National Aeronautics and Space Administration

Requirements and System Design

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Access to Space for All Systems Engineering Webinar Series

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Webinar Overview

This webinar will cover discussions on the requirement and systems design aspects.

- How do you define requirements for a small spacecraft mission?
- Why are requirements important to NASA missions?
- How trade studies are used to determine parts selection and why is it important?
- What is a concept of operations (ConOps) and why is it vital to a NASA mission?

This webinar will consist of two five-minute requirements definition activities based on case studies

Why are requirements important to NASA missions?

- How do we do what has never been done before now?
    - How do we explore?
    - Requirements help us:
        - Go from the unsolvable to things we can solve
        - Set expectations across teams
        - Describe our mission needs
        - Understand if what we are building will allow us to do what we want to / need to do
        - Bound spectacular ideas into resolvable actions

Requirements Case Study 1 – Which cup did we make?

How do we define requirements? Where do we start?

- Prior to writing technical requirements you first must understand the stakeholders/customers expectations: **What is the project scope?**
  - Project scope = needs, goals, objectives and basic operations concepts

- To define the project scope, you need to ask:
  - Who are the stakeholders/customers?
  - What's is wrong with what is available currently? What new capabilities are needed?
  - What is the implementation approach?
  - What are the goals? Can they be easily defined in a brief mission statement?
  - What are the objectives for the mission?
  - What is the system concept including inputs and outputs?
  - What is the operations concept?

Concept to Plan to Project – Idea Development Through Successful Mission

- What are do we want to do – what are we being asked to do?

Explore Space

- What is needed to do that?

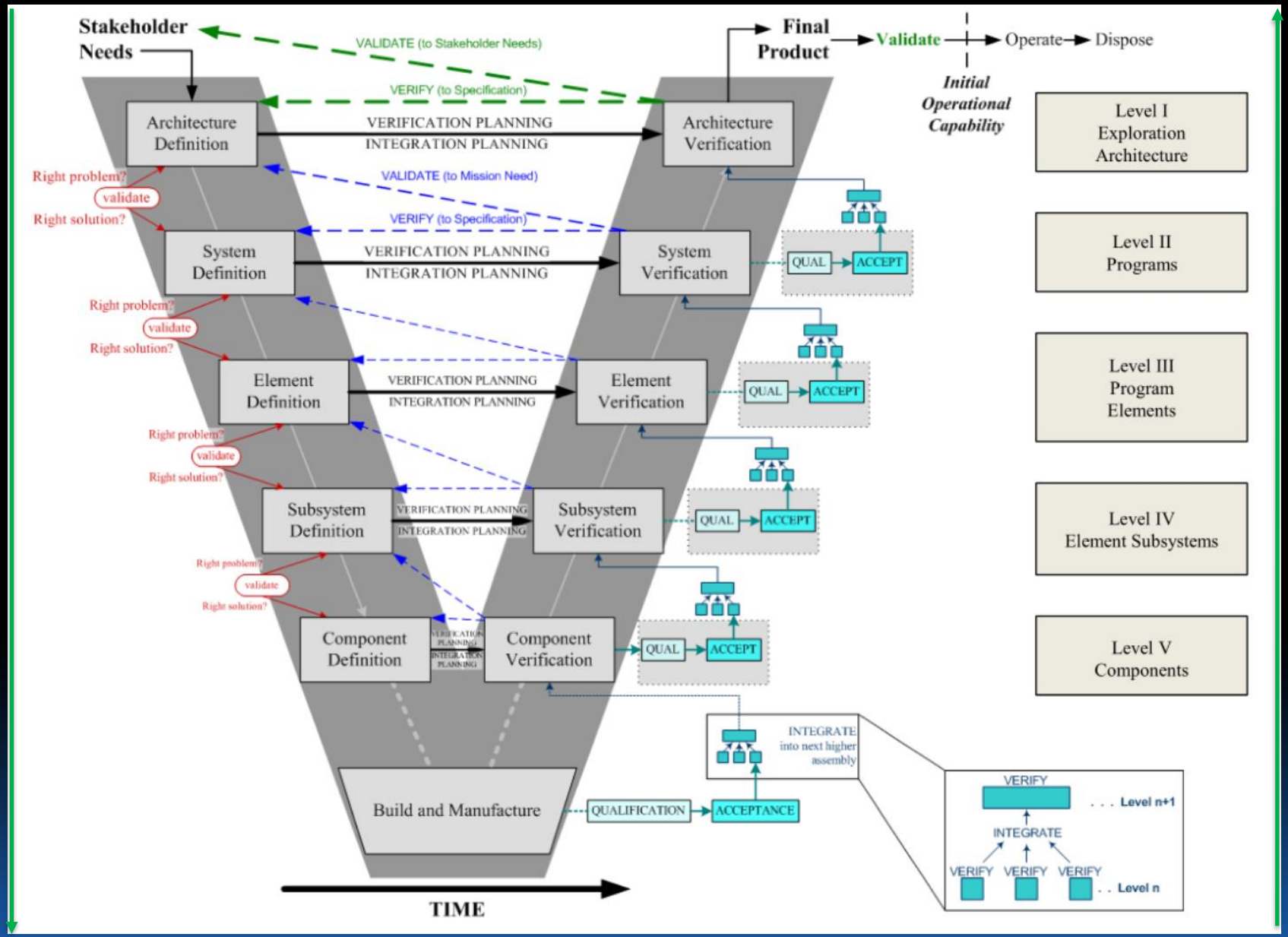
Spacecraft or probe?

