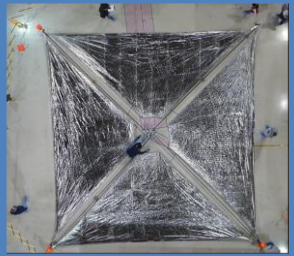
National Aeronautics and Space Administration






Requirements and Testing

October 30, 2024

Access to Space for All Systems Engineering Webinar Series

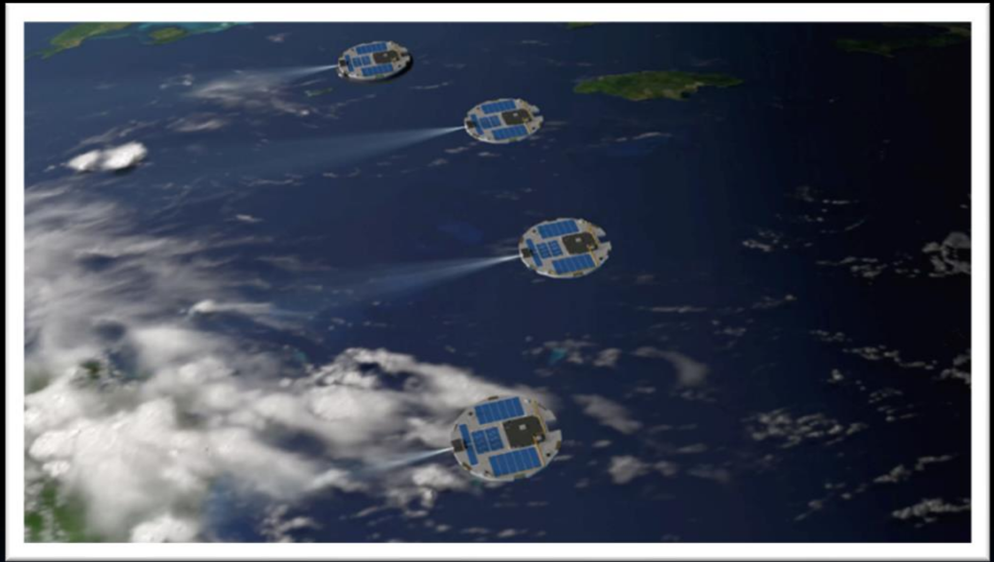
Jan Stupl, Ph.D.
Project Manager
NASA Small Spacecraft Technology Program
www.nasa.gov/smallsat-institute

Webinar Overview

This webinar will leverage and build upon information shared in the previous webinar series, impart more in-depth knowledge in requirements development, testing protocols, and procedures. This webinar will cover:

- Why requirements are needed
- Examples of good and bad requirements
- What makes for a good requirement
- How to develop and write clear, concise and well-defined requirements
- How requirements are evaluated
- What testing is required for a small satellite mission
- The various testing parameters to be evaluated and the type of apparatus used

Today's webinar will utilize examples of NASA activities



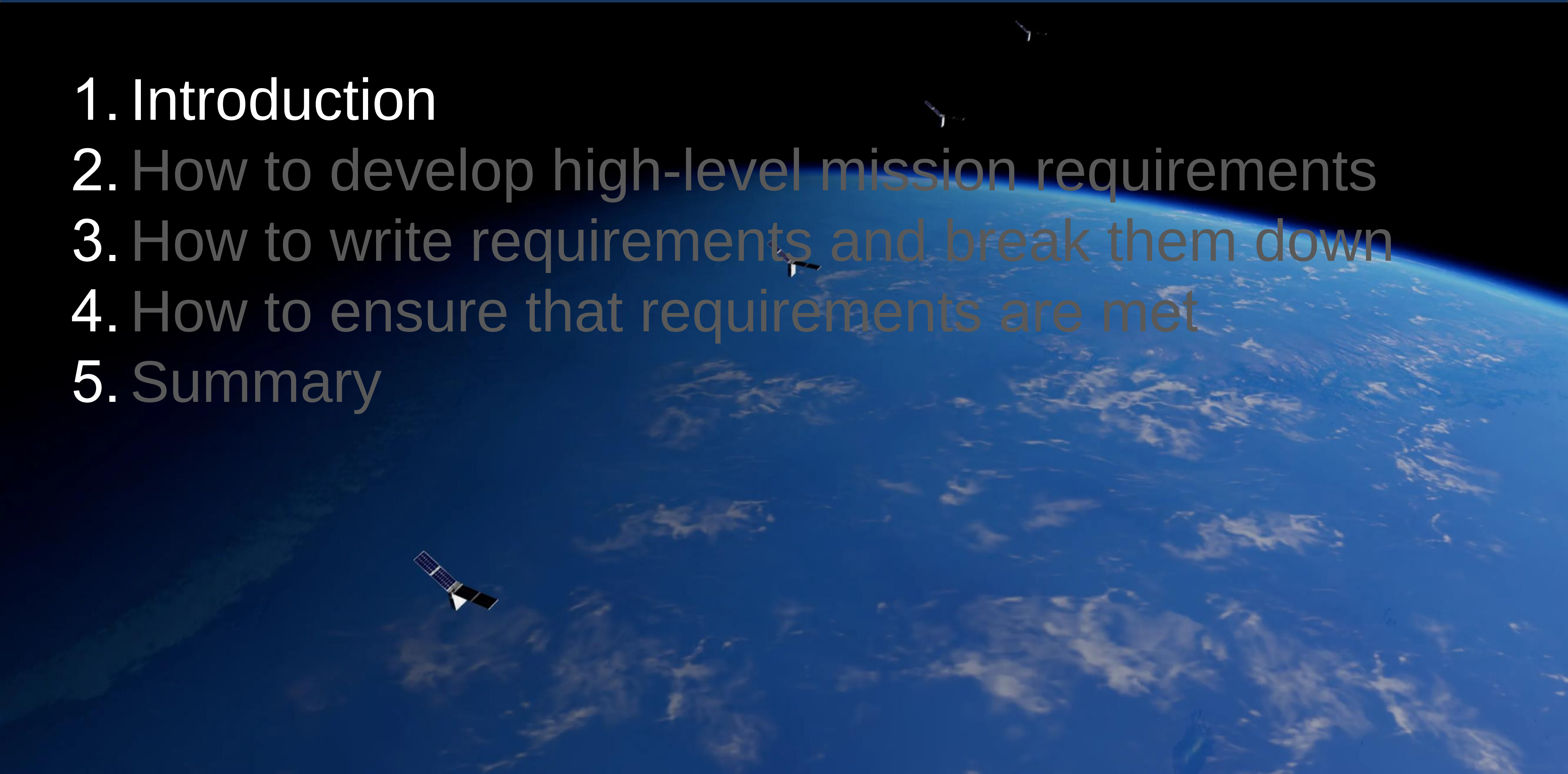
DiskSat Technology Demonstration.
Credit: NASA and The Aerospace Corporation

Webinar Agenda

1. Introduction
2. How to develop high-level mission requirements
3. How to write requirements and break them down
4. How to ensure that requirements are met
5. Summary

Webinar Agenda

1. Introduction
2. How to develop high-level mission requirements
3. How to write requirements and break them down
4. How to ensure that requirements are met
5. Summary



Requirements Help You to Build a Good Product

Requirements Definition:

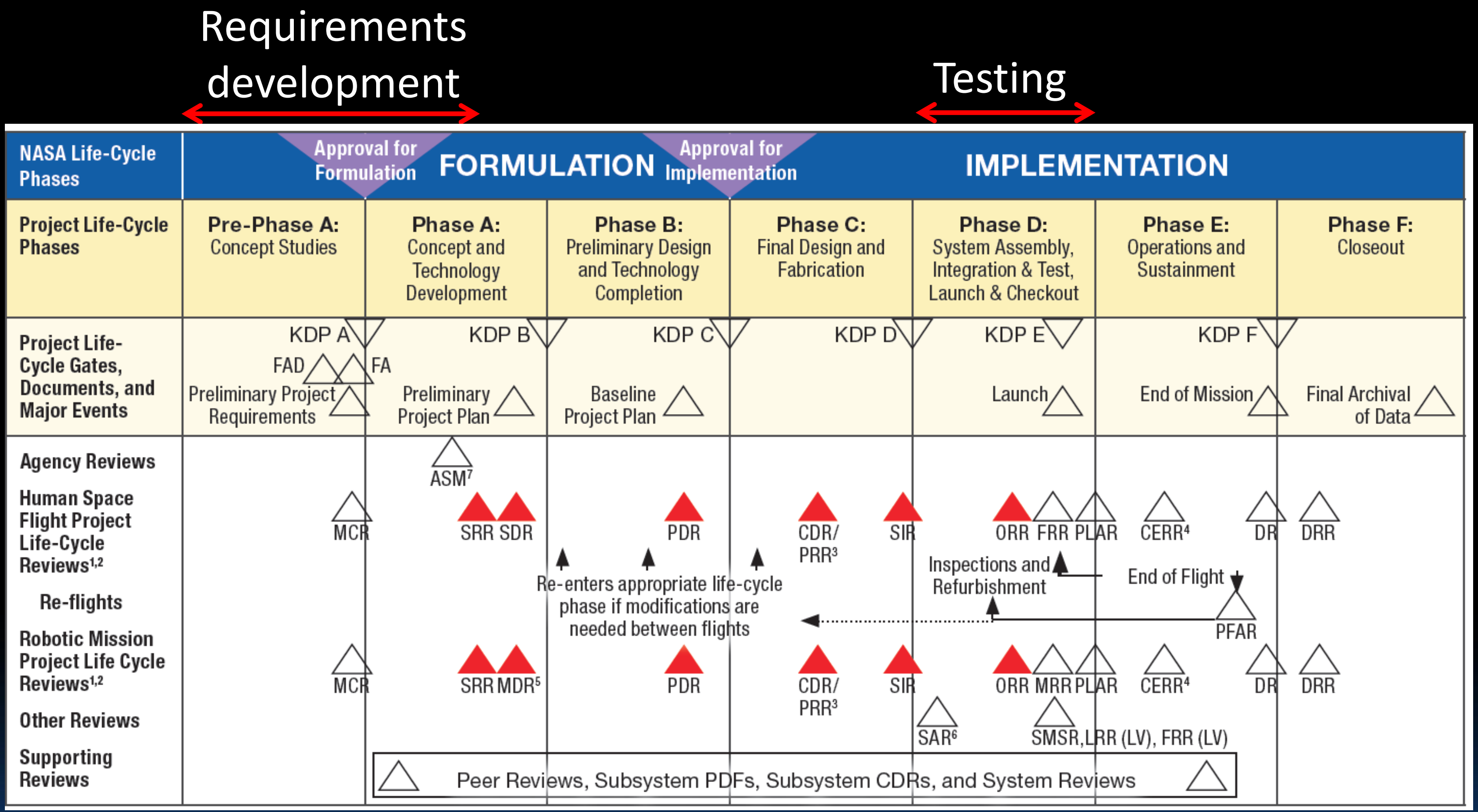
Requirements are statements that define a need, capability, capacity, or demand. They can pertain to personnel, equipment, facilities, or other resources or services and include specified quantities for specific periods of time or at a specified time. (detailed definition see: NASA Procedural Requirements (NPR) 7123.1C NASA Systems Engineering Processes and Requirements).

For example: *The spacecraft shall support at least 6 months mission lifetime.*

To build a successful product:

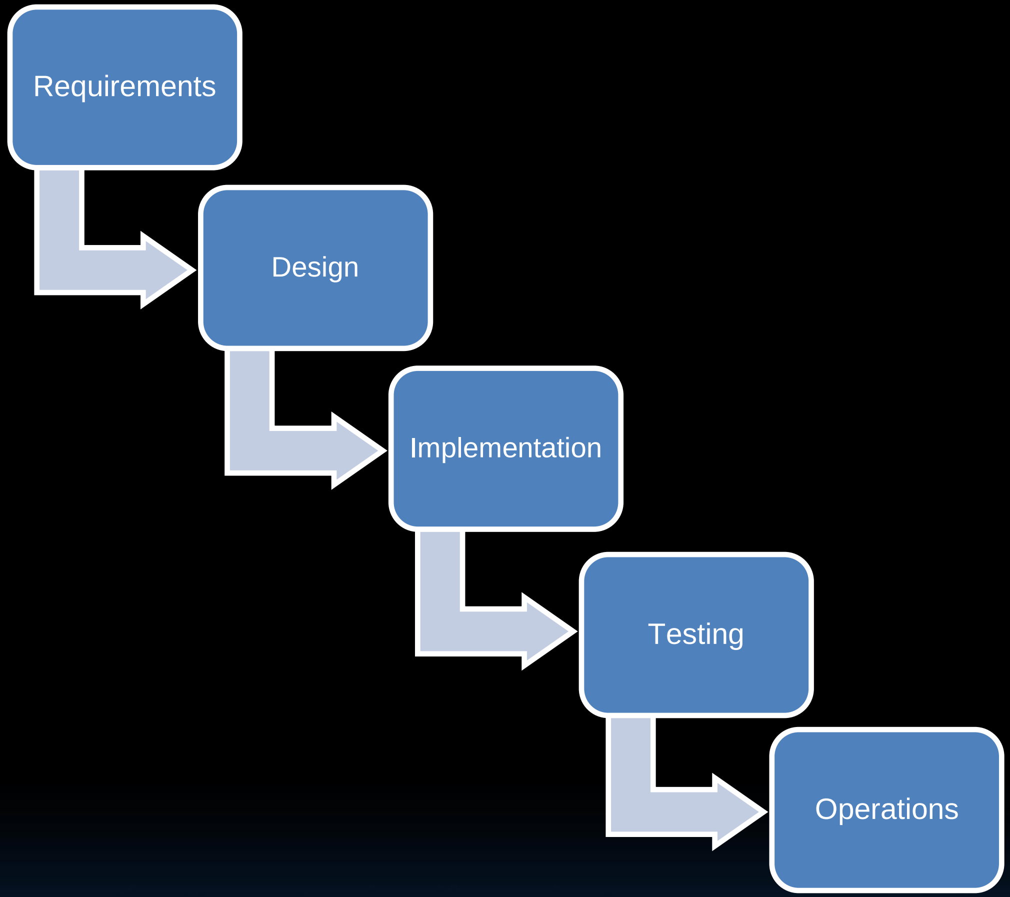
- Define requirements at the system and sub-system level
- Build the product
- Test that the product meets requirements!

In the “waterfall” method, requirements are set in the very beginning of a project and tested before operations start

