Developing Successful Satellite Mission Concepts

Fit4Space April 2024

DEFENCE AND SPACE

Nikki Antoniou – ISR Team Leader

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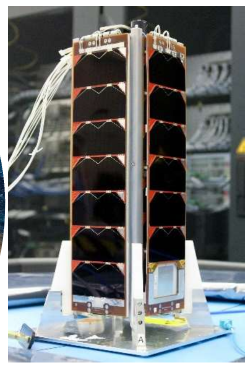
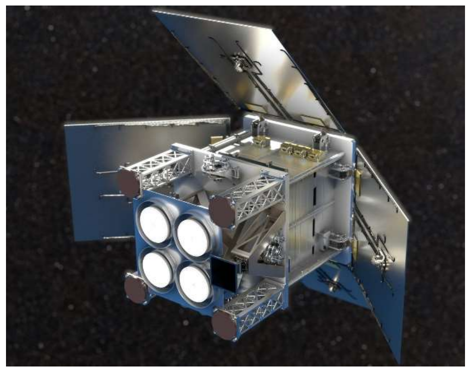
About me – Nikki Antoniou

ISR Team Leader – UK NEO Future Programmes





- Joined Airbus in 2006 on the Graduate scheme
- 18 years in Systems and Future Programmes Teams within Airbus Space System (including SSTL)

- **Major missions and studies worked on:**
  - Galileo IOV Payload
  - ESA LISA Pathfinder
  - ESA FLEX Auxiliary Instruments Study
  - ESA Sample Fetch Rover Study
  - Airbus Active Debris Removal Technologies (Harpoon)
  - ESA Solar Orbiter
  - Orbital Test Bed (SSTL)
  - VESTA-1 (SSTL)
  - SSTL-Micro and SSTL-Cube Platform Ranges
  - ESA D3S Space Weather Study (SSTL
  - ESA Hydrognss (SSTL)
  - UKSA LEOPARD Study (Active Debris Removal)
  - UKSA CLEAR Study (Active Debris Removal)

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There are Two Important Mantras of Space Mission Design

Bearing these in mind should help you improve your decisions and approach.

1) Don’t assume the design will change much beyond the initial concept, many times initial assumptions will carry through to implementation.
   - *The way implementation happens with contractual agreements can often (but not always) mean that the design fixes at the point of sale, as costs and scope of work are then agreed.*

2) You must build an understanding of the consequences of your decisions and actions in the early phase design.
   - *E.g. get reviews from those who have implemented these things before, get feedback on how implementation has gone, and/or follow one of your designs into build to see what impact some decisions have had.*

