

# EE-584 Spacecraft Design & Systems Engineering

## Lecture 2 - Mission Design & Spacecraft Systems Engineering System thinking and conceptual design



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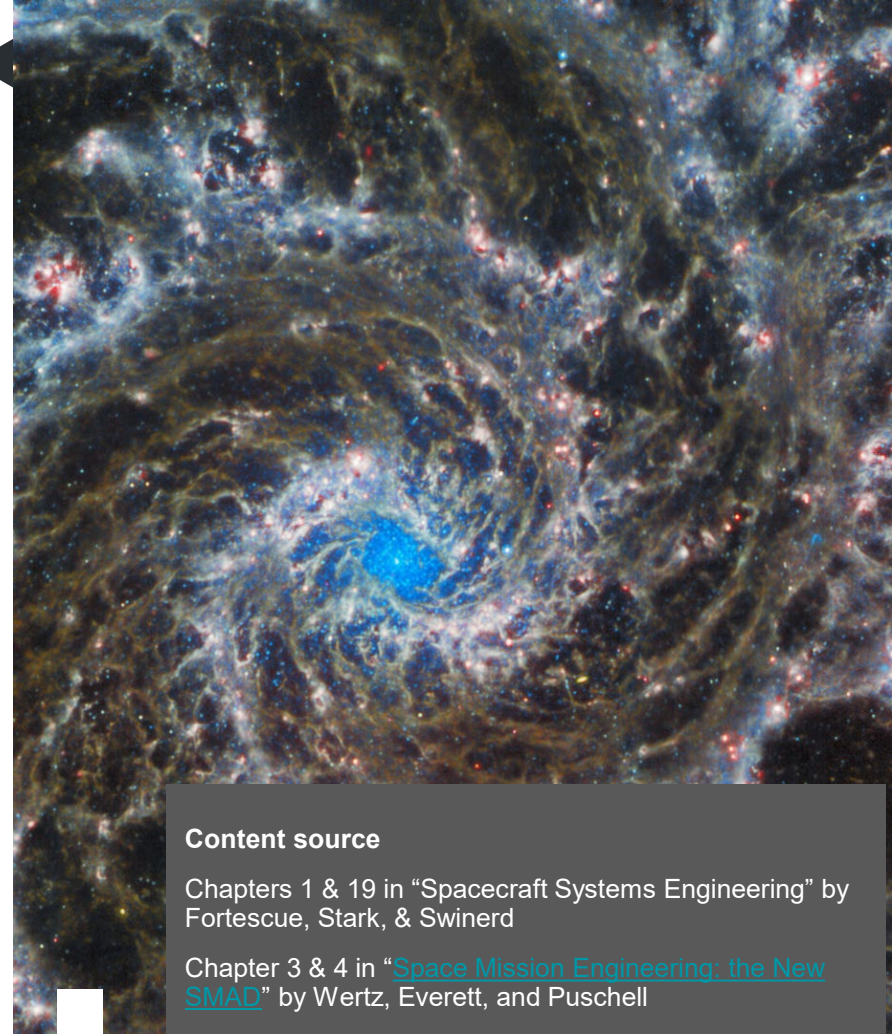
# EPFL Learning Outcomes

By the end of this lecture you should be familiar with...

- What are the first step to define a mission
- Definition of Objectives and Constraints
- Stakeholder analysis
- High level requirements
- Mission Concept
- Concept of Operations



Source: NASA/JWST



## Content source

Chapters 1 & 19 in "Spacecraft Systems Engineering" by Fortescue, Stark, & Swinerd

Chapter 3 & 4 in "[Space Mission Engineering: the New SMAD](#)" by Wertz, Everett, and Puschell

Let's look at the whole process of **Space Mission Engineering**

## Definiton of Objectives and Constraints

1. Define broad objectives and constraints (qualitative)
2. Define principal players
3. Define program timescale
4. Estimate quantitative needs, requirements, and constraints

## Definition of Alternative Mission Concepts & Designs

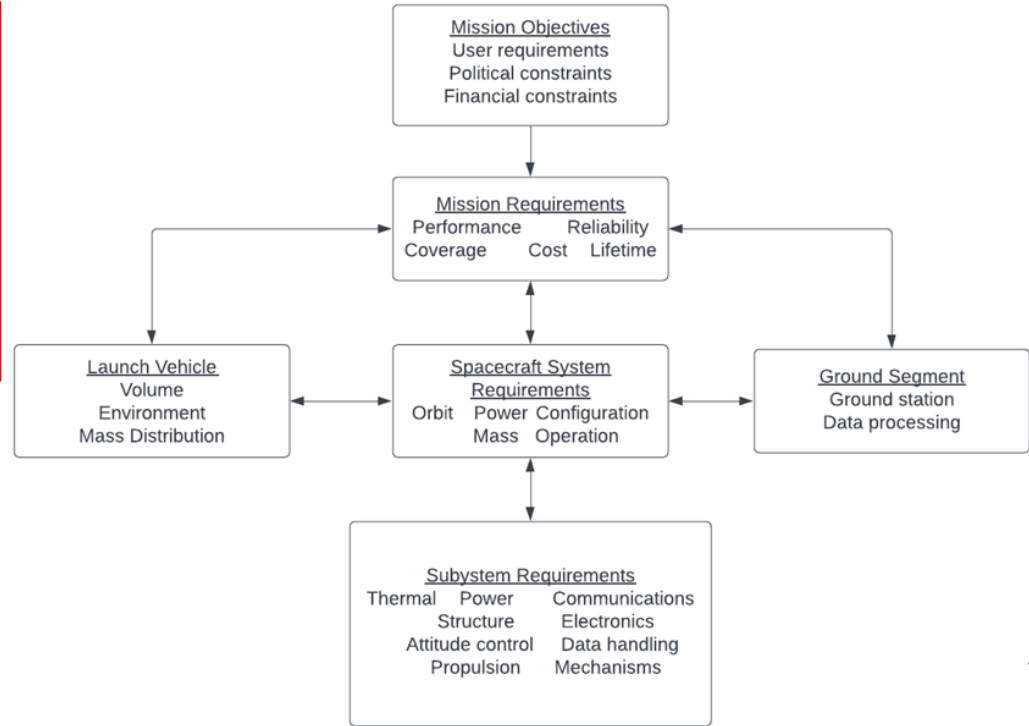
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7. Define the likely system drivers and key requirements (trade-off criteria, "rules of the game")