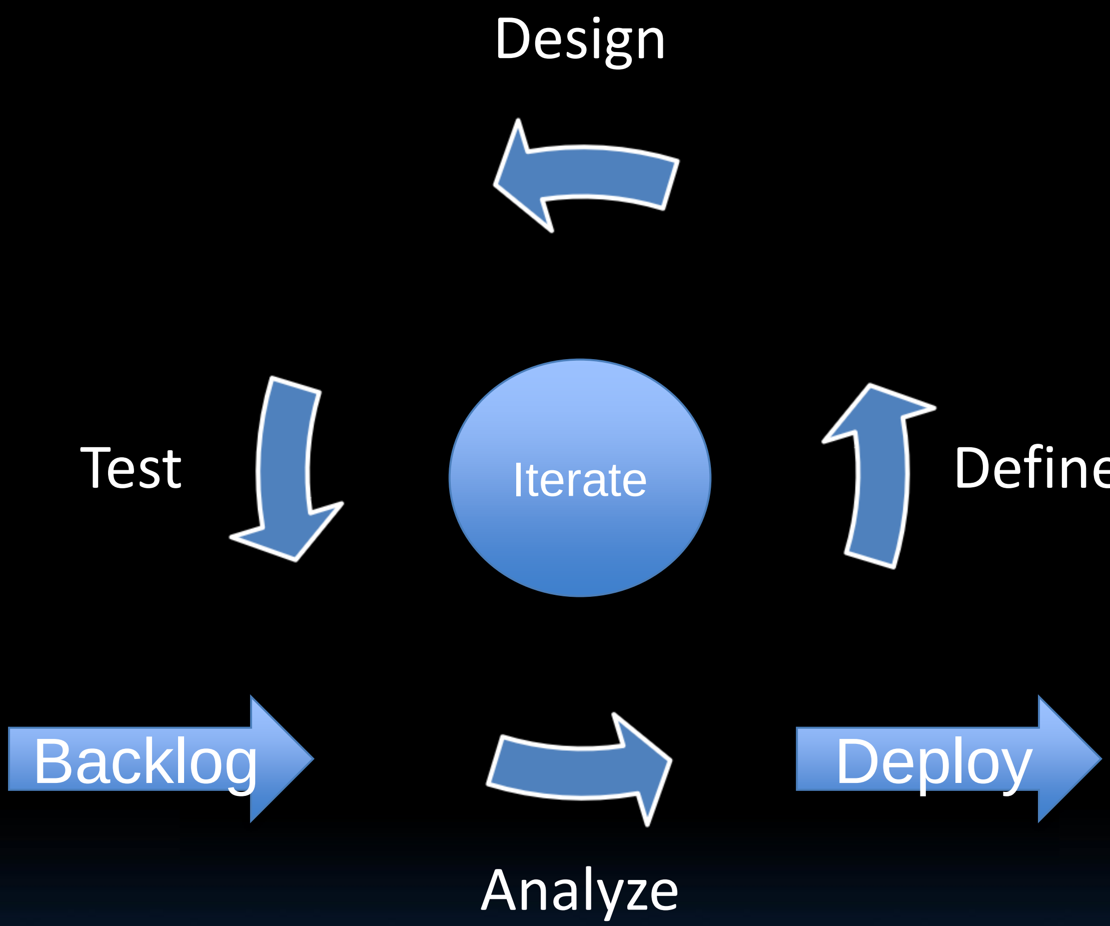


NASA Space Flight Project Life Cycle from NPR 7120.5E

The waterfall method is a linear approach to manage a project, the “agile” approach is an iterative alternative



Waterfall



Agile

Adapted from: https://www.nimblework.com/blog/agile-vs-waterfall-embracing-the-hybrid-project/

Webinar Agenda

1. Introduction
2. How to develop high-level mission requirements
3. How to write requirements and break them down
4. How to ensure that requirements are met
5. Summary

The Science Traceability Matrix is a tool to develop and define *what* a science mission needs to accomplish

The Science Traceability Matrix (STM) follows the Scientific Method

Ask a question → Construct a hypothesis based on current knowledge and make predictions → Test the Hypothesis

Science Goals	Science Objectives	Scientific Measurement Requirements		Instrument Requirements	Projected Performance	Mission Requirements (Top Level)
		Physical parameters	Observables			
GOAL 1	Objective 1					

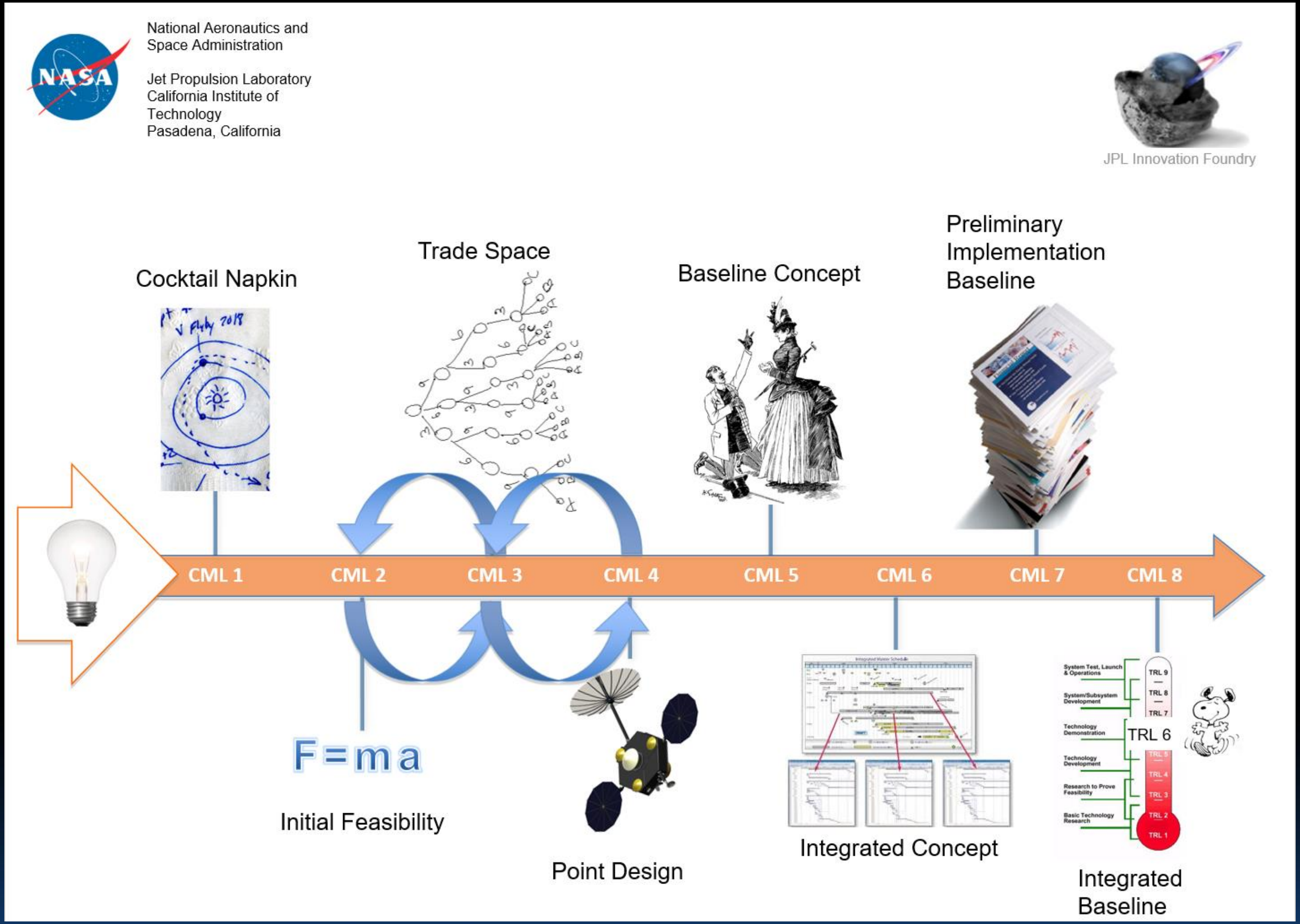
The Science Traceability Matrix is a tool to develop and define *what* a science mission needs to accomplish

Science Goals	Science Objectives	Scientific Measurement Requirements		Instrument Functional Requirements	Projected Performance	Mission Functional Requirements (Top Level)
		Physical Parameters	Observables			
Goal: Understand the origin and diversity of terrestrial planets. **Objective:** Characterize planetary surfaces to understand how they are modified by geologic processes. **Important Question:** What were the sources and timing of the early and recent impact flux of the inner solar system? [Visions & Voyages 2013-2022, Chapter 5]	**Hypothesis**: Venus used to have a thinner atmosphere, on the order of Earth's present day atmosphere (1 bar). **Predictable Feature**: A thinner atmosphere would allow smaller meteorites to impact the surface than are presently observable with Magellan data.	**Crater size** **Density of craters with a certain size** **Complexity / Symmetry of craters** **Ejecta blanket**	**Diameter:** **Depth (rim to floor)** **Rim Height** **Terracing width** **Existence of collapse zone** **Central Uplift Height**	**3D image data:** **Vertical resolution**: ± 1 meter **Horizontal resolution**: ± 5 meters **Color**: B&W or gray scale	Craters as small as 50 meters in diameter can be detected with a certainty of 70%; 100 meters with 80%; 200 meters with 90%.	Full planetary surface examination required.

Writing example, not a real science case!