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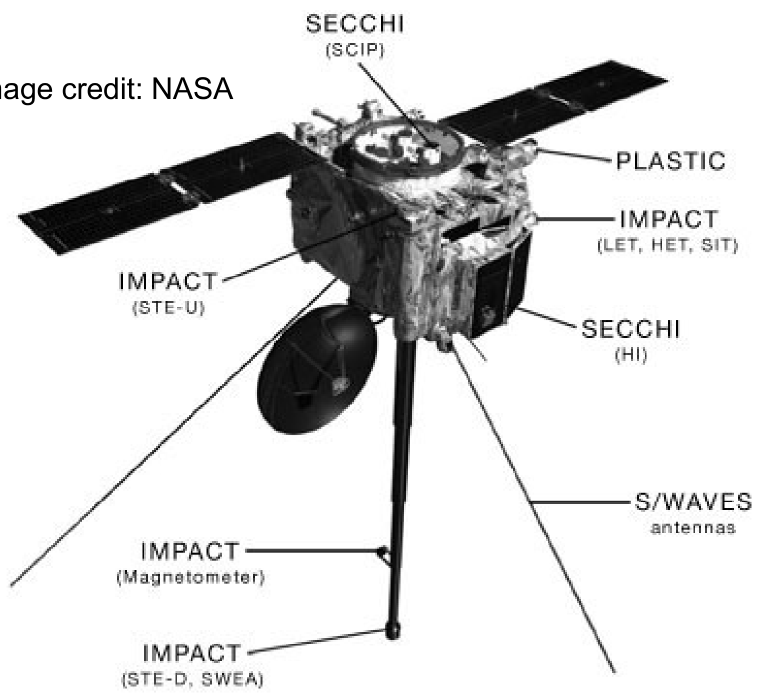
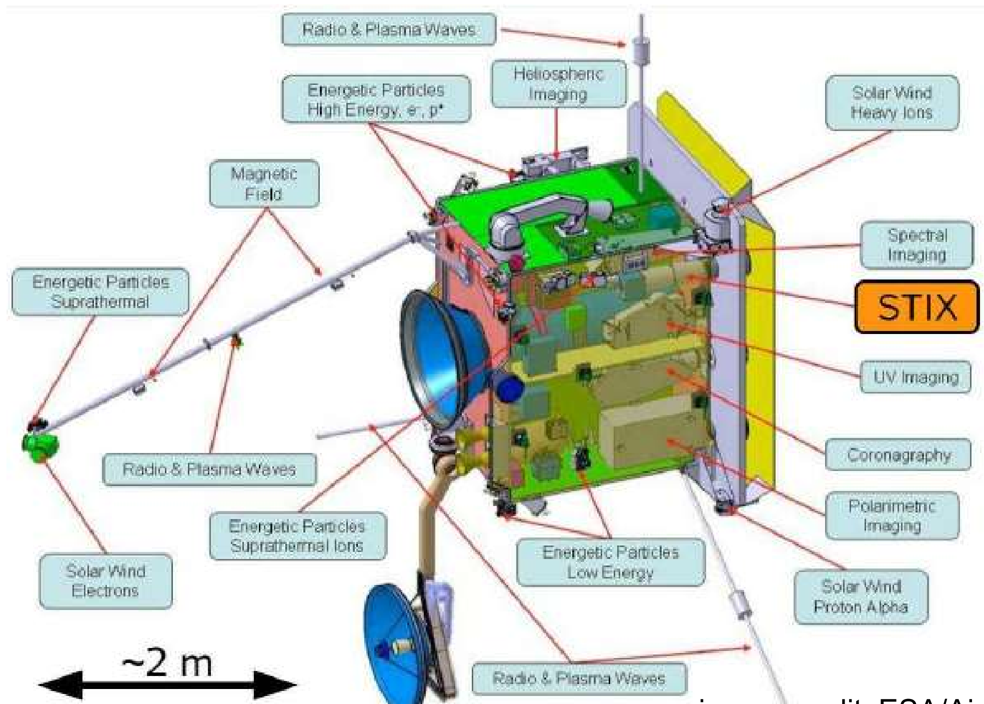
Example: NASA STEREO → ESA Solar Orbiter

Why challenging assumptions in the early phases can save significant pain later on

Solar Orbiter built on the STEREO mission heritage, but with some significant increases in the number of instruments on board

image credit: NASA





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So What Could Go Wrong With Your Mission On-Orbit?

A **very** small list of example failure modes that need to be considered when designing a mission

- **Launch failure** (be wary of that tempting first launch discount!)
- **Mechanical damage** to satellite during launch (make sure testing is sufficient!)
- **Incorrect orbit insertion** (look at launcher track record and plan accordingly for propellant)
- **Failure to deploy of** deployable appendages (all deployable elements present extra risks)
- **Solar flare** (upset or damage risks to EEE components)
- **Debris strike** (e.g. like happened to the gravity gradient boom on the Cerise satellite)
- **Battery string or solar array string failure** (reduced power storage/generation capabilities)
- **Payload failure** (potential for partial or total loss of mission)
- **Insufficient radiation tolerance** (service interruptions or potential loss of functions / mission)
- **Poor thermal management** (overheating of components, leading to safe mode entry and risk of damage)
- **Unsafe failure modes** (potential to get stuck in an unsafe orientation for power/thermal)
- **Ground segment connection issues** (rain fade / power outages / interference / availability)
- **Failure to de-orbit properly at end of life** (mission must be able to meet ISO guidelines on debris prevention and minimising casualty risks)

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What Design Considerations Does a Spacecraft Mission Need?