- What is needed to do that?

Seating for crew members (?) [Apollo]*

- What is need to do that (at the component level)

Bolts to secure seating to spacecraft



- Can we do what we want to do– what are we being asked to do?

Explore Space

- Did we build the correct system

Spacecraft with verified seating

- Did we complete the correct subsystem

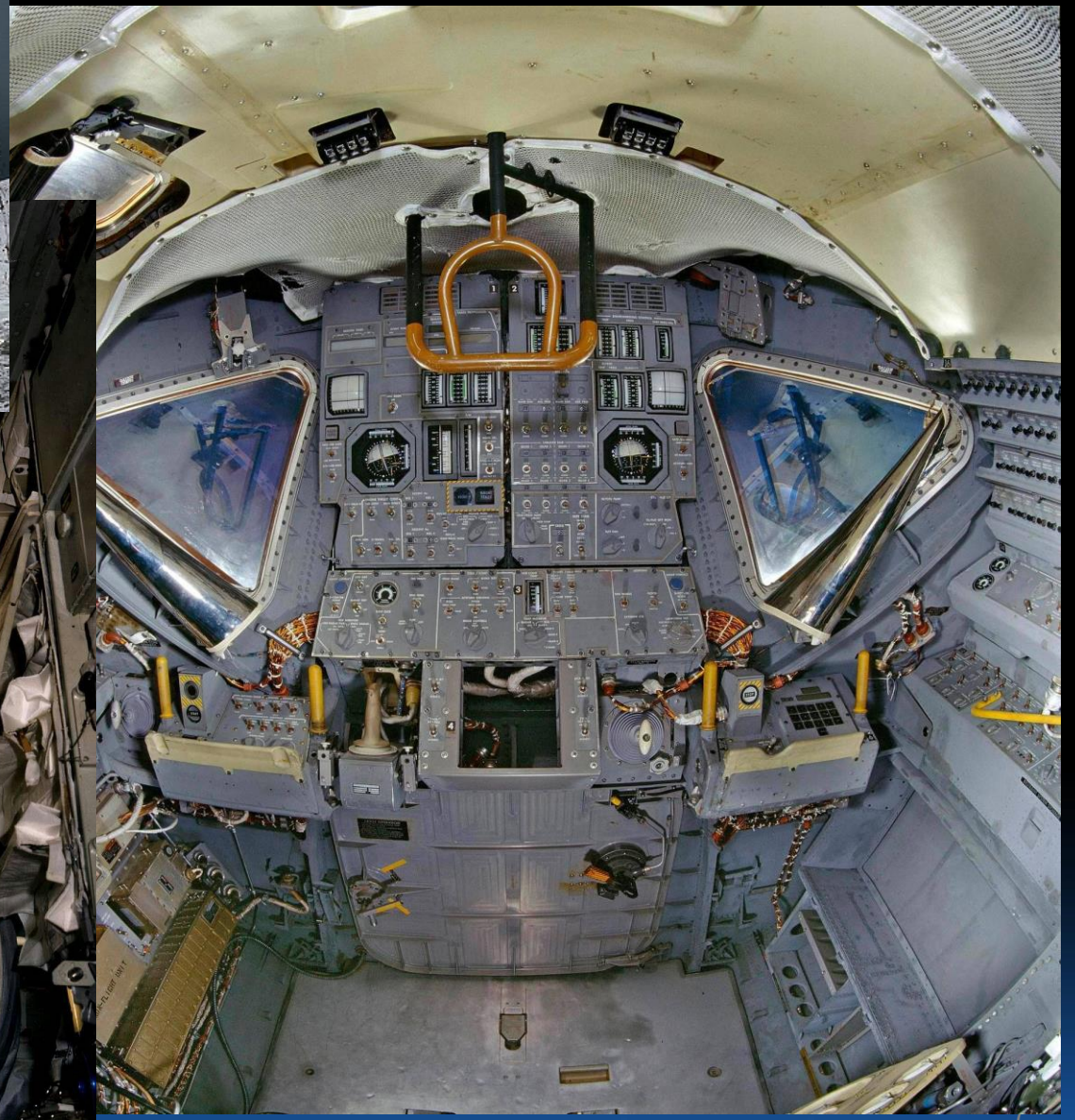
Integrate seating into spacecraft and test