## Evaluation of Alternative Mission Concepts

8. Trade-off analysis
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10. Revise requirements and constraints
11. Iterate and explore other alternatives, if needed

## Definition and Allocation of System Requirements

12. Define system requirements
13. Allocate requirements to system elements



### Further reading:

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- **Ch. 3** in "[Space Mission Engineering: the New SMAD](#)" by Wertz, Everett, and Puschell



This course should actually be called

## Spacecraft Design and **Space Mission Engineering**

*Mission Engineering* is the definition of mission parameters and refinement of requirements so as to meet the broad and often poorly defined objectives of a space mission in a timely manner at minimum costs and risk.



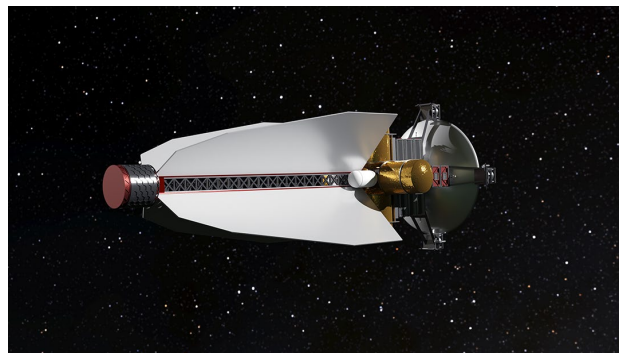
### Need-driven process

Provide better communications to firefighters



### Capability-driven process

Order of magnitude increase in power capabilities



# How Does a Space Project Start?

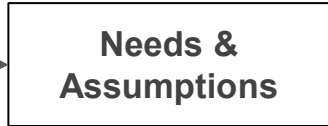
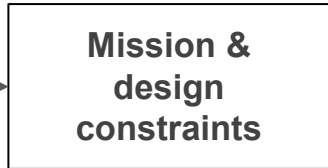
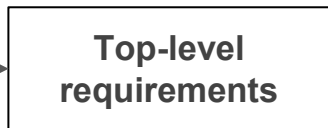
## The Space Mission Engineering Process

**Stakeholders:** it all starts with a **need/problem/goal**...

*this tends to be messy and unclear*



*breakdown customers specifications into requirements*



*clarify, clarify, clarify*

*...always question customer needs and assumptions*

*...ask for a justification when necessary!*

*..keep track of these...*

*Remember: requirements are also iterated!*

*..we aren't thinking about solutions just yet*  
*good example --> transport X instrument from A to B across Y basin*  
*bad example --> an MMRTG-powered instrument carrying rover*

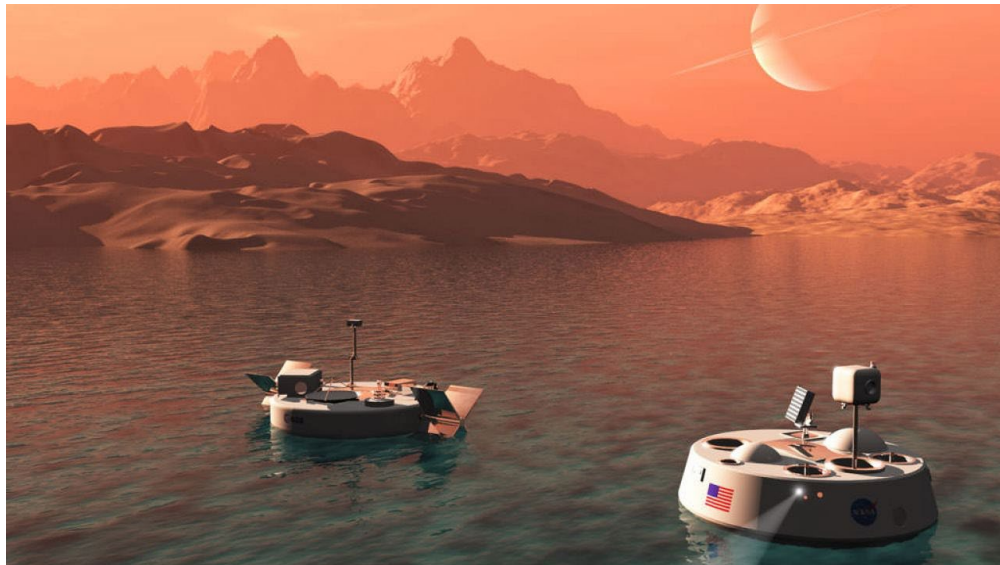


An artistic rendering of a Titan landscape. The sky is a deep, layered orange and red. Several parachutes are descending from the sky, each carrying a probe. The probes are cylindrical with various instruments on top. The ground is a mix of dark, jagged rocks and a lighter, sandy or silty shore. In the foreground, a probe is resting on the shore. A large body of water, likely a lake or sea, occupies the middle ground. The overall scene is a depiction of a future mission to Titan.

# Titan orbiter and lake probe

## The Space Mission Engineering Process

### Scientific interests



Credit: bisbos.com

### Example Titan's lake landing mission

- SI1** Further investigation of Titan's atmosphere and the chemically active weather cycle.
- SI2** Investigation of Titan's liquid deposits on the surface and the sub-surface.