The main topics to consider when you first start scoping your mission

Payload / Mission Objectives

e.g. pointing, agility, stability, data latency, accuracy, reliability, automation, operations planning, service provision, throughput, ground station locations, start of service date, ground processing needs, availability of system, demanding resource requirements (e.g. high power draw / very large volume or mass).

Orbital / Environmental

e.g. altitude, inclination, LTAN / RAAN, mission duration, thermal, station keeping, radiation environment, atomic oxygen, collision risks, end of life de-orbit/graveyarding requirements, launch environment, launch options, separation tumble rates, variable solar flux / eclipse durations, solar cycles, drag, solar flares, protected regions, transfer.

Satellite Mission

Subsystem Considerations

e.g. power generation, maximum mass, volume, propellant type, delta-V, thrust, data interfaces, data rates, data storage,switches, up/downlinks, ISLs, thermal management, battery sizing, lifetime considerations, ground interfaces, AOCS, FDIR, MGSE, EGSE, AIT/EVT flow, launch site fuelling/charging, safety, sep system.

Commercial Viability

e.g. schedule, cost, TRL level, parts availability, risk, supply chain, security restrictions, procurement restrictions, facility availability, launch date availability, resource availability, tools, required developments, support contracts, liabilities, penalties, exchange rates, ESCROW, partnership requirements, funding conditions.

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System Considerations

What is a typical satellite configuration

- No two satellite concepts are identical, as they need to adapt to specific needs for the environment, payload, mission lifetime, propulsion needs, etc.
- However there are usually core subsystem groups within a system which are generally universal (although subsystem names can vary from project to project).
  - **Data Handling / Command Subsystem** – the main computing functions of the platform.
  - **Radio Frequency / TM/TC Subsystem** – the main communications channels for the platform.
  - **Guidance, Navigation and Control [GNC] / Attitude and Orbit Control [AOCS] Subsystem** – where all the pointing and orbit stabilisation functions are controlled from.
  - **Power / Electrical Subsystem** – where all the battery charging and power distribution and control takes place from.
  - **Propulsion Subsystem** – if the craft has propulsion to control its movement.
  - **Mechanical Subsystem** – structure, fittings, fixtures and brackets of the satellite.
  - **Payload Subsystem** – For the capability of the spacecraft which fulfil the purpose of the mission – e.g. cameras, communications payloads, robotics and all supporting equipment and downlink communications.