- Did we get the correct component

Build and test seating for crew

* - Apollo Lunar Excursion Module (LEM)

- Good requirements can help lead to designs that may not be what we expect
- From our earlier example, do we need seating for the crew – or – do we need a safe environment?
- Describe what we need to accomplish
  - Land humans safely on the Moon and return to orbit
- Try **not** to describe exactly how to do that
  - While seated in a chair, land humans safely on the Moon and return to orbit



Requirements Help Tell Our Story

- Good Requirements Examples
  - Longevity of the mission
    - 8 days or 8 decades?

  - Example:
    - Mission Y shall operate in a circular sun synchronous orbit of 550km with a Local Time of the Ascending Node of 1200
    - Mission Y shall be operable in the orbital environment for 8 months

- What can we learn from these requirements --- what lower-level requirements come from these requirements
  - Electrical power charging environment
  - Thermal needs
  - Radiation shielding based on environment
  - If we need imagery, will we have sunlight / Earth reflection during key mission phases?
  - When will the mission pass over ground stations ---> how much data do we need to transmit in those 8 months to be successful? ---> how many ground stations do we need?

Guidelines for Writing Requirements

- Requirements should:
  - Be in the form “responsible party shall perform such and such.”
  - Mention who shall (do, perform, provide, weigh, or other verb) followed by a description of what should be performed.
  - Be free of how it will be accomplished
  - Not include descriptions of the operations
  - Be clear and unambiguous
  - Be concise and simple
  - Be stated as completely as possible
  - Be singular avoiding requirements within requirements
  - Be verifiable

Requirements Examples

- Bad Requirements Examples
  - Some funny – some not so funny

  - Actual Examples
    - Build a spacecraft that has a fiber optic system that has no mass, no signal loss, and does not require power
    - Get to Proxima Centauri by tomorrow!! (I tried and was not successful…yet ☺)

  - More Complicated Actual Examples
    - Creating massive amounts of work – that may not be needed
      - The mission shall meet document A
      - Document A was 785 pages of requirements including requirements that pointed to other documents
      - Solution: Find what is important and cite that exact portion of a standard
    - Requirements not specific enough
      - Perform a thermal analysis – good!
      - Thermal analysis performed using a tool that end customer cannot use
      - Solution: Perform a thermal analysis using <<specify software need>>
    - Verification expectations from design team to approval authority
      - Provide a spacecraft that can control pointing to accuracy level B
      - Spacecraft built with that control system – but – system can only be verified using analysis
      - This may be OK – or this may stop a mission – depending on agreement with stakeholders
      - Solution: Ensure that if a system cannot be tested (which can happen when trying to do the impossible) that stakeholders agree that verification via analysis is acceptable

