Systems Engineering Part 2

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AFRL/RV

Agenda

- Review
- Where are we?
- Transitioning from System Concept Review (SCR) to System Requirements Review (SRR)
- A note on UNP “constraints/guidelines”
- What is a requirement?
- Importance of effective requirements definition
- How do we track and document requirements?
- How do you do “Requirements Definition”?
- Examples
- Want to learn more?

References

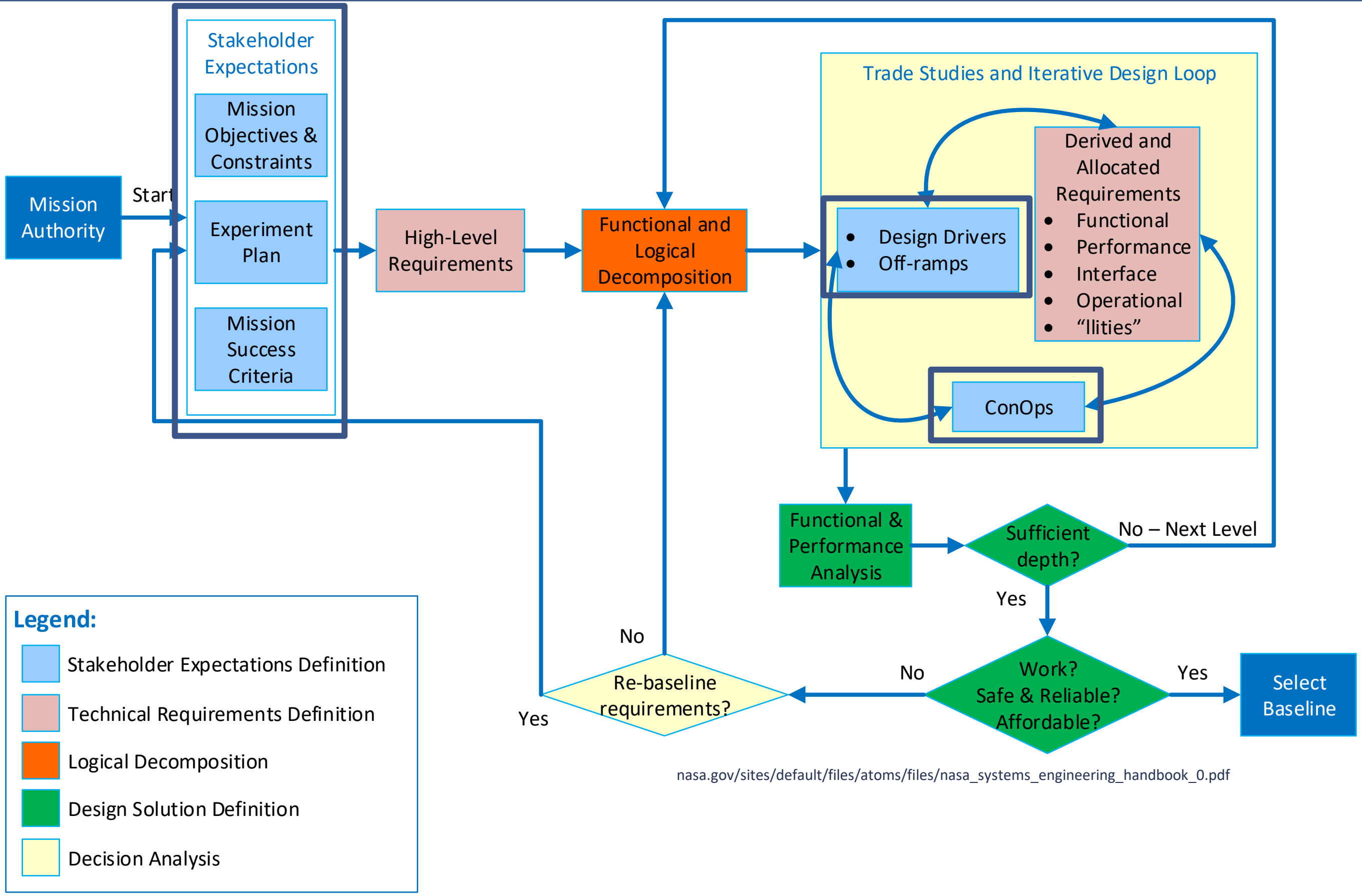
- Significant credit to Sam Baxendale, author of the NS-10 Systems Engineering EAT series from which this heavily drew. Also references:

  - “UNP NS-11 User’s Guide”, AFRL/RV, 2022
  - “Applied Space Systems Engineering”, Larson/Kirkpatrick/Sellers/Thomas/Verma, 2009
  - “Space Mission Engineering”, Wertz/Everett/Puschell, 2011
  - “The NASA Systems Engineering Handbook”, NASA, 2007
  - “INCOSE Systems Engineering Handbook”, INCOSE, 2010
  - “Michigan Tech MEPIV Lecture: An Introduction to Systems Engineering”, King, 2019
  - “UNP NS9 EAT: Systems Engineering”, Straight, 2016
  - “UNP NS9 EAT: Requirements”, MP, 2016
  - “ISO/IEC 15288 IEEE Systems Engineering Standard”, IEEE, 2015
  - “ECSS-E-10A European Systems Engineering Standard”, ESA, 2018

Review

- **Mission Statement:** "A multiple sentence statement of the entire mission's purpose, usually focusing on the scientific or technological goals of the mission. Can be viewed as the mission's elevator pitch."
- **Mission Objectives:** "Broad statements of what the mission must do to be useful."
- **Mission Success Criteria:** "While Mission Objectives state 'what the mission must do', Mission Success Criteria state 'how well the mission must do it'. Can be thought of as a mission's pass/fail criteria; all minimum success criteria must be met to 'pass' the mission."
- **Mission Overview:** "An expression of the intent of the mission. Shall include the mission statement, objectives, and success criteria."
- **CONOPS:** "The process and procedure by which the fully developed systems will fulfill the mission. It is more broadly a document describing the characteristics of the proposed systems from the viewpoint of individuals who will use the systems. This document should comprehensively cover the entire mission's lifetime, not just the experiment."
- **Experiment Plan:** "A discussion of the experiments that will be performed."
- **CONOPS vs. Experiment Plan:** "The Experiment Plan describes what data and final results are necessary to answer the fundamental science/technology question(s) of the mission. The CONOPS addresses how that data is obtained/downlinked and when it occurs on the mission timeline."
- **Constraint:** "A condition, outside of the mission authority's control, that must be met."
- **Design Driver:** "An element of the mission that, in order to be accomplished, forces the rest of the design/operation to morph and accommodate to that element. Design Drivers are often abstract interpretations of specific constraints and requirements that have significant impacts on the design/operation of systems. Design Drivers may not be formally tracked, but should be actively understood and addressed."
- **Off-Ramp:** "Identified alternatives to accomplish the mission."
- **Stakeholder:** "A stakeholder is any person or organization who will be impacted by the mission at any phase in the life cycle. Stakeholders could already be identified or be parties seen to benefit from a mission's data. Merely stating AFRL as a customer does not adequately capture who the customer is. A name, office, or a program would be examples of a particular customer at AFRL. The UNP PMO does not qualify as a customer of a program's data."

Where are we?