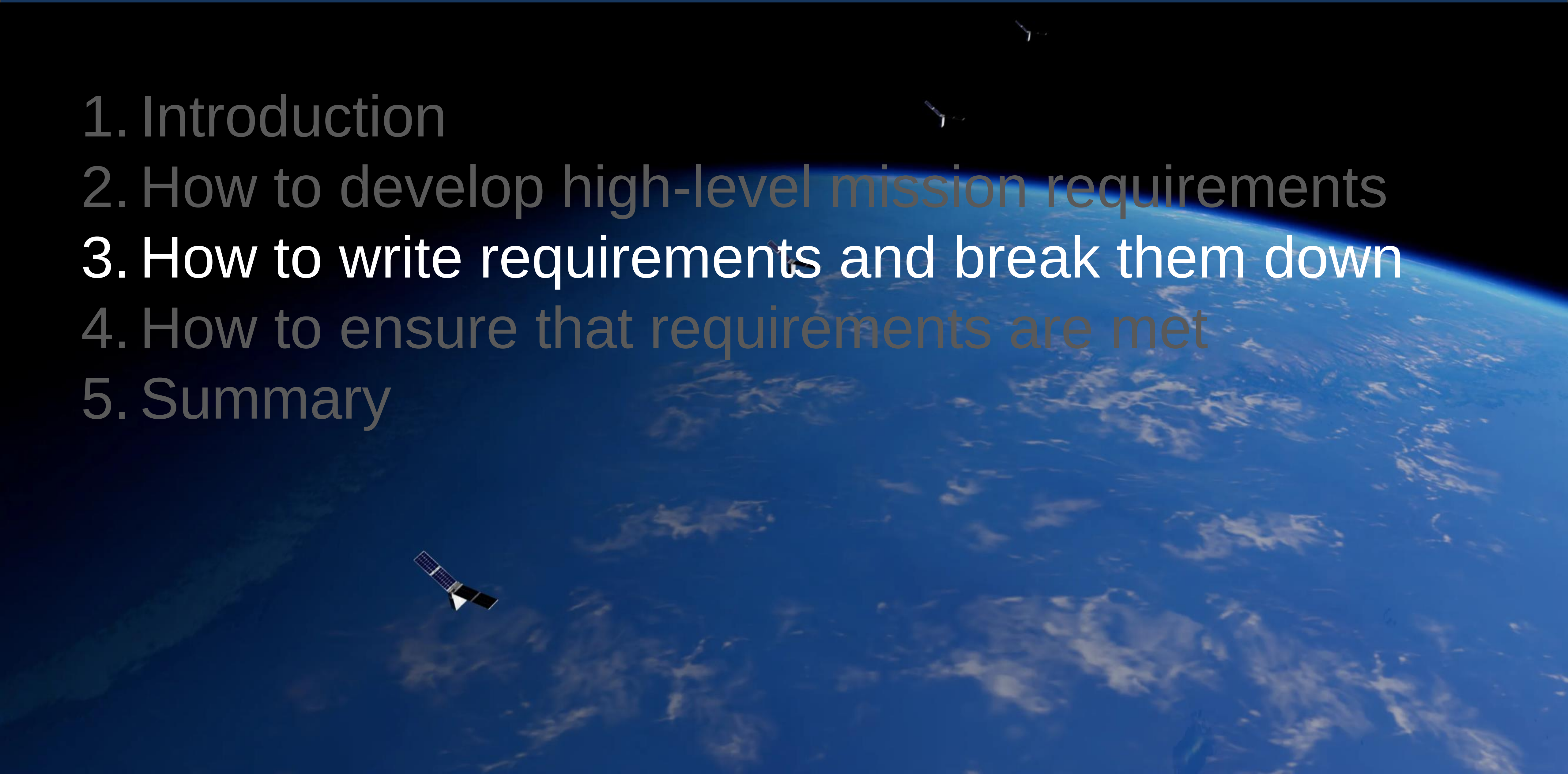
Source: Adapted from Chartres, James & Fulsang, Ejner "Traceability in Science Proposals", NASA Ames Research Center, Mission Design Center ca. 2014

JPL’s Concept Maturity Level approach helps to develop *how* a mission accomplishes its goals



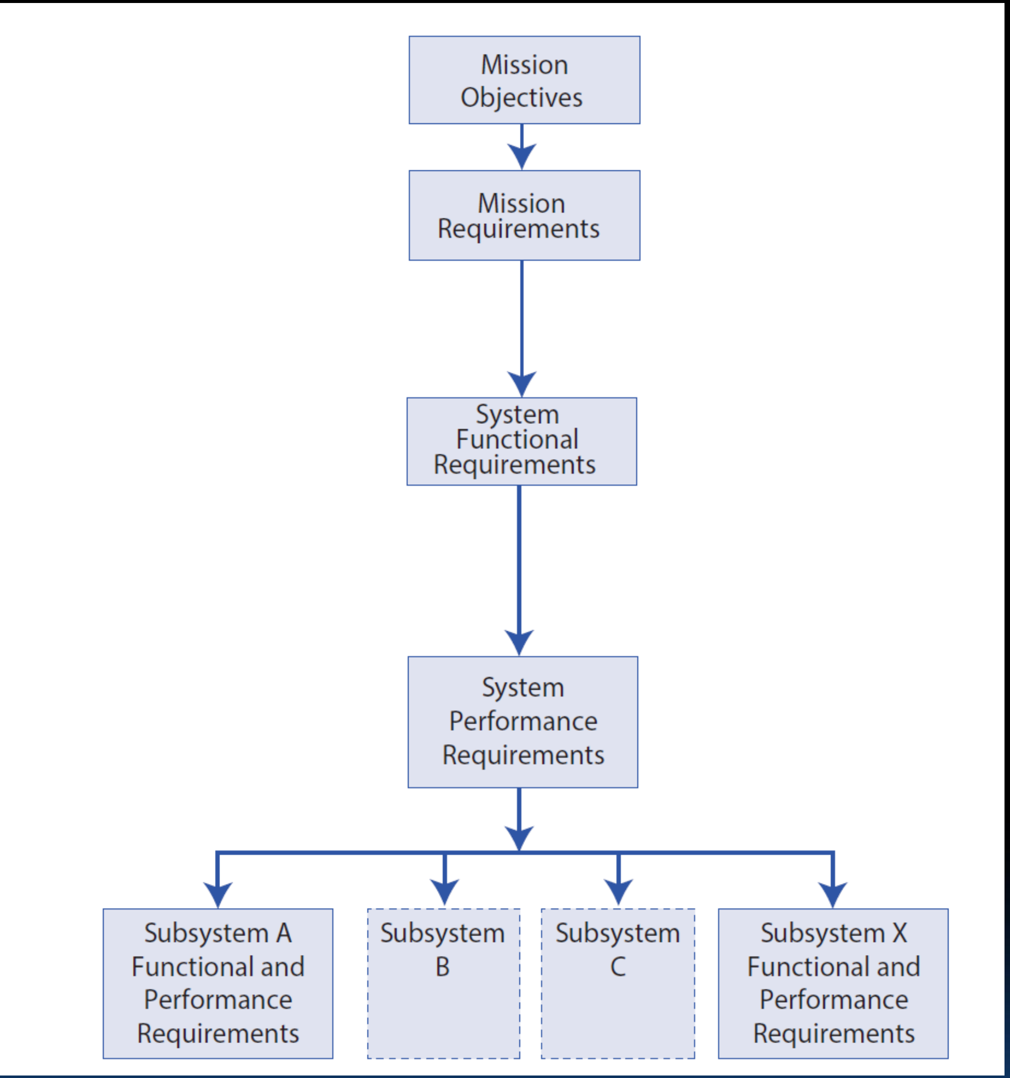
Source: Wessen, Randii et al., "Space mission concept development using concept maturity levels", AIAA SPACE 2013 Conference & Exposition, San Diego, California, September 10-12, 2013