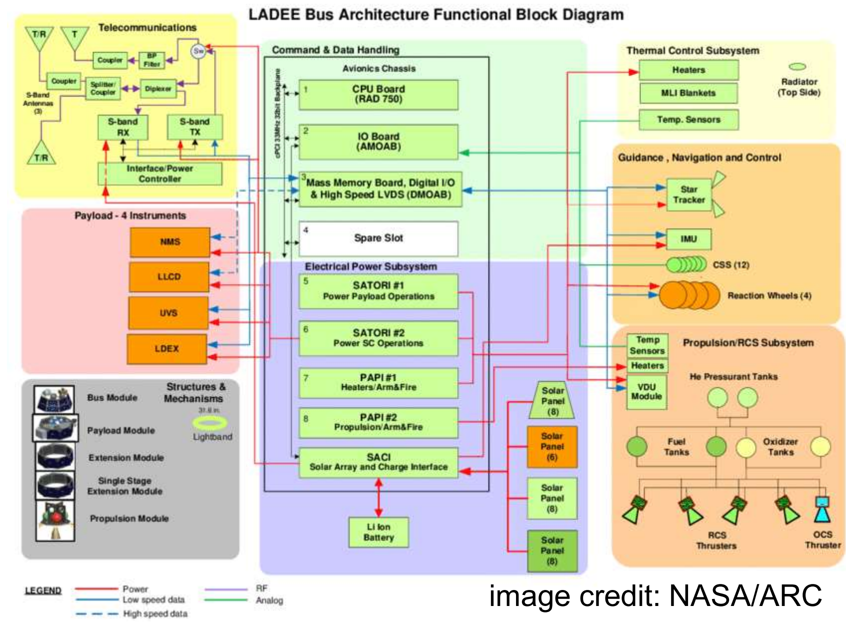

image credit: NASA/ARC

A “System Block Diagram” as shown above as an example is used to outline how the subsystems have been grouped for an individual mission.

It shows all the major connections between the major units, both power and data, and should be a good system summary.

It does not show the mechanical subsystems.

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Data Handling Subsystem (DHS)

Aka Command Subsystem

The data handling system is the brains of the satellite.

On the platform side, it typically consists of:
- On-board computer (OBC)
- OBC Software
- Interface Units
- Data harnessing, interfaces and buses

On the payload side, if typically consists of:
- Payload data processing
- Payload data storage
- Payload Software

(These often will be grouped under the payload subsystem)

Definition of how the satellite will operate is defined within the software. This also includes the approach to take towards monitoring satellite health and failure actions.

Typical pitfalls in designing a DHS:

- Numbers and types of interfaces
- Software protocols for moving data around
- Precision timing for sending commands
- Data rates in/out of units
- Data storage volume
- Connections to RF up/downlinks
- Software failure modes

Airbus's PureLine Amethyst is a **centralized avionics with onboard computer** in a single unit

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Radio Frequency (RF) Subsystem

Aka Telecommand and Telemetry (TM/TC) Subsystem and Payload Data Downlink Subsystem

The main communication channels for the platform.

On the Platform side, it usually consists of:
- Telemetry (TM) Downlink Transmitter
- Telecommand (TC) Uplink Receiver
- Or a Combined TM/TC Transceiver
- Sometimes an Inter-Satellite Link

On the Payload side, it usually consists of:
- Payload Data Downlink Transmitter
- Sometimes an Antenna Pointing Mechanism
- Sometimes an Inter-Satellite Link

Satellite RF communications rely on modulation and coding schemes to transmit and receive signals over long distances and noisy channels.
- **Modulation** is the process of changing the characteristics of a carrier wave, such as amplitude, frequency, or phase, to encode information.
- **Coding** is the process of adding redundancy or error correction to the information bits, to improve the reliability and efficiency of the transmission.

Typical pitfalls in designing an RF Subsystem:
- Uplink / Downlink Rates
- Downlink Protocols (e.g. CCSDS vs Saratoga)
- Encryption
- Modulation and Coding Schemes
- Ground Station Design and Margins
- Link Budget
- Minimum Angle of Elevation of GS
- Power Draw of Downlink Transmitter
- Pointing and Tracking Requirements
- Ground test setups

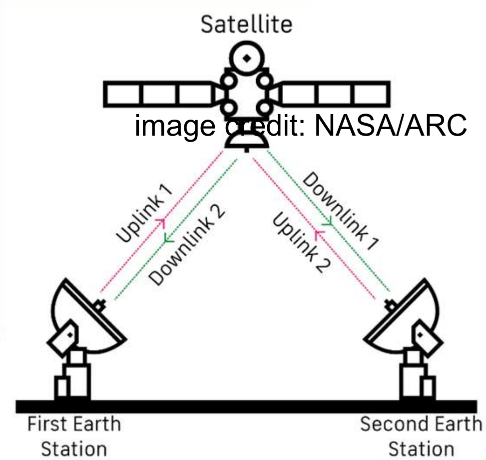

image credit: NASA/ARC

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Power Subsystem

Aka Electrical Subsystem

There are some major functions that the power system does:

- Generate power from the solar arrays
- Store power in the battery
- Distribute power from both the arrays and the battery directly to units
- Control the on/off status of power to units

- And often it will be critical in initiating FDIR actions by switching off unnecessary units and turning on safety configs or monitors, etc.