Questions to Help Write Requirements

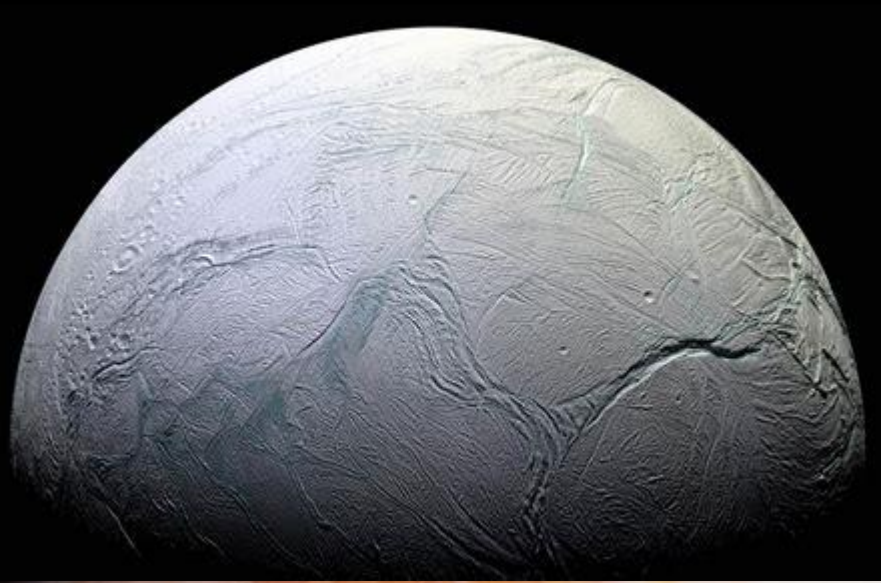
- Is the requirement:
  - Achievable?
    - Must reflect need or objective for which a solution is technically achievable
  - Verifiable?
    - Should not be defined by words such as: excessive, sufficient, resistant, etc……..
  - Unambiguous?
    - It must be expressed in terms of need, not solution, that is, it should address the “why” and “what” of the need, not how to do it
  - Traceable?
    - Lower-level requirements must clearly flow from and support higher level requirements
  - Consistent?
    - It must be consistent with other requirements without any contradictions
  - Appropriate?
    - It should not be so detailed that it constraints solutions for the current level of design

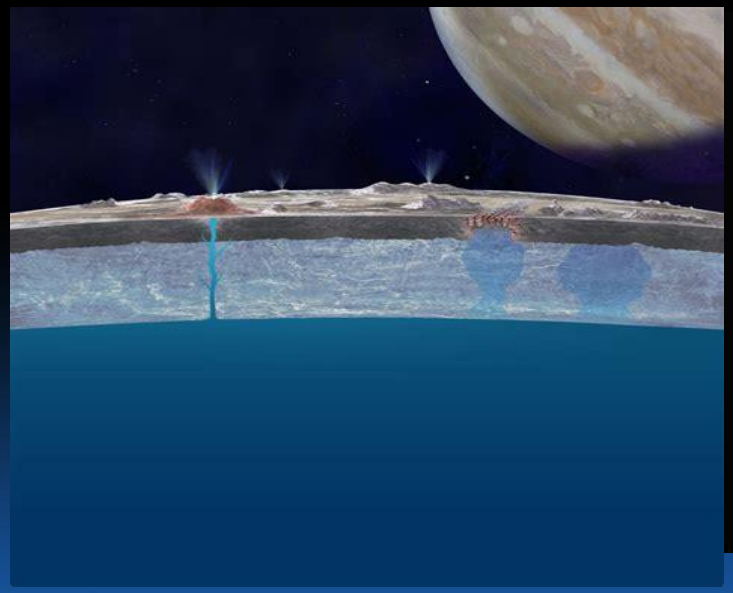
Requirements Case Study 2

- Mission to System Layout – System Architecture Model Development

<u>Mission Goal: Explore Europa</u>

- Case Study Goal:
  - Define the major components of the mission
  - Build the foundation for developing more detailed requirements