Webinar Agenda



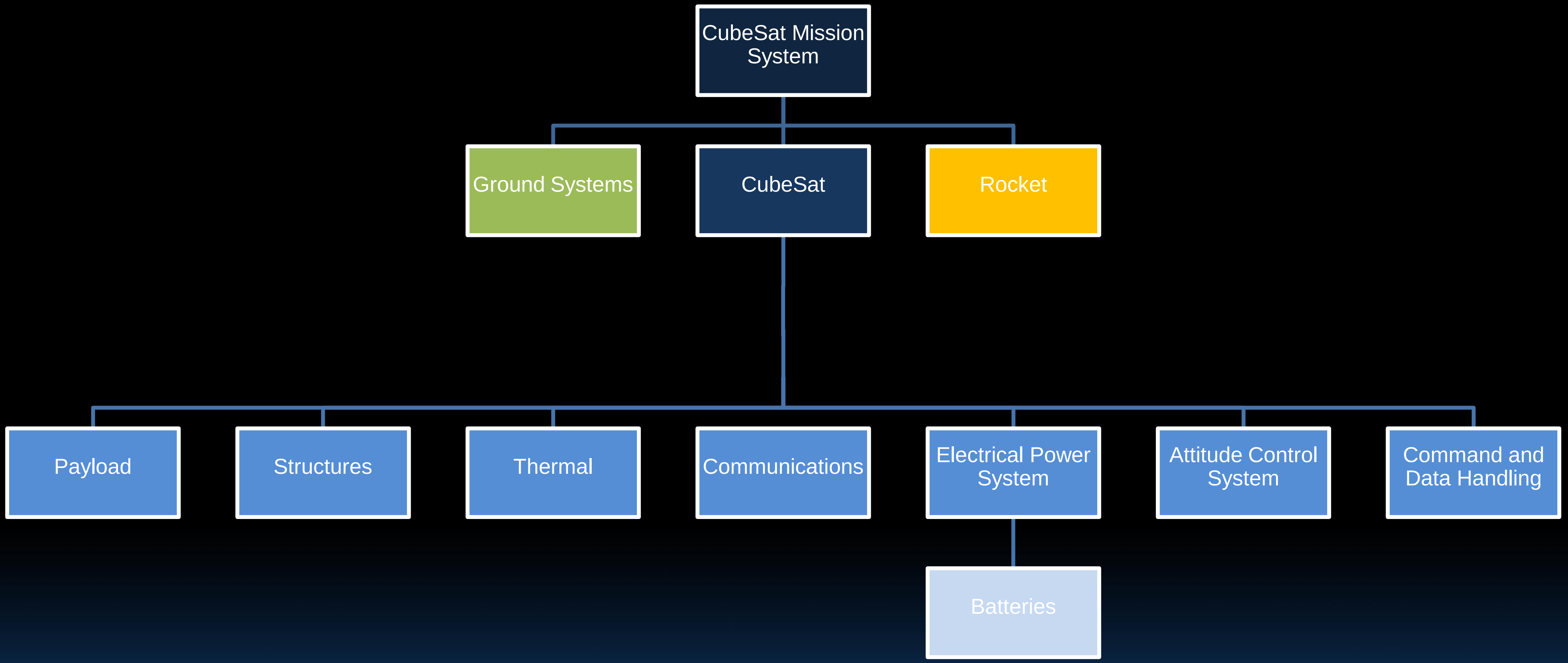
1. Introduction
2. How to develop high-level mission requirements
3. How to write requirements and break them down
4. How to ensure that requirements are met
5. Summary

Requirements decomposition breaks-down high-level requirements into more specific child requirements



Source: NASA Systems Engineering Handbook (simplified)

Requirements decomposition breaks-down high-level requirements into more specific child requirements – CubeSat Mission Example



There are common stylistic guidelines for writing requirements

Requirements should:

- Be in the form “responsible party/system shall perform such and such.”
- Mention what 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

Questions to help write requirements that are technically sound

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 constrains solutions for the current level of design

Use Case – Pen Requirements (1/3)

- First step is to define the purpose of the pen: to apply ink to a surface, usually paper, for writing or drawing
- After we know the main purpose, we can define the design requirements.
  - First, we will think about the functional requirements and then consider the aesthetics and additional considerations
- **Functional requirement considerations**
  - **Dimensions** – length and thickness
    - Length - not too long, that can fit inside a standard pencil case. Not too short – that will be comfortable to hold and use
    - Thickness – not too thick that will be comfortable to hold and use, not too thin that will not brake easily
  - **Grip** – Material and texture should be comfortable to hold for extended writing sessions
  - **Ink Type** – This could be ballpoint, gel, rollerball, fountain pen, etc. Each has pros and cons like ink flow, drying time, and refill ability
  - **Ink Color** – Standard blue or black, or maybe a multi-colored pen, or color with glitter etc.
  - **Tip Size** – Fine point for detailed writing, or broader for smoother lines
  - **Refillable** – Eco-friendlier and more cost-effective over time
  - **Cover or Retractable** – Consider convenience and potential for ink leakage
  - **Durability** - The pen should withstand everyday use and carrying around

Use Case – Pen Requirements (2/3)

- **Aesthetics requirement considerations**
  - **Material** – Plastic, metal, wood, or even recycled materials. Consider weight, durability, and desired look
  - **Color of the pen itself** – Solid colors, patterns, or even customizable options
  - **Finish** – Matte, glossy, metallic, etc. can impact how the pen feels and looks
  - **Clip (if applicable)** – For easy attachment to pockets or notebooks
  - **Target Audience** – Students, professionals, artists? Design elements can cater to specific preferences
- **Additional considerations**
  - **Ink Cartridge Availability** – Refillable pens need readily available refills
  - **Cost** – Balancing functionality and aesthetics with a target price point
  - **Innovation (optional)** – Unique features like stylus functionality, built-in laser pointer, a special eraser for the pen, a marker, build in paper, another tip size or a particularly smooth writing experience
- To complete the requirement definitions in this example case – we need to quantify values and units as applicable, and make informed choices as to the material/ color/ ink type etc.

Use Case – Pen Requirements (3/3)

- Example for pen requirements
  - Pen shall have overall dimensions of 15 +/- 0.1 cm in length
  - Pen shall have a thickness of 0.55 +/-0.05cm.
  - Pen shall have a ballpoint ink type.
  - Pen shall have a black ink type.
  - Pen shall have a tip size of 0.7 mm +/- 0.1 mm .
  - Pen shall be able to refill the ink.
  - Pen shall have a retractable mechanism.
  - Pen shall have a durability of no less than five years, if used according to ISO PEN-1.
  - Pen shall have a total mass of 1.5 g +/- 0.2 g .
  - Pen shall be transparent with a green spiral around the pen (from tip to tip).
  - Pen shall have a matte finish.
  - Pen shall have a clip.
  - Pen shall cost less than $2 each.

Use Case – Pen Requirements (3/3)

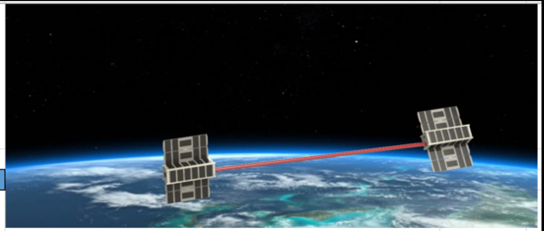
- Example for pen requirements
  - Pen shall have overall dimensions of 15 +/- 0.1 cm in length and a thickness of 0.55 cm.
  - Pen shall have a ballpoint ink type.
  - Pen shall have a black ink type.
  - Pen shall have a tip size of 0.7 mm +/- 0.1 mm .
  - Pen shall be able to refill the ink.
  - Pen shall have a retractable mechanism.
  - Pen shall have a durability of no less than five years, if used according to ISO PEN-1.
  - Pen shall have a total mass of 1.5 g +/- 0.2 g .
  - ~~Pen shall be transparent with a green spiral around the pen (from tip to tip).~~
  - Pen shall have a green spiral around the pen (from tip to tip).
  - Pen shall be transparent.
  - Pen shall have a matte finish.
  - Pen shall have a clip.
  - Pen shall cost less than $2 each.

Use Case – Pen Requirements (3/3)

- Example for pen requirements
  - Pen shall have overall dimensions of 15 +/- 0.1 cm in length and a thickness of 0.55 cm.
  - Pen shall have a ballpoint ink type.
  - Pen shall have a black ink type.
  - Pen shall have a tip size of 0.7 mm +/- 0.1 mm .
  - Pen shall be able to refill the ink.
  - Pen shall have a retractable mechanism.
  - Pen shall have a durability of no less than five years, if used according to ISO PEN-1.
  - Pen shall have a total mass of 1.5 g +/- 0.2 g .
  - ~~Pen shall be transparent with a green spiral around the pen (from tip to tip).~~
  - Pen shall have a green spiral around the pen (from tip to tip).
  - Pen shall be transparent.
  - ~~Pen shall have a matte finish~~.
  - Pen shall have a clip.
  - Pen shall cost less than $2 each.

Example: Requirements for a CubeSat

CLICK Requirements Verification Matrix (RVM) V3



Document Owners: P. Serra, P. Grenfell

Objective Statement

Advance state of the art in free space optical communications by demonstrating the feasibility of lasercom crosslinks between nanosatellites using miniaturized optical transceivers.