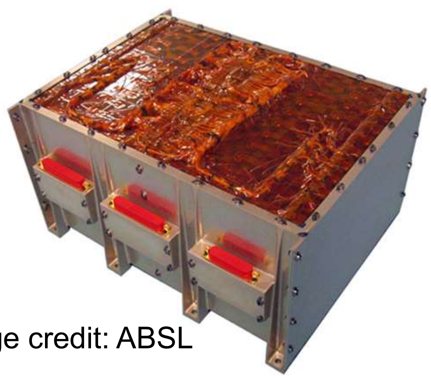
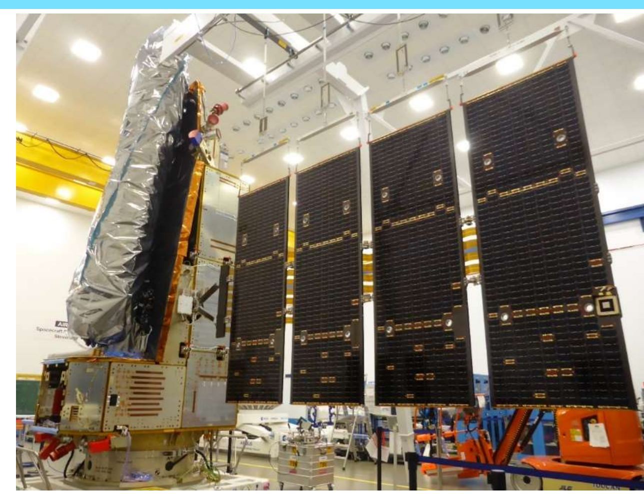


image credit: ABSL

Typical pitfalls in designing a Power Subsystem:

- Number of switches available
- Voltage of bus (5/12/28/50V)
- Conversion losses between voltages
- Current of switches
- Power generation of arrays at end of life in worst case lighting
- Inrush currents and surge protection
- Failure modes and designing for credible failures



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Attitude and Orbit Control [AOCS] Subsystem

Aka Guidance, Navigation and Control [GNC]

NOTE GNC versus AOCS: the term AOCS is commonly used when the orbit guidance is not performed on board, which is the case for standard LEO, MEO and GEO missions. GNC is commonly used for the on-board segment, when the satellite position is controlled in closed loop, for instance in case of rendezvous and formation flying.

Typical systems on a LEO craft would include…

Sensors:

- Star trackers
- Magnetometers
- Gyros
- Sun sensors

Actuators:

- Wheels
- Magnetorquers
- Propulsion system

GEO crafts don't benefit from the Earth's magnetic field so don't usually use magnetics in their control.

Typical pitfalls in designing an AOCS / GNC Subsystem:

- Size, mass and volume of the system
- Power consumption of wheels and other actuators
- Time to slew and settle for agile manoeuvres
- Whether to use propulsion or an actuator-only solution.
- When RDV and docking is involved for GNC, need to be mindful of how control passes between the systems.
- Failure modes and actions on failures.
- Active or passive safe modes – often the AOCS units will be needed to manage safe modes.

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Propulsion Subsystem

Controlling manoeuvres and occasional AOCS element

- Propulsion is often a significant factor in the size and capability of satellites.
- It is a particularly driving factor at the smaller end of the satellite spectrum due to size and power restrictions.
- Costs and complexities of systems increase as the overall delta-v requirements increase.