## The Space Mission Engineering Process

Scientific interests → Problem statement



Credit: bisbos.com

### Example Titan's lake landing mission

*Through utilization of an autonomous lake lander, a study of the surface lakes of Saturn's moon Titan, will be performed over the extension of minimum 16 days, in order to investigate and clarify the complex organic chemistry and search for possible indication of life.*



## The Space Mission Engineering Process

Scientific interests → Problem statement → Mission Goals

### Example Titan's lake landing mission



Credit: bisbos.com

**MG1** Further investigation of the formation and evolution of Titan through measurement of the composition of a methane lake.

**MG2** Study of the lake-atmosphere interaction to clarify the role of the methane lakes in the chemically active weather cycle.

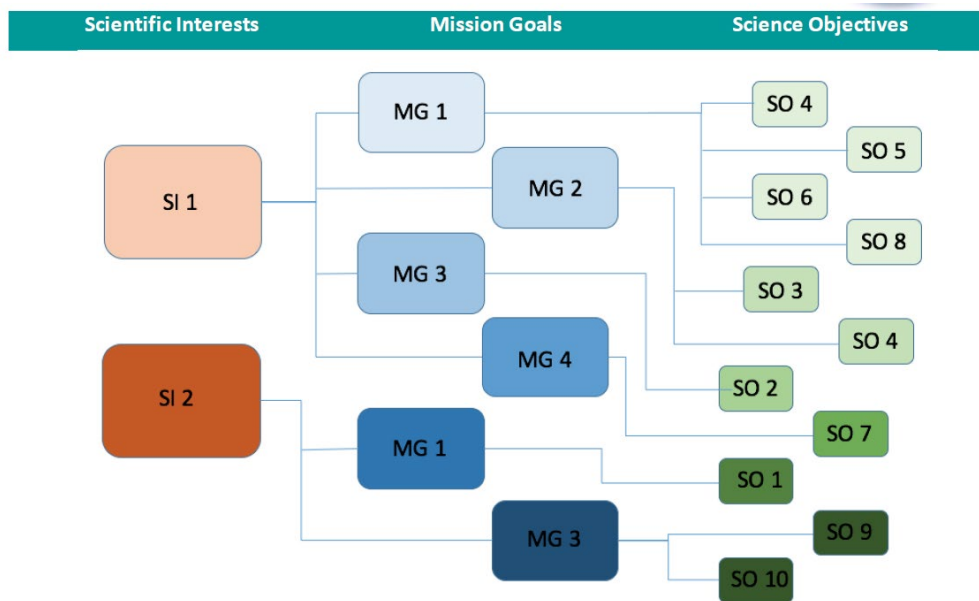
**MG3** Investigate possible prebiotic organic chemistry in the methane lake environment.

**MG4** Measuring tidal changes for Titan lakes over the course of Titan's 16-day orbit of Saturn, to examine the interaction with a possible interior ocean.



## The Space Mission Engineering Process

Scientific interests → Problem statement → Mission Goals → Scientific goals



## Example Titan's lake landing mission

**SO1** Resolve the chemical processes that could lead to the formation of the complex organics, found in different altitudes of the atmosphere of Titan, and surface.

**SO2** Investigate the relative significance of reactive oxygenic species.

**SO3** Investigate the key processes which determine the global distribution of the chemical components of the Titan atmosphere.

**SO4** Characterize the flow of energy and atmospheric circulation.

...



# Stakeholder Analysis introduction

- Stakeholders are....
  - Individuals and groups, both inside and outside the organisation who can influence the success of project implementation
  - Anyone who can be impacted by the project implementation
- Why we do a stakeholder analysis?
  - To assess which individuals or groups are likely to support, resist or remain neutral during the project implementation...

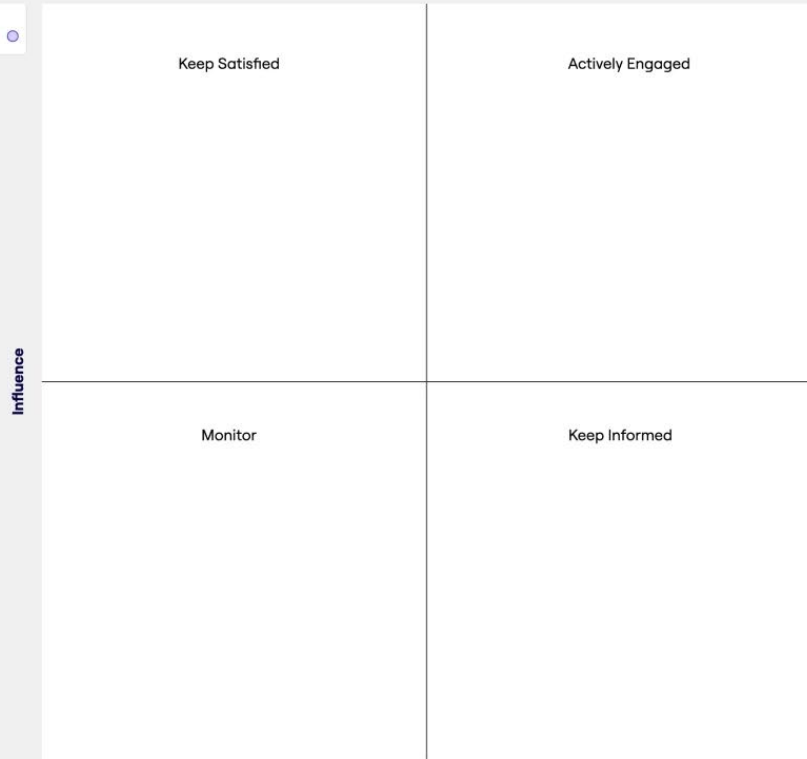
# Stakeholder analysis

- How are they impacted by the project?
- To what degree do they have power to influence the success of the project?
- What specific support is needed from them to advance the project?