Note for Engineering: The payload shall be designed to meet baseline requirements with sufficient margin. These specifications shall be

Change Log

22-Oct-17	Version 1.0. Initial RVM for CLICK SRR.	A. Crews
7-Nov-17	Version 1.1. Updates from SRR.	A. Crews
23-Apr-17	Version 2.0. Updates for PDR.	A. Crews
13-Sept-18	Version 2.1 Updates for NASA RFQ	A. Crews, P. Grenfell, P. Serra, R. Fitzgerald
1-July-21	Version 3.0 Re-Organization for CDR	P. Grenfell
28-Sept-21	Version 3.1 Re-Organization for CDR	P. Grenfell, Jan Stupl

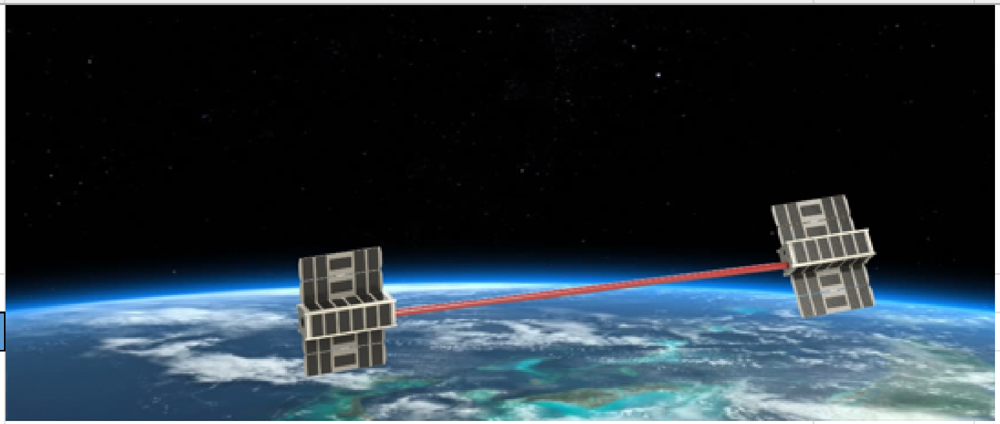
RQMT ID	Requirement	NOTES / RATIONALE
1	**Mission Level Requirements**	
1.1	The CLICK satellites shall demonstrate an optical communications crosslink at a data rate of at least 20 Mbps at 580 km with a BER better than 1e^-4 without error correction code.	Threshold: 20 Mbps is achieved at range of at least 230 km. **Baseline: 20 Mbps is achieved at range of at least 580 km.** Extended: 20 Mbps is achieved at range of at least 855 km.
1.2	The CLICK satellites shall demonstrate a minimum crosslink range of 25 km or less.	Threshold: Minimum crosslink range of 38 km or less. **Baseline: Minimum crosslink range of 25 km or less.** Extended: Minimum crosslink range of 10 km or less.
1.3	The CLICK satellites shall demonstrate an optical downlink from a LEO reference orbit to a ground station.	Threshold: Data rate is 10 Mbps for 30 cm ground station aperture. **Baseline: Data rate is 20 Mbps for 30 cm ground station aperture.** Extended: Data rate is 50 Mbps for 30 cm ground station aperture.
1.4	The CLICK satellites shall demonstrate the ability to operate a full duplex crosslink.	Threshold: Half-duplex crosslink. **Baseline/Extended: Full-duplex crosslink.**
1.5	The CLICK satellites shall have a mission lifetime of at least 6 months	Threshold: Mission lifetime of at least 3 months. **Baseline: Mission lifetime of at least 6 months.** Extended: Mission lifetime of at least 12 months.
1.6	The CLICK satellites shall have the ability to control inter-satellite range.	Threshold:Intersatellite range from less than 38 km to greater than 230 km. **Baseline: Intersatellite range from less than 25 km to greater than 580 km.** Extended: Intersatellite range from less than 10 km to greater than 855 km.
1.7	The CLICK satellites shall maintain the optical crosslink for at least 5 minutes.	Threshold: Maintain crosslink for at least 10 seconds. **Baseline: Maintain crosslink for at least 5 minutes.** Extended: Maintain crosslink for at least 10 minutes.
1.8	The CLICK satallites shall demonstrate precision ranging at 0.5 m without using GPS at a range of 580 km.	Threshold: Precision ranging at 5 m and range of 230 km. **Baseline: Precision ranging at 0.5 m and range of 580 km.** Extended: Precision ranging at 5 cm and range of 855 km.

Mission - L1 | Project - L2 | Payload- L3 | Ground Station - L3 | Mission Ops - L3 | Bus - L3

CubeSat Laser Infrared CrosslinK (CLICK) Mission
Credit: NASA

Example: Requirements for a CubeSat

CLICK Requirements Verification Matrix (RVM) V3



Document Owners: P. Serra, P. Grenfell

Objective Statement

Advance state of the art in free space optical communications by demonstrating the feasibility of lasercom crosslinks between nanosatellites using miniaturized optical transceivers.

Note for Engineering: The payload shall be designed to meet baseline requirements with sufficient margin. These specifications shall be

Change Log

22-Oct-17	Version 1.0. Initial RVM for CLICK SRR.	A. Crews
7-Nov-17	Version 1.1. Updates from SRR.	A. Crews
23-Apr-17	Version 2.0. Updates for PDR.	A. Crews
13-Sept-18	Version 2.1 Updates for NASA RFQ	A. Crews, P. Grenfell, P. Serra, R. Fitzgerald
1-July-21	Version 3.0 Re-Organization for CDR	P. Grenfell
28-Sept-21	Version 3.1 Re-Organization for CDR	P. Grenfell, Jan Stupl

RQMT ID	Requirement	NOTES / RATIONALE
1	**Mission Level Requirements**	
1.1	The CLICK satellites shall demonstrate an optical communications crosslink at a data rate of at least 20 Mbps at 580 km with a BER better than 1e^-4 without error correction code.	Threshold: 20 Mbps is achieved at range of at least 230 km. **Baseline: 20 Mbps is achieved at range of at least 580 km.** Extended: 20 Mbps is achieved at range of at least 855 km.
1.2	The CLICK satellites shall demonstrate a minimum crosslink range of 25 km or less.	Threshold: Minimum crosslink range of 38 km or less. **Baseline: Minimum crosslink range of 25 km or less.** Extended: Minimum crosslink range of 10 km or less.