Typical pitfalls in designing a Prop Subsystem:

- Size, mass and volume of the system
- Power consumption of thrusters and heaters
- Thrust of thrusters and time to do manouevres
- Ground handling dangers and costs
- Cleanliness & contamination

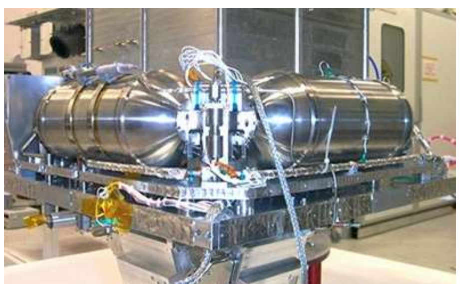

image credit: SSTL

Cold Gas | Monopropellant | Bipropellant

Butane | Xenon | Hydrazine / Green Propellants | Bipropellant Hydrazine (includes oxidiser)

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Payload Subsystem

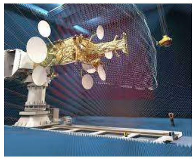
Every spacecraft / constellation payload suite is unique!

The scope of what consists a “payload suite” is so varied from mission to mission, however there are some very common mistakes for all payload suites.

The most important aspect of the payload subsystem is defining what the payload consists of and what elements need to budgeted for as part of the payload concept of operations.

e.g. if you need to do significant slewing and settling to image with an optical payload, those AOCS operations need to be accounted for when you do your payload budgeting.

The other aspect is ensuring that the demands of this combined system don’t out-strip the capabilities of the platform throughout the mission lifetime, and that managing that supply-demand relationship has be adequately designed for through the mission’s Concept of Operations and Mission Operations Centre software / processes.



Typical pitfalls in designing a Payload Subsystem:

- The payload interfaces must be able to be accommodated by the craft, e.g.
  - Number of data/power connections
  - Volume / Mass / Mounting interfaces
  - Data management and storage
  - Environmental protection & management
- The payload suite is not just the payload alone, the power/mass/data allocation usually also includes all items associated with the payload:
  - Data Storage and Data Downlink
  - Payload Control & Processing
  - Heating and/or Cooling
  - AOCS Manoeuvres to Support Ops

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Mechanical Subsystem

Aka Primary and Secondary Structure Items

The load-carrying structure of a spacecraft is primary structure. Primary structure is sized based on the launch loads, with strength and stiffness being the dominant factors in the design. When a primary structure fails, catastrophic failure of the mission occurs.

Secondary structures, such as solar panels, thermal blankets, and subsystems, are attached to primary structures. They stand on their own and transmit little to no critical structural loads. While failure of a secondary structure typically does not affect the integrity of the spacecraft, it can have a significant impact on the overall mission

Secondary structures also can be secured for safety during the launch phase, such a hold down and release mechanisms for deployable and actuated elements. This prevents damage.

Typical pitfalls in designing a Mechanical Subsystem:

- Launch failures / in orbit failures
- Access to critical elements such as battery and propulsion fuelling during launch site preparations.
- Vibration and microvibration issues for stable payloads
- Visibility for RF/optical downlinks
- Reliability of moving parts

If it doesn't need to move – don't make it move! Simple is always best with mechanical design

Adapted from: https://www.nasa.gov/smallsat-institute/sst-soa/structures-materials-and-mechanisms/

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Other Factors: Launch

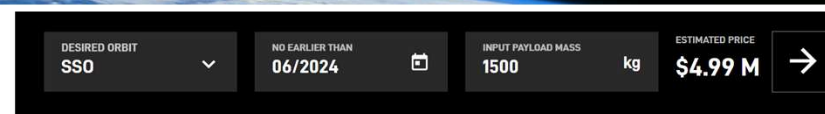
Launch can be a critical factor in developing a low-cost satellite mission

Launch costs vary greatly depending on the launcher you are destined to launch on, and whether you are the primary passenger or not.