Who are the stakeholders for the following project:

- I, student, will complete my masters at EPFL
- Who can influence the success of the project? Who can be impacted by project implementation? Each «who» is an individual or a homogeneous group

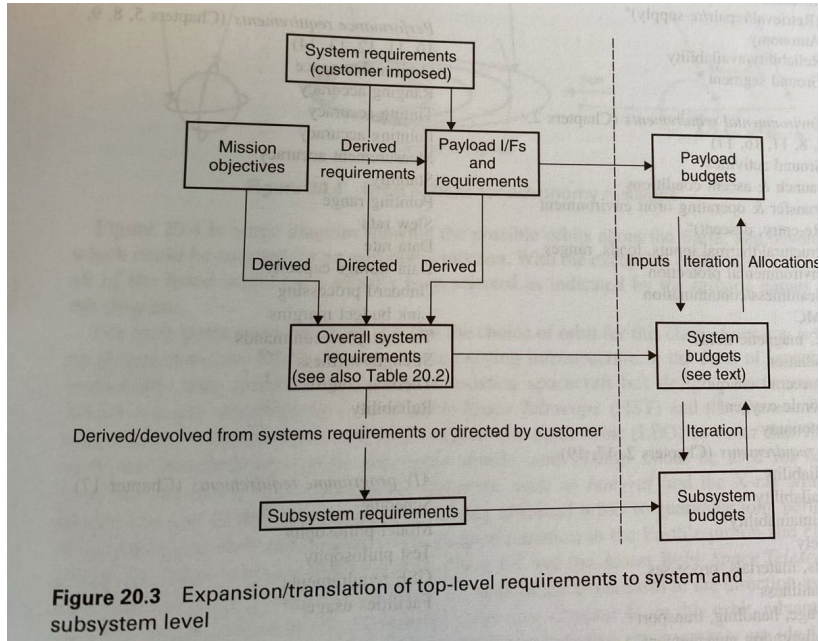
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Key Contact	Executive Decision makers
Departments	Board Members
Subject Matter Experts (SMEs)	Etc.

Interest/Availability

# How Does a Space Project Start? High level requirement



1. Listen to the customer need
2. Translate into high level requirements
3. Define you mission objectives
4. Then you flow-down to your S/C requirements and subsystems



## More about requirements:

- **Ch. 6** in [“Space Mission Engineering: the New SMAD”](#) by Wertz, Everett, and Puschell
- [NASA How to write good requirements](#)

## The Space Mission Engineering Process

Translate customer needs to **mission-level requirements** and defined main technical **assumptions**.

### Requirements (“shall”: unique, quantitative, measurable)

- *Functional requirements* (“The TVC shall **provide vehicle control** about the **pitch and yaw axes**”) [**actor-action-subject**]
- *Performance requirements* (“The TVC shall **gimbal** the **engine** a **maximum of 9 deg., +/- 0.1 deg**”)[**actor-action-subject-performance**]
- *Constraints* (“The TVC shall weight less than 60kg”)
- *Interface requirements* (“The TVC shall interface with the J-2X per conditions specified in the CxP722262 Ares I US J-2X Interface Control Document, Sec. 3.4.3”)
- *Environmental requirements* (“The TVC shall use the vibroacoustic and shock loads defined in the CxP722262 Ares I Systems Vibroacoustics and Shock Environments Book in all design, analysis and testing activities”)
- *Others*: including human factors, reliability, safety, facilities, personnel, maintainability, operability, etc.

**Remember**: good requirements are clear and concise, correct, feasible, flexible, unambiguous, singular, verifiable, consistent, complete, absent of redundancy, and absent of conflicts.



Let's look at the whole process of **Space Mission Engineering**

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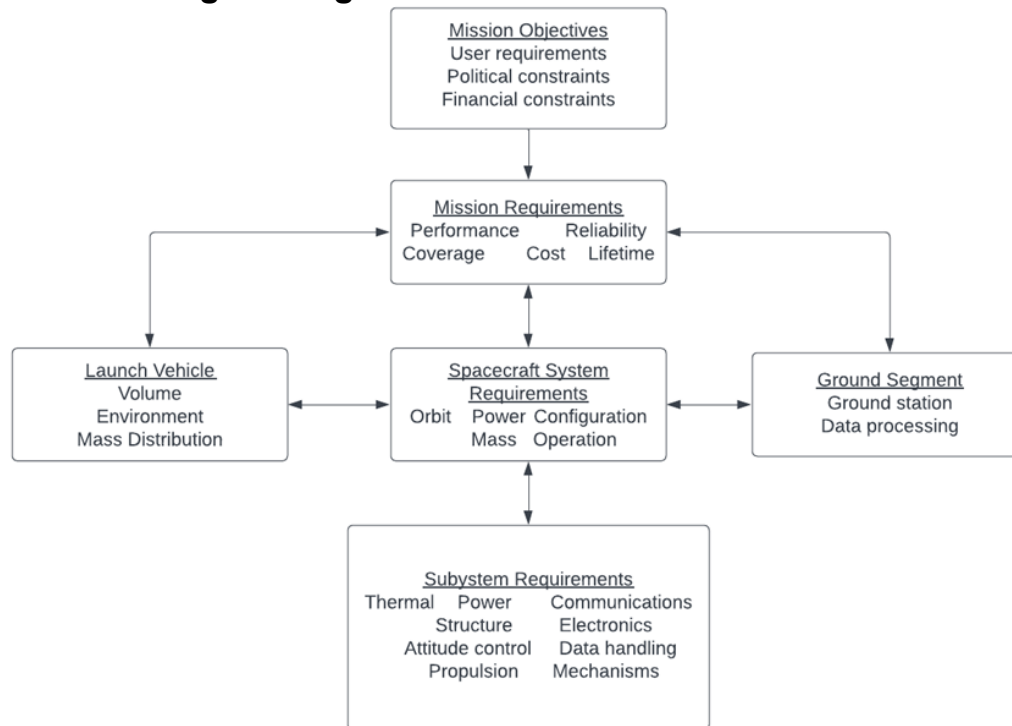
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- **Ch. 3** in "[Space Mission Engineering: the New SMAD](#)" by Wertz, Everett, and Puschell

## The Space Mission Engineering Process

Define the **architecture**

*What the problem is*



But wait...*mission concept vs architecture vs operations?*

**Mission Architecture:** definition of the set of 8 major elements: 1) what to sense or interact with, 2) payload, 3) spacecraft bus, 4) ground segment, 5) mission operations, 6) command, control & communications architecture, 7) orbit/constellation, 8) launcher.