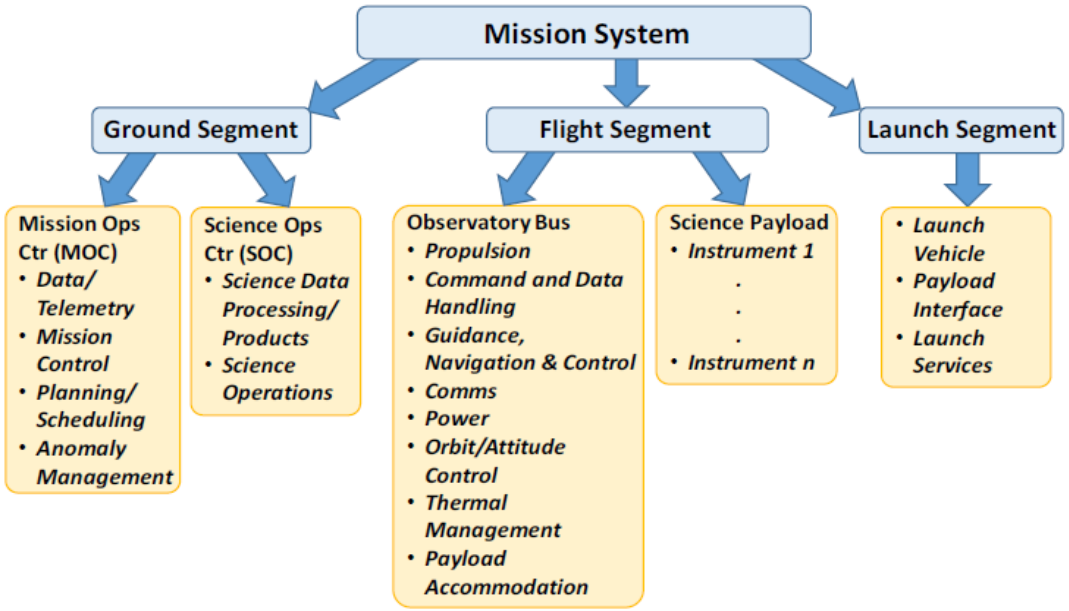




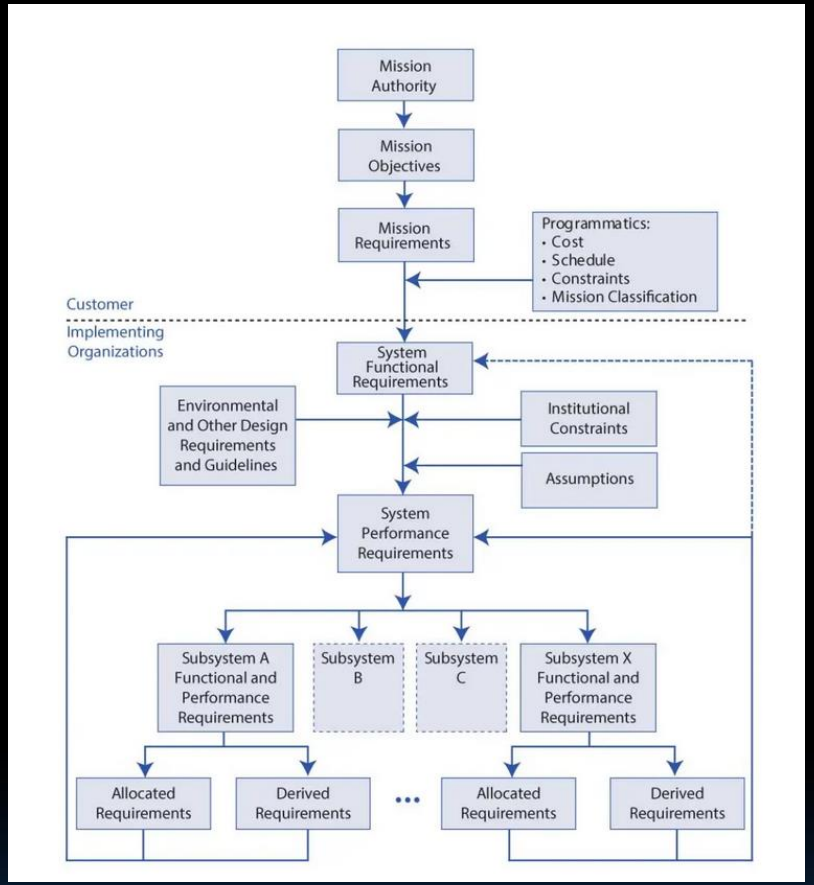
Case Study - System Architecture Model Development