- Constraints coming from the launch slot volume / mass / etc can often drive the design, especially for small satellites
- While cheap launches may be available without specific orbital locations e.g. any SSO LEO, if you need something specific you may need to be a primary passenger, OR you may need to carry extra fuel for the transfer.
- The timeframe for a launch can also be seriously delayed, and provision for ground storage and also what happens in terms of charging if the craft is stuck on the launch pad for an extended period

Orbital Rocket Launch Costs	Price per Launch in USD
Sounding Rockets	1 million
New Shepard	5 million
Electron	7.5 million
Falcon 9	67 million
Delta IV Heavy	350 million
SLS	4.1 billion
Soyuz-2	35-80 million
Long March	30-81 million
PSLV	21-31 million
GSLV	47 million
Ariane 5	178 million

Source: https://spaceimpulse.com/2023/08/16/how-much-does-it-cost-to-launch-a-rocket/



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AIT / EVT Costs and Considerations

Testing completeness and acceptable levels risks

- When designing a mission, you may need to cut costs so you may hear “lets reduce the process”.
- But then you need to ask… what does this really mean?
- You should immediate ask how much RISK can you afford to take.
    - What quality levels are you going to follow?
    - What radiation assurance strategy will you take?
    - What testing approaches can you streamline?
    - Can you build in batches to save time and money?
- Then determine on a case by case basis what isn’t essential for this particular mission to still meet requirements in the end.

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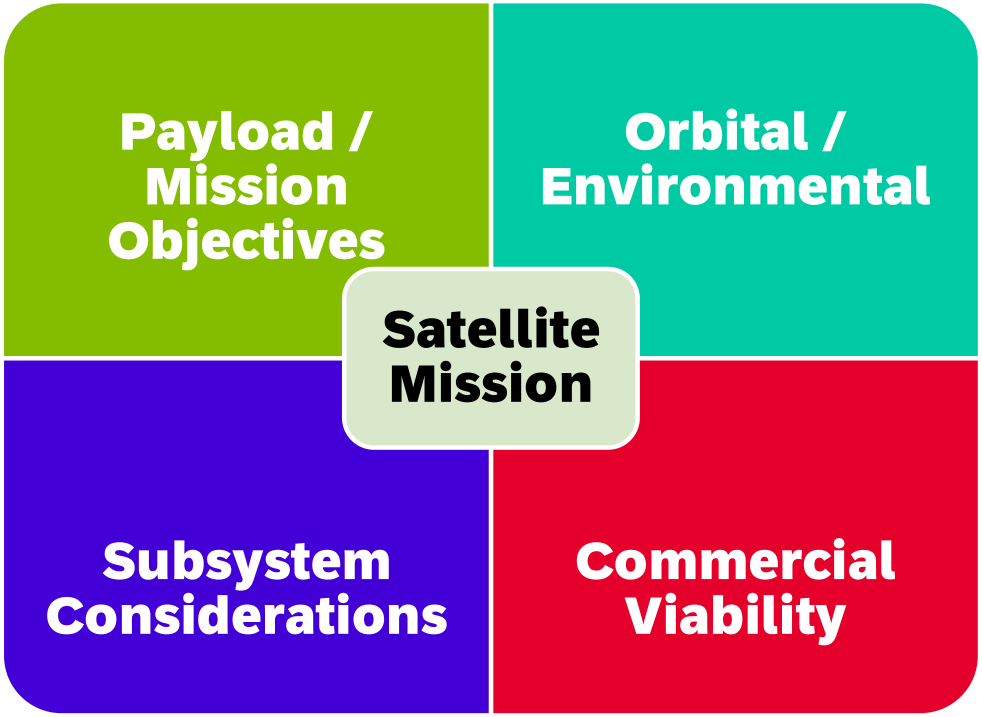
Conclusions : Is all about acceptable risks

A satellite mission design is a careful trade

- Balance in the trade is the optimal solution, but sometimes there will be driving factors which override.
- Setting the boundary conditions within which you design your mission are so important to getting the best outcome from the early design phases.
- Identified risks should be noted, tracked and re-evaluated as the design evolves to ensure they are acceptable.



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Any Questions?

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