**Mission Concept:** defines how all these elements work together to satisfy stakeholder needs. E.g.: how is information delivered to end-users?

**Mission operations:** the actionable workflows for people, HW, and SW involved in the mission.



# How Does a Space Project Start?

## The Space Mission Engineering Process

Define the **architecture**

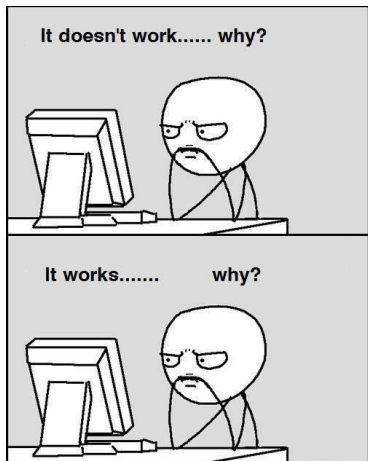
*What the problem is*

*...this has a big impact in the overall design of the system!!*

**System Engineers**

**Starting point for the design cycle**

**CONOPS**



MemeBlender.com

*How the system will do it*

*What the system needs to do*

**Functional decomposition**

**Product decomposition**

We will assess the degree of maturation of the technologies used via Technology Readiness Levels (TRLs)

**Top-down approach**  
Main objective → top-level functions → bottom-level functions (reduced interactions, simple interfaces) [break down by "how?"]

**Bottom-up approach** by matching basic functions to components and grouping these into subsystems



## The Space Mission Engineering Process

### Functional Analysis

- Solution neutral - what will the system do and why?

*Functional Analysis is the systematic process of identifying, describing, and relating the functions a system has to be able to perform, in order to be successful*

1. Define a functional tree (top-down) (aren't unique)
  - a. Bottom functions (re)define new functional requirements
2. Map bottom functions to products/devices
3. Define a product tree (bottom-up) by grouping basic components

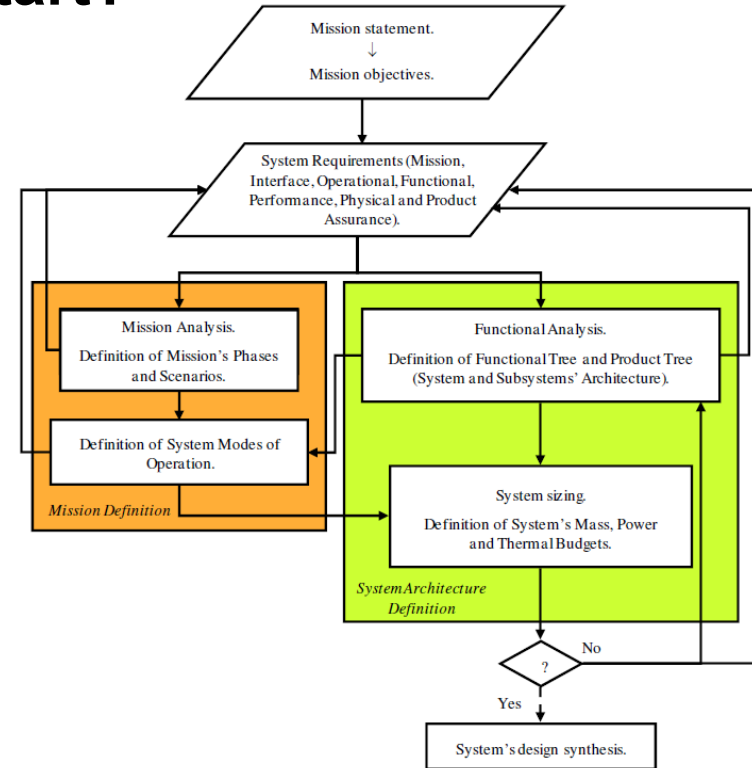


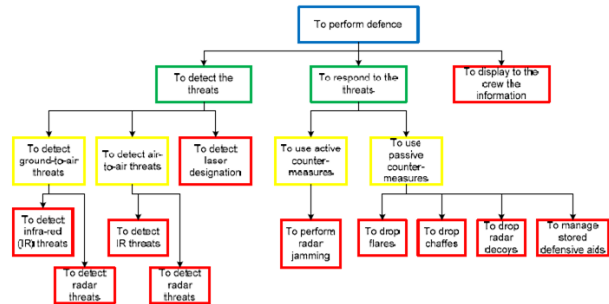
Fig. 1. Conceptual design process flow-chart

#### Read more :

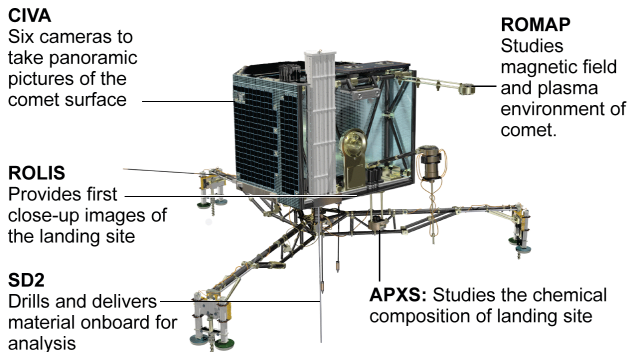
- Vijay Kumar, [Functional Analysis in Systems Engineering: Methodology and Applications](#), JETIR, 2(10), 2015
- NASA's [Functional Analysis Module](#), Space Systems Engineering 19