- Also known as “Requirements Decomposition”
- Or, how are we supposed to do this anyway?!?

- Not Comprehensive – But – How Close Did We Get:



- Coordinate Systems
- Engineering Units, Tolerances, and Conversion
- Interface Requirements
- Mass Properties
- Structural/Mechanical
- Fluid
- Electrical (Power)
- Electronic (Signal)
- Software and Data
- Environments
- Electromagnetic Effects
- Cable and Wire Design
- Acoustic
- Structural Loads
- Vibroacoustics
- Human Operability



Link to NASA-Developed Publicly Available Resource for Architecture Definition

Trade Studies – Learning from Those Who Have Gone Before

- Has what we are trying to do been done before?
- Is there an industry with similar technology even if that industry is wildly different than space exploration?
  - Launch Technology
  - Formula 1
  - Submarine / Submersible Technology
- Are there alternative solutions that either reduce costs without reducing effectiveness or increase effectiveness without increasing cost
- Trade studies are critical to answering these questions and finding solutions we may not initially have known about or considered

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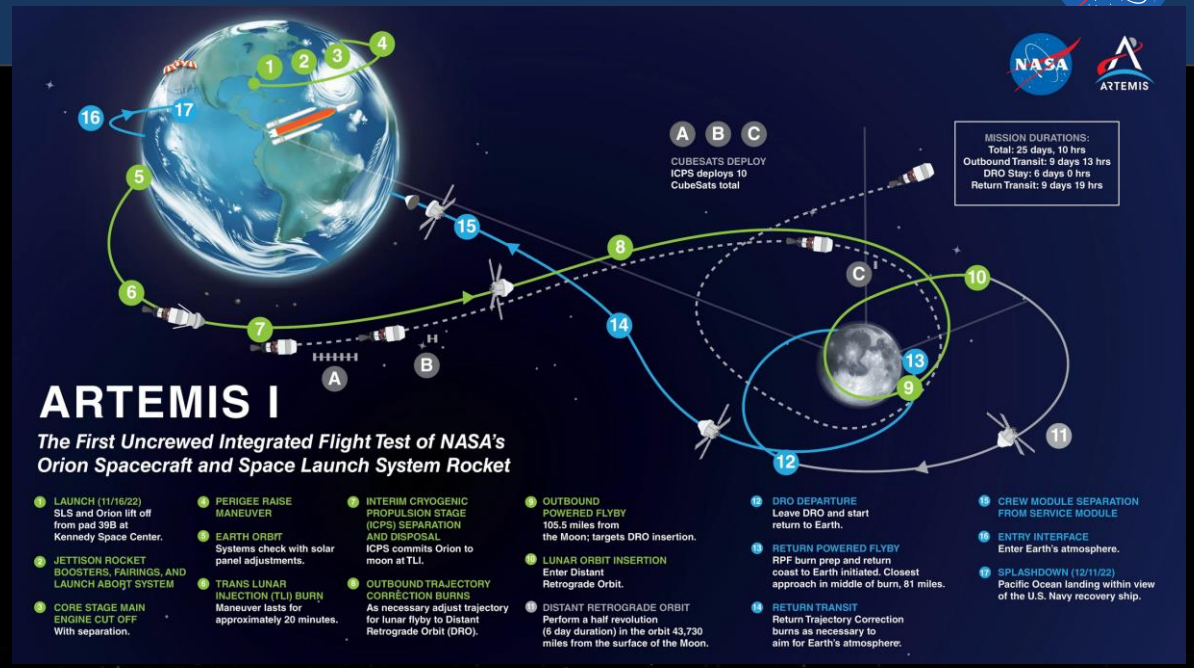
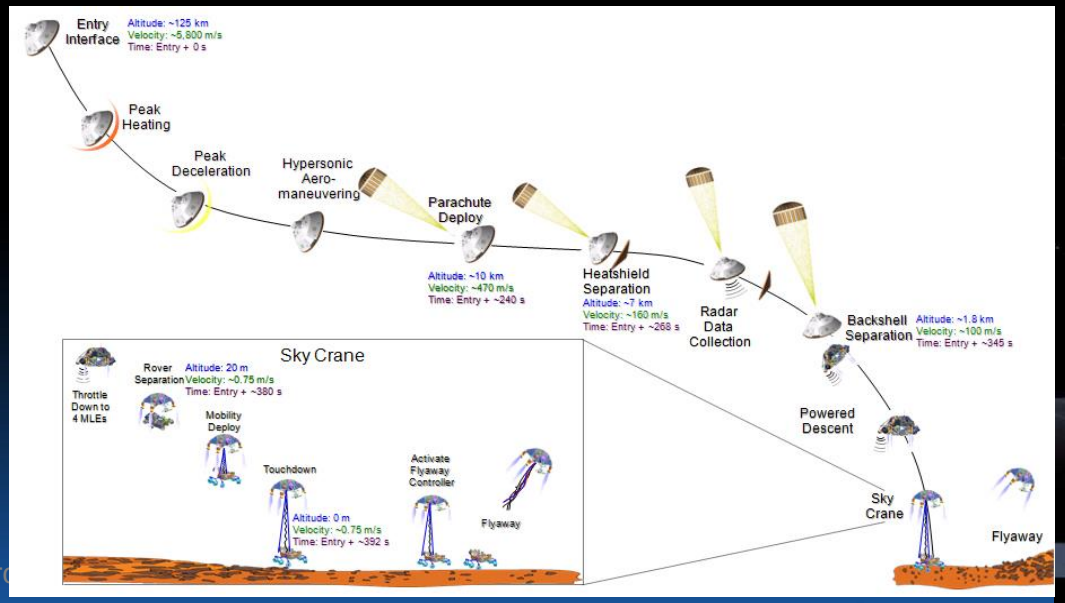
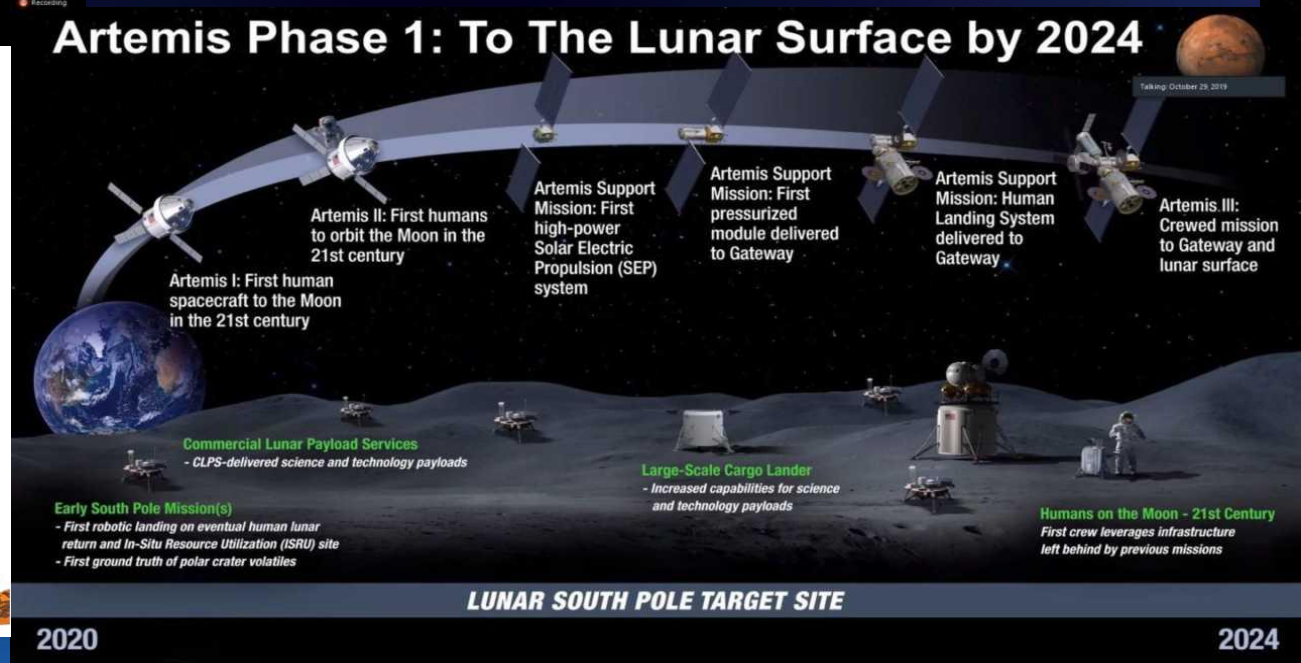
Concept of Operations (ConOps)

- Visual description of
  - What we are going to do
  - How a mission will be accomplished
  - How all the pieces of a mission fit together

- Imagine if we were given 5-minutes to explain the entirety of a program, how would we do that?







Questions?

www.nasa.gov/smallsat-institute/

Up Coming Webinar: System Assembly, Integration and Test, and Spacecraft Handling

This webinar will cover Systems Assembly, Integration and Test, and Spacecraft Handling as they relate to a small spacecraft project.

- What are the elements of system assembly, Integration and Test, and Spacecraft Handling?
- What are the various steps involved for each?
- Why is it important to a space mission?

Purpose

"To assemble and integrate the system (hardware, software, and humans), meanwhile developing confidence that it will be able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use".

Up Coming Webinar: Topic Preview

Steps for System Assembly, Integration and Test, and Spacecraft Handling

"To assemble and integrate the system (hardware, software, and humans), meanwhile developing confidence that it will be able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use."

- Update documents developed and baselined in previous phases
- Monitor project progress against plans
- Identify and update risks
- Integrate/assemble components according to the integration plans
- Perform verification and validation on assemblies according to the V&V Plan and procedures
- Prepare and baseline relevant documentation
- Document lessons learned. Perform required Phase D technical activities from NPR 7120
- Satisfy Phase D reviews' entrance/success criteria from NPR 7123

References

NASA Procedural Requirements 7123.1D, Systems Engineering Processes and Requirements, Expiration Date: July 05, 2028
https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7123&s=1B

NASA Procedural Requirements 7120.8A, NASA Research and Technology Program and Project Management Requirements, Expiration Date: September 14, 2028
https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=8A

NASA Procedural Requirements 7120.5F, NASA Space Flight Program and Project Management Requirements, Expiration Date: August 3, 2026
https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E

NASA SP-2016-6105 Rev2*,* NASA Systems Engineering Handbook
https://lws.larc.nasa.gov/vfmo/pdf_files/[NASA-SP-2016-6105_Rev2_]nasa_systems_engineering_handbook_0.pdf

https://www.nasa.gov/reference/appendix-c-how-to-write-a-good-requirement/

Definitions

- NASA Procedural Requirements (NPR) 7120.5: NASA Spaceflight Program and Project Management Requirements
  - Establishes the requirements that NASA formulates and implements space flight programs and projects
- NASA Procedural Requirements (NPR) 7120.8: NASA Research and Technology Program and Project Management Requirements
  - Research and Technology typically using ground systems or sub-orbital vehicles, aircraft, sounding rockets, and balloons)
  - More recently CubeSats, SmallSats, ISS payloads have been included

Backup Slides

www.nasa.gov/smallsat-institute/

Steps to Requirements Development for Systems and Subsystems