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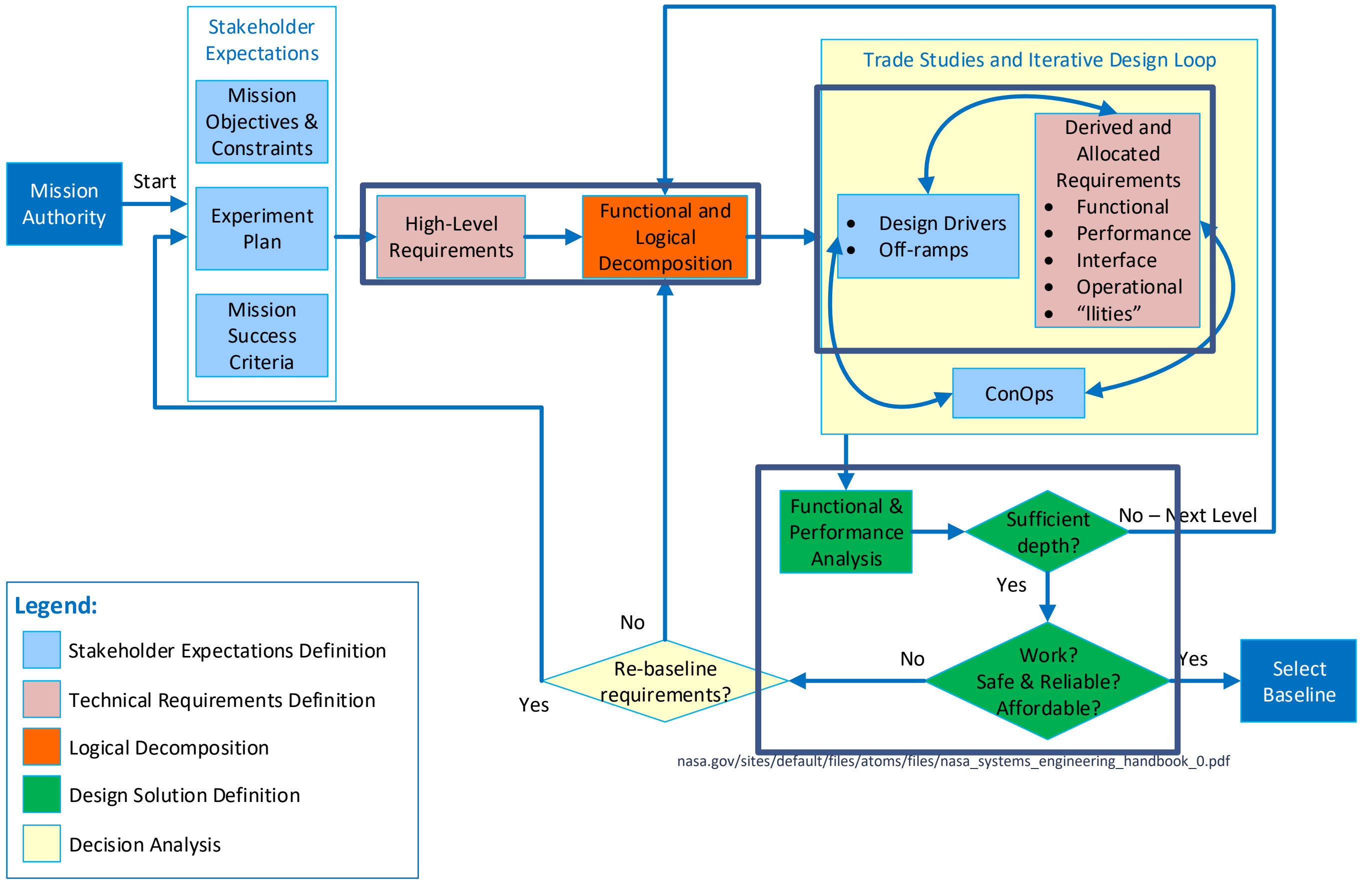
In preparation for SCR, teams hopefully cycled through this process at least once; with a focus on the circled areas

Where are we?

TBR = "To Be Resolved", <u>temporary</u> placeholder for quantitative figure of merit.

Note: TBRs are acceptable for SCR, but teams should strive to eliminate most TBRs by SRR



In preparation for SCR, some assumptions and TBRs were likely made in the circled areas

Where are we?