More in L06

## Functional Tree



## Product Tree

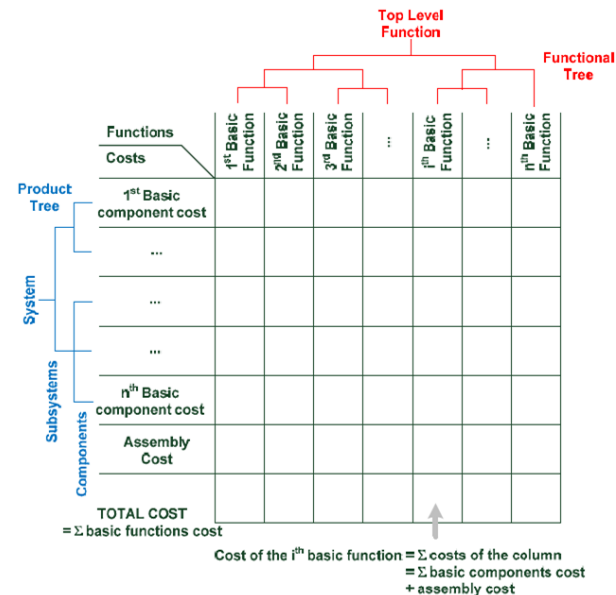


## Function/Product Matrix

Basic devices	Basic functions										
	To detect infra-red (IR) threats	To detect radar threats	To detect laser aiming	To perform radar jamming	To drop flares	To drop chaff	To drop radar decoys	To manage stored defensive aids	To display to the crew the information		
Missile warning receiver	X										
Infra-red (IR) warning system	X										
Radar warning receiver		X									
Laser warning system			X								
Jammer				X							
Jamming decoy dispenser						X	X				
Jamming system				X							
Chaff/flares dispenser					X	X					
Store management system							X				
Multi Function Display (MFD)									X		

Table 1. Example of functions/devices matrix

## Cost/Function Matrix



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- NASA's [Functional Analysis Module](#), Space Systems Engineering 20

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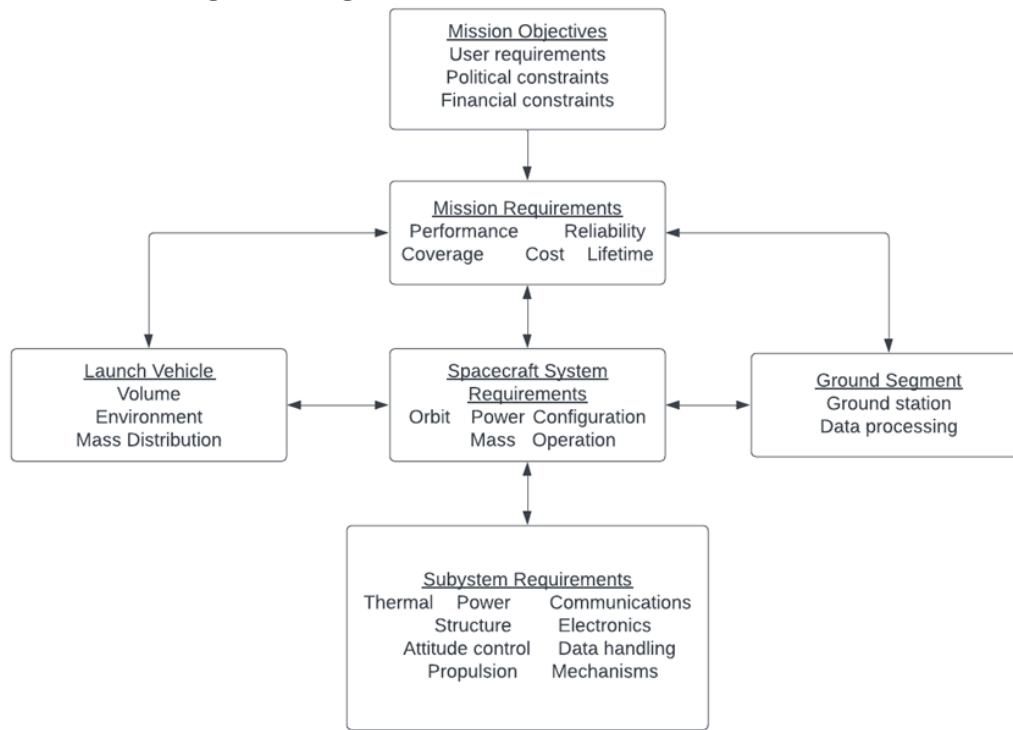
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## The Space Mission Engineering Process

### Concept of Operations (CONOPS)

As defined by: NASA

More info in: ANSI/AIAA G-043-1992, Guide for the Preparation of Operational Concept Documents



- CONOPS help define the **operational foundation** of a mission early on.
- What → description of how the system will be operated during the mission.
- How → imagine the operations of the future system and document the steps of how the end-to-end system will be used.
- CONOPS leads to new requirements and functions as different use cases are considered.
- CONOPS helps define mission **phases, scenarios, and modes of operation.**
- CONOPS contained:
  - o Description of major phases of the mission
  - o Operational scenarios and/or design reference missions (DRMs)
  - o Timeline
  - o End-to-end communication strategy
  - o Command and data architecture
  - o Operational facilities (e.g. mission control. Science data center)
  - o Integrated logistics support (resupply, maintenance, and assembly)
  - o Critical events

