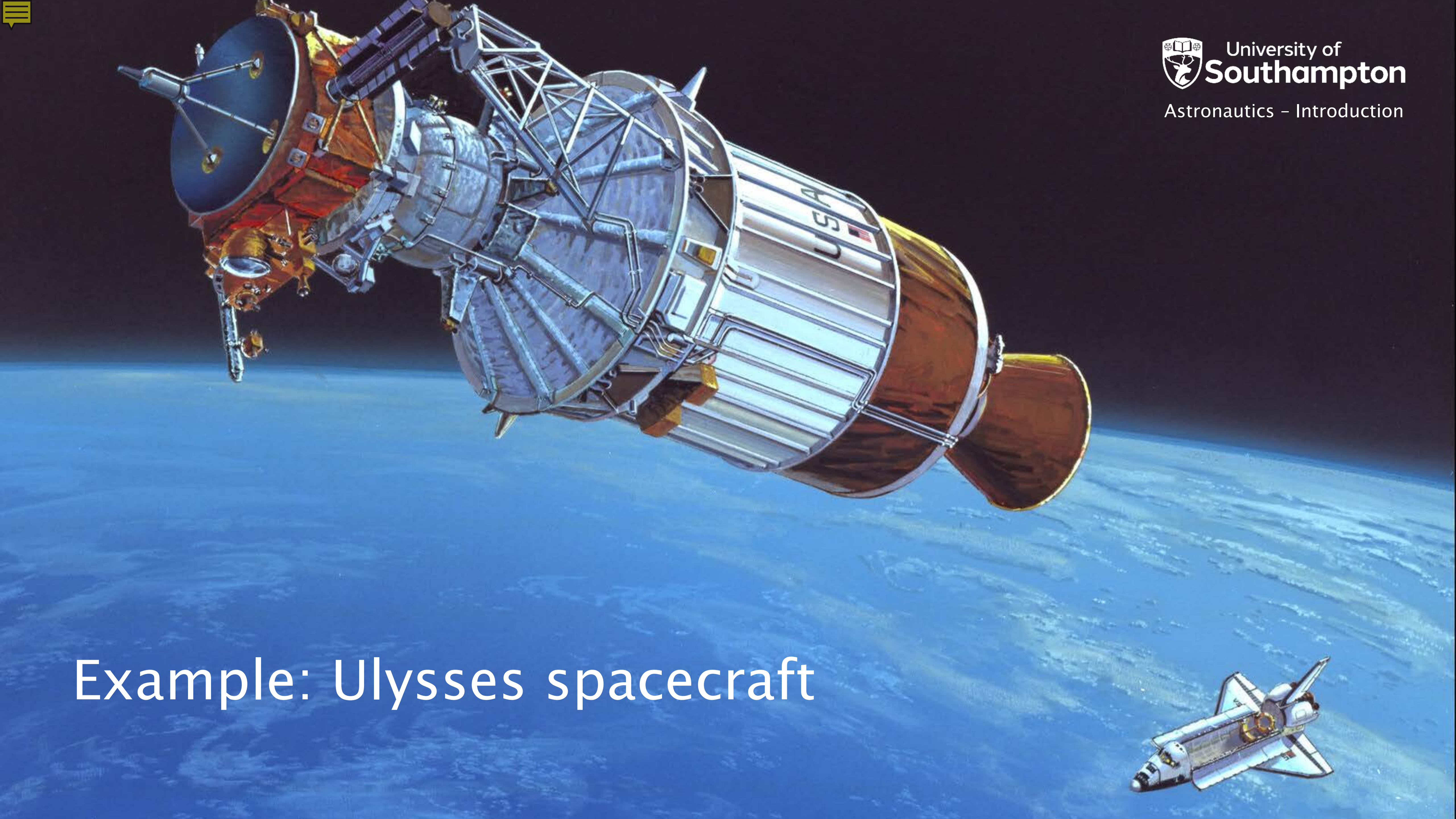


Example: Ulysses spacecraft



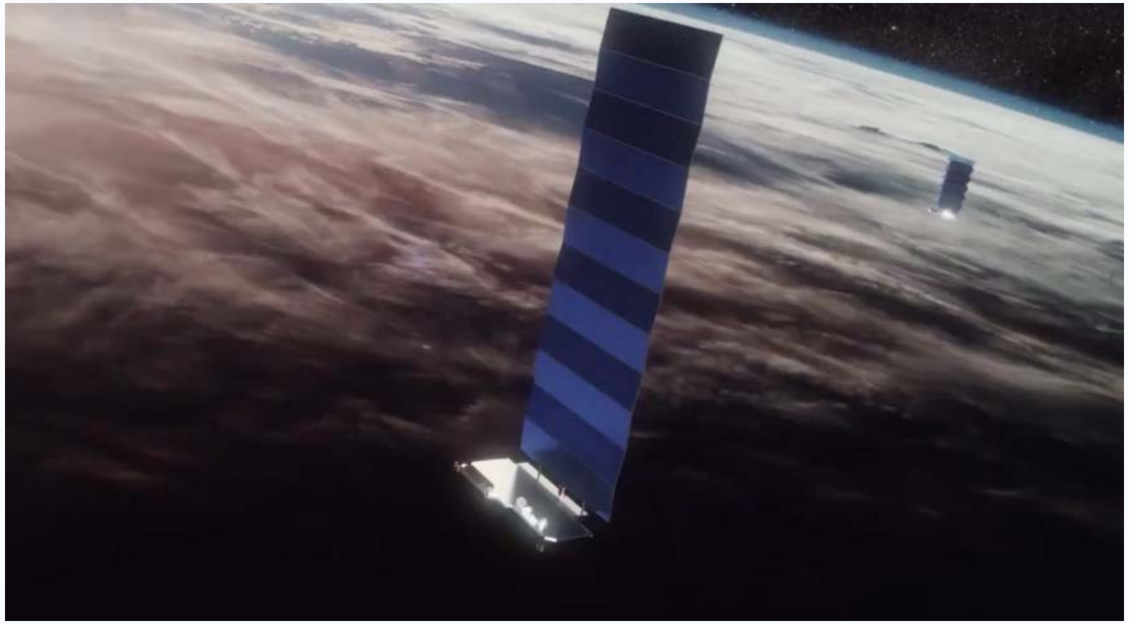
Had to use RTG due to large orbit, had to large orbit since it needed to have a gravity assist from jupiter due to lack of powerful launch vehicle





Example: Ulysses spacecraft

Example 2



Chapter 1 recap

Chapter 1 – Systems Engineering

- Introduction
- Spacecraft subsystems

General knowledge of the satellite subsystems breakdown and their respective function

- Spacecraft design method and development
- Example

- What is systems engineering?
- The development of the engineering requirements
- The design phases
- Principle system level trade-offs

Activity

- The systems engineering topic is covered in chapter 20 of Fortescue, Stark & Swinerd:
  - Read this chapter in preparation for the next few lectures & to support your learning of this topic
  - Access to the e-book is available via the Library website: https://onlinelibrary.wiley.com/doi/book/10.1002/9781119971009