Example: Requirements for a CubeSat

2	REQUIREMENT	NOTES / RATIONALE
2	**Project Requirements**	
2.1	The CLICK satellites shall have orbit determination capability to support crosslink acquisition.	REQ 1.1. Link Budget Document
2.2	The CLICK satellites shall have an optical transmitter capable of closing the link budget at the required ranges.	REQ 1.1. Link Budget Document
2.3	The CLICK satellites shall have an optical receiver capable of closing the link budget at the required ranges.	REQ 1.1. Link Budget Document
2.4	The CLICK satellites shall have pointing, acquisition, and tracking (PAT) capabilities	REQ 1.1. Link Budget Document
2.5	The CLICK satellites sensors shall be functional with the receive power at the minimum crosslink range.	REQ 1.2. Link Budget Document
2.6	The CLICK satellites shall be able to acquire and track each other at the minimum crosslink range.	REQ 1.2. Link Budget Document
2.7	The CLICK satellites shall be able to point at and track the ground station from a LEO reference orbit.	REQ 1.3. Link Budget Document
2.8	The CLICK satellites shall be able to close the link budget to the ground station.	REQ 1.3. Link Budget Document
2.9	The CLICK satellites shall have transmit and receive signals that are distinguishable and do not interfere with each	REQ 1.4. Definition of full-duplex.
2.10	The CLICK satellites shall be capable of transmitting and receiving signals simultaneously.	REQ 1.4. Definition of full-duplex.
2.11	The CLICK satellites' initial mean orbit altitude shall be sufficient in order to enable operations for at least 6 months.	REQ 1.5. Lifetime
2.12	The CLICK satellites shall be able to survive all conditions in the reference orbital environment for the mission lifetime.	REQ 1.5. Lifetime
2.13	The CLICK satellites shall be able to initiate a relative drift rate of at least 4 km/day.	REQ 1.6. Allows satellites to achieve goal separation distance
2.14	The CLICK satellites shall be able to maintain average relative drift rate within +/-4 km/day.	REQ 1.6. Provides a wide enough margin to allow for slow drag
2.15	The CLICK satellites shall provide power to operate the payload over the duration of the optical crosslink.	REQ 1.7. Duration of crosslink affects power requirements.
2.16	The CLICK satellites shall store and downlink statistical data from the crosslink experiment.	REQ 1.7. Duration of crosslink affects data requirements.
2.17	The CLICK satellites shall maintain pointing accuracy during the duration of the optical crosslink	REQ 1.7. Pointing accuracy needs to be maintained during crosslink. See Link Budget Document
2.18	The CLICK spacecraft shall be able to use an existing RF ground station.	REQ 1.1. Project
2.19	The CLICK spacecraft shall be able to use the MIT-PorTeL optical ground station.	REQ 1.3. Project
2.20	The CLICK spacecraft shall be able to close an RF crosslink.	REQ 1.1. Link Budget Document.
2.21	The CLICK mission shall have a mission operations center.	REQ 1.1, 1.3. Project
2.22	The CLICK payloads shall not exceed 96 mm x 96 mm x 150 mm in volume and 1700 g in mass	Comply with programmatic constraints.
2.23	The CLICK satellites shall be designed to withstand the prelaunch and launch environments and comply with	Comply with programmatic constraints.
2.24	The CLICK spacecraft shall comply with the deployer requirements.	Comply with programmatic constraints.
2.25	The CLICK spacecraft shall comply with cleanliness standards and safety responsibility.	Comply with programmatic constraints.
2.26	The CLICK spacecraft shall be designed for EMC and for mitigation of EMI, specifically susceptibility to launch vehicle and range radiation environments.	Comply with programmatic constraints.
2.27	The CLICK spacecraft shall have a safe disposal sequence in order to deorbit within 25 years from the conclusion of the spacecraft mission.	Comply with programmatic constraints.
2.28	The CLICK spacecraft shall comply with applicable external laser regulations.	Comply with external constraints.
2.29	The CLICK satellites shall have an average ram area less than the maximum average ram area able to achieve a six-month orbital lifetime from the minimum-altitude reference orbit.	REQ 1.5. Lifetime
2.30	The CLICK satellites shall be deployed into orbit with an along-track velocity difference small enough to enable	REQ 1.1.
2.31	The CLICK satellites shall be capable of holding attitude along velocity vector to within +/- 5 degrees during drift.	REQ 1.6.
2.32	The CLICK satellites shall start in an orbit with an osculating eccentricity at most 0.003.	is the highest eccentricity that would not drop the perigee of the orbit below the minimum starting altitude of 375 km, and thus unacceptably shorten the life of the satellites.

Example: Requirements for a CubeSat

RQMT ID	REQUIREMENT	Rationale/Comment
6	**Flight System Requirements**	
6.1	**S/C - general**	
6.1.1	The CLICK S/C shall support at least 6 months mission lifetime in a 400 - 600 km altitude Low Earth Orbit with an inclination greater than 34 degrees.	Requirement for S/C survival. Altitudes to support mission lifetime & deorbit. Inclination to support MIT Portel ground station.
6.1.2	The CLICK S/C shall be in a 3U form factor.	Follow CubeSat design standards as managed by California Polytechnic State University definitions. Program was selected for one 3U CSLI launch.
6.1.3	The CLICK S/C shall support a payload as described in the CLICK Payload to S/C ICD.	Document A9SP-1803-XR003 of the RFQ package.
6.1.4	The CLICK S/C shall have a configurable deployment timer of up to 1 hour in duration that can be set before integration into the deployer.	Timer will initialize S/C after deployment. It prevents RF transmissions, initialize operations. Duration could be as long as 1 hour. Exact time to be determined by launch services provider.
6.1.5	The CLICK S/C shall comply with NASA requirements for battery safety "CREWED SPACE VEHICLE BATTERY SAFETY REQUIREMENTS - JSC-20793 Rev D" or equivalent as needed for launch provider.	CLICK is currently planning to launch with NanoRacks post ISS boost (CLICK A) and a government launch (CLICK B & C).
6.5.10	The CLICK S/C center of mass shall be compliant with standard CubeSat deployment systems.	common dispenser requirement
6.5.11	No CLICK S/C components or structure, other than rails or rail roller/slider switch (if used), shall contact the dispenser interior.	<May change depending on dispenser>
6.5.12	CLICK S/C rail surfaces that contact the dispenser guide rails shall have a hardness equal to or greater than hard anodized aluminum (Rockwell C 65-70).	<May change depending on dispenser>

When developing requirements, keep in mind that they drive the whole project

- Describe what needs to be done
- Drive schedule and cost
- Tell us what we need to test to ensure the product performs as planned

→ Communication with stakeholders is key!

Definitions: Stakeholders and Customers

Definitions from NPR 7123.1C NASA Systems Engineering Processes and Requirements

- **Stakeholder**: A group or individual who is affected by or has an interest or stake in a program or project.

- **Customer**: The organization or individual that has requested a product and will receive the product to be delivered. The customer may be an end user of the product, the acquiring agent for the end user, or the requestor of the work products from a technical effort. Each product within the system hierarchy has a customer.

Webinar Agenda

1. Introduction
2. How to develop high-level mission requirements
3. How to write requirements and break them down
4. How to ensure that requirements are met
5. Summary

While you verify that you meet requirements, also validate that the customer is happy!

- **Verification** of a product shows proof of compliance with requirements—that the product can meet each “shall” statement as proven though performance of a test, analysis, inspection, or demonstration (or combination of these).

- **Validation** of a product shows that the product accomplishes the intended purpose in the intended environment—that it meets the expectations of the customer and other stakeholders as shown through performance of a test, analysis, inspection, or demonstration.

Source: NASA Systems Engineering Handbook

For each requirement, plan how you want to verify it

- **Analysis:** Use of mathematical model or analytical technique to verify a requirement
- **Demonstration:** Basic confirmation of performance capability, without detailed data gathering
- **Inspection:** Visual examination of end product, or records
- **Test:** Detailed data gathering to verify performance

Ideally: Test as you fly, and fly as you test. (if you can afford it)

REQUIREMENT	TRACEABILITY	ALLOCATION	Verification			
			T	D	A	I
Flight System Requirements						
Spacecraft - general						
CLICK spacecraft shall be in a 3U form factor.		S/C				
CLICK spacecraft shall support a payload as described in the payload to s/c ICD.		S/C				
CLICK spacecraft shall have a configurable deployment timer of up to 1 hour in duration that can be set		S/C				

For each requirement, plan how you want to verify it

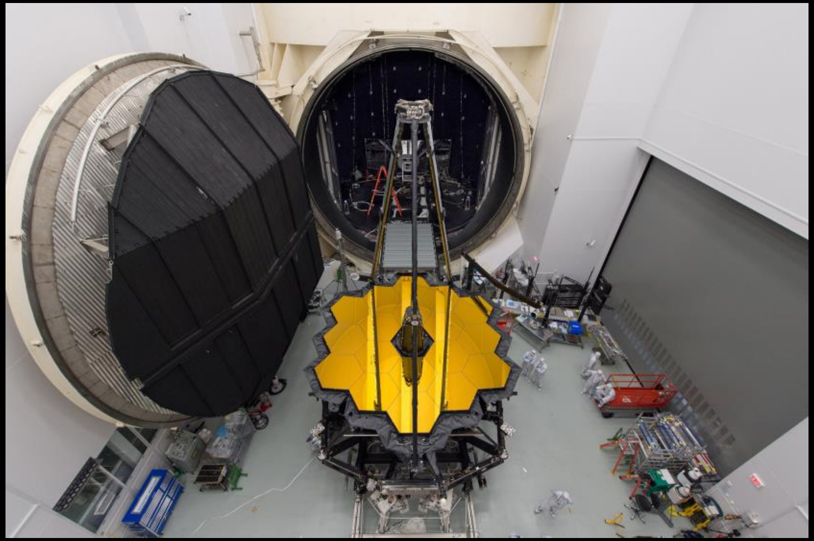
TABLE D-1 Requirements Verification Matrix