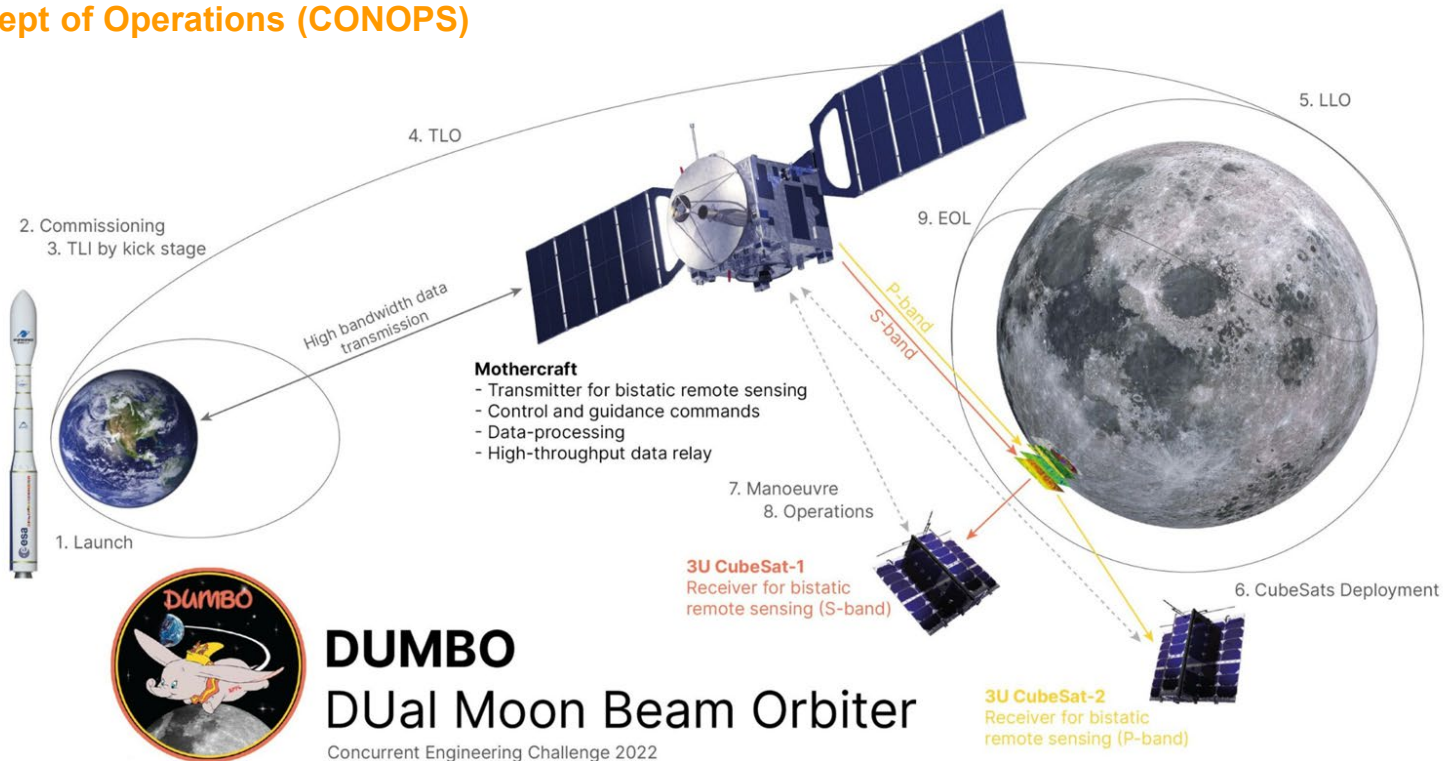
\*\* CONOPS aren't simply a pretty picture: [JWST Operations Concept Document](#).



# How Does a Space Project Start?

## The Space Mission Engineering Process

### Concept of Operations (CONOPS)



## DUMBO DUal Moon Beam Orbiter

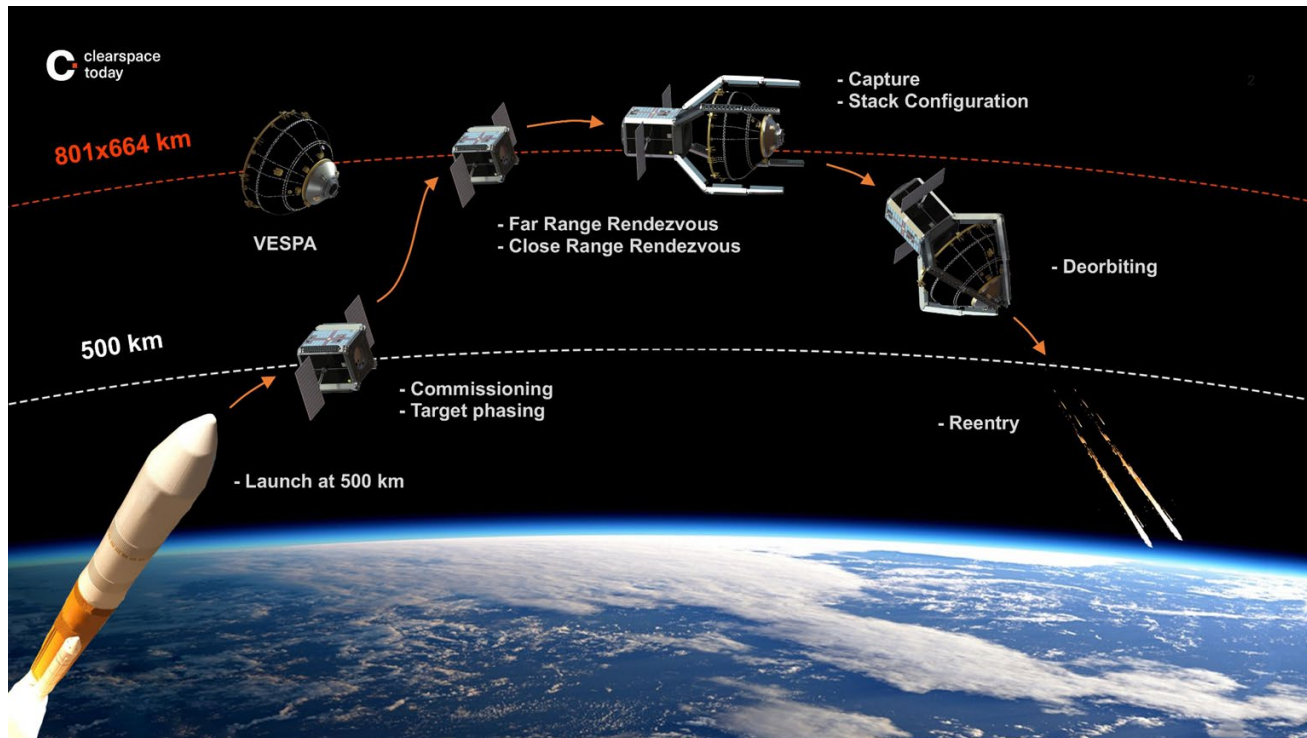
Concurrent Engineering Challenge 2022



## The Space Mission Engineering Process

### Concept of Operations (CONOPS)

Source: ClearSpace



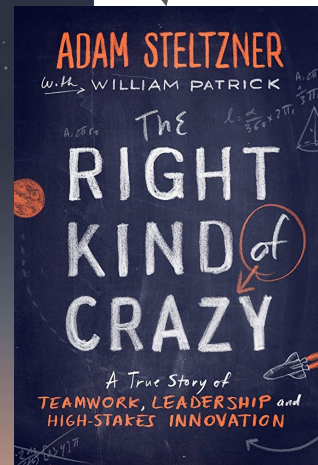
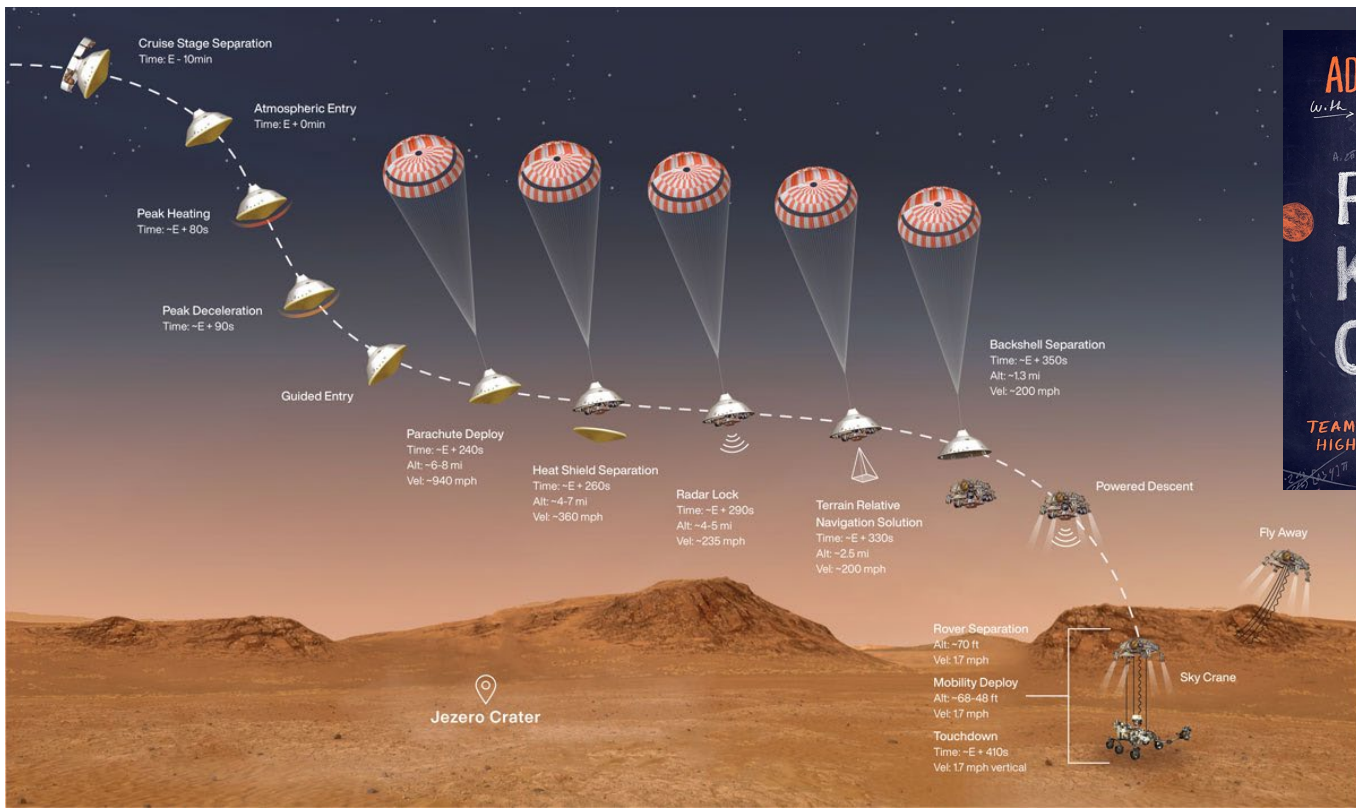
# How Does a Space Project Start?

## The Space Mission Engineering Process

### Concept of Operations (CONOPS)

Source: NASA/JPL-Caltech

*reading recommendation!*



# CONCLUSION

- We looked at Space Mission Engineering
  - How to define objectives and constraints
  - Stakeholder analysis
  - High level requirements and the type of requirements
  - Mission concept
  - CONOPS
- Next week- Intro to System engineering deep dive