Requirement No.	Document	Paragraph	Shall Statement	Verification Success Criteria	Verification Method	Facility or Lab	Phase[a]	Acceptance Requirement?	Preflight Acceptance?	Performing Organization	Results
Unique identifier or each requirement	*Document number the requirement is contained within*	*Paragraph number of the requirement*	*Text (within reason) of the requirement, i.e., the "shall"*	*Success criteria for the requirement*	*Verification method for the requirement (analysis, inspection, demonstration, test)*	*Facility or laboratory used to perform the verification and validation.*	*Phase in which the verification and validation will be performed.*	*Indicate whether this requirement is also verified during initial acceptance testing of each unit.*	*Indicate whether this requirement is also verified during any pre-flight or recurring acceptance testing of each unit*	*Organization responsible for performing the verification*	*Indicate documents that contain the objective evidence that requirement was satisfied*
P-1	xxx	3.2.1.1 Capability: Support Uplinked Data (LDR)	System X shall provide a max. ground-to-station uplink of…	1. System X locks to forward link at the min and max data rate tolerances 2. System X locks to the forward link at the min and max operating frequency tolerances	Test	xxx	5	Yes	No	xxx	TPS xxxx
P-i	xxx	Other paragraphs	Other "shalls" in PTRS	Other criteria	xxx	xxx	xxx	Yes/No	Yes/No	xxx	Memo xxx
S-i or other unique designator	xxxxx (other specs, ICDs, etc.)	Other paragraphs	Other "shalls" in specs, ICDs, etc.	Other criteria	xxx	xxx	xxx	Yes/No	Yes/No	xxx	Report xxx

[a] Phases defined as: (1) Pre-Declared Development, (2) Formal Box-Level Functional, (3) Formal Box-Level Environmental, (4) Formal System-Level Environmental, (5) Formal System-Level Functional, (6) Formal End-to-End Functional, (7) Integrated Vehicle Functional, (8) On-Orbit Functional.

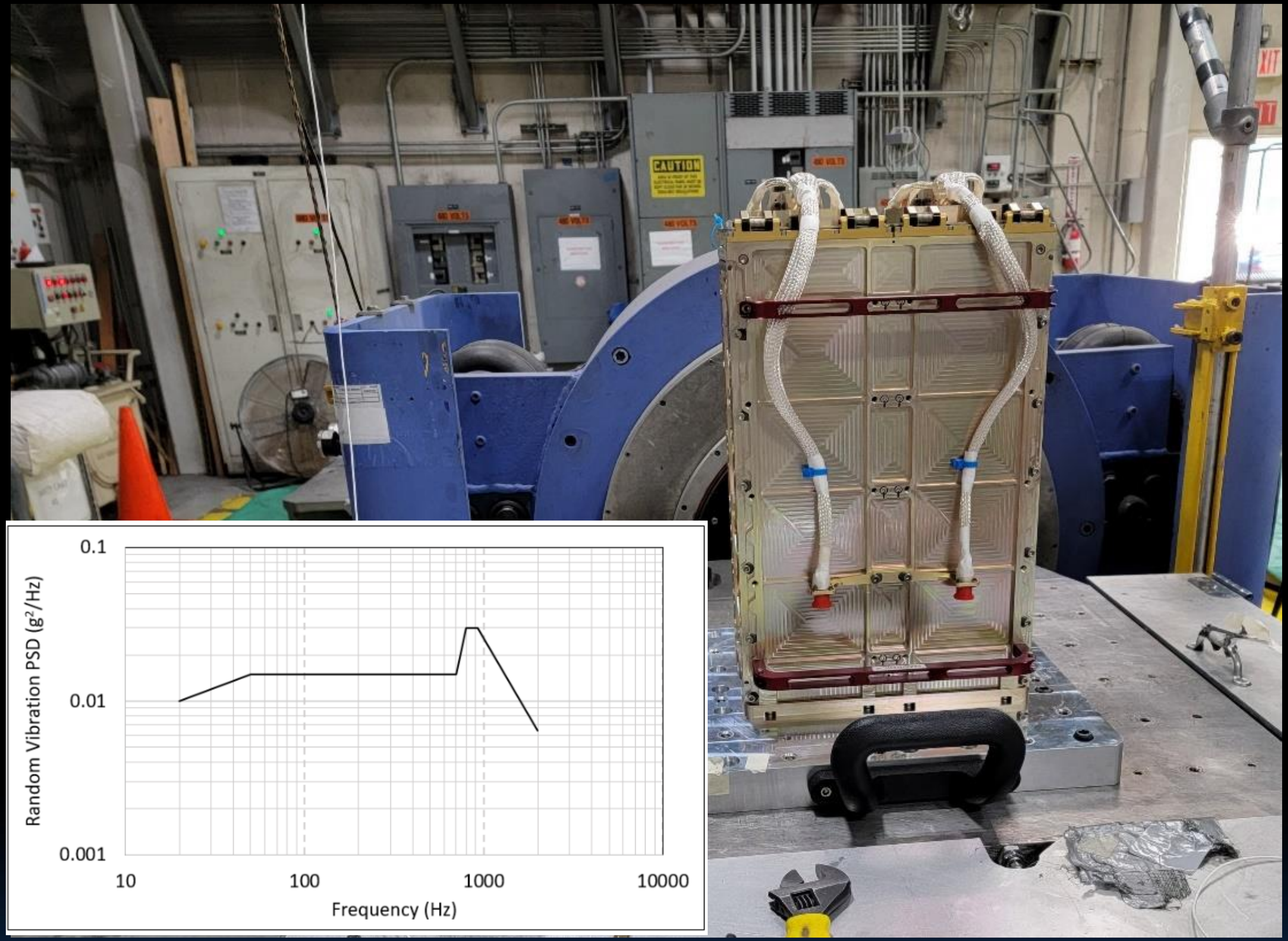
Source: NASA Systems Engineering Handbook

Design your test plan to what you need



Thermal vacuum testing of the James Webb Space Telescope at NASA Johnson Space Center
Source: NASA – D. Stover
https://www.esa.int/ESA_Multimedia/Images/2017/11/Testing_Webb

Minimum environmental testing:
What your rocket needs,
i.e. Rideshare Payload User's Guide.
Envelope of launchers:
GSFC-STD-7000A
(General Env. Verf. Standard GEVS)



Random vibration test of 4 x 1.5U CubeSats.
Shown in Maverick Space 6U deployer on vibration table at Quanta Laboratories, Santa Clara, CA

Webinar Agenda

1. Introduction
2. How to develop high-level mission requirements
3. How to write requirements and break them down
4. How to ensure that requirements are met
5. Summary

Summary

- Requirements help to build good products.
- Mission design tools like the Science Traceability Matrix, Concept Maturity Level approach, and the SMAD mission design approach help develop high level requirements.
- Systematic Requirements decomposition ensures that requirements are developed to the lowest useful level.
- There are several levels of requirement verification. Testing is the most comprehensive and involved one.

References

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/

Wessen, Randii R. et al., "Space mission concept development using concept maturity levels" https://hdl.handle.net/2014/44299 AIAA SPACE 2013 Conference & Exposition, San Diego, California, September 10-12, 2013, JPL Open Repository

Feldman, Sabrina, “The Science Traceability Matrix”, NASA PI Launchpad Workshop, November 18, 2019, NASA Jet Propulsion Laboratory, https://smd-cms.nasa.gov/wp-content/uploads/2023/04/Launchpad_Session3_STM_18Nov2019_smf_final.pdf

References

Wertz, James et al., “Space Mission Engineering: The New SMAD”, Microcosm Press; First Edition (July 29, 2011)

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

Upcoming Sessions

- Session 2: **Project Lifecycle Reviews,**
  Wednesday 27 November 2024, from 5:00pm to 6:30pm (CET)

- Session 3: **Model Based Systems Engineering (MBSE)**,
  Wednesday 22 January 2025, from 5:00pm to 6:30pm (CET)

- Session 4: **Design and Develop Science Missions**
  Wednesday 28 February 2025, from 5:00pm to 6:30pm (CET)

Upcoming Webinar: Project Lifecycle Reviews

This webinar will dissect project lifecycle review elements and discuss their importance to project management. This overview includes:

- What are the elements of project life cycle phases?
- Which elements are required for each phase?
- What are the key milestones for the various phases?
- How is it determined to transition to the next phase?
- How does systems engineering and project management play a role in the different phases?

Purpose:
To provide attendees with information and knowledge of the project lifecycle reviews elements and how they relate to project management.

Questions?

www.nasa.gov/smallsat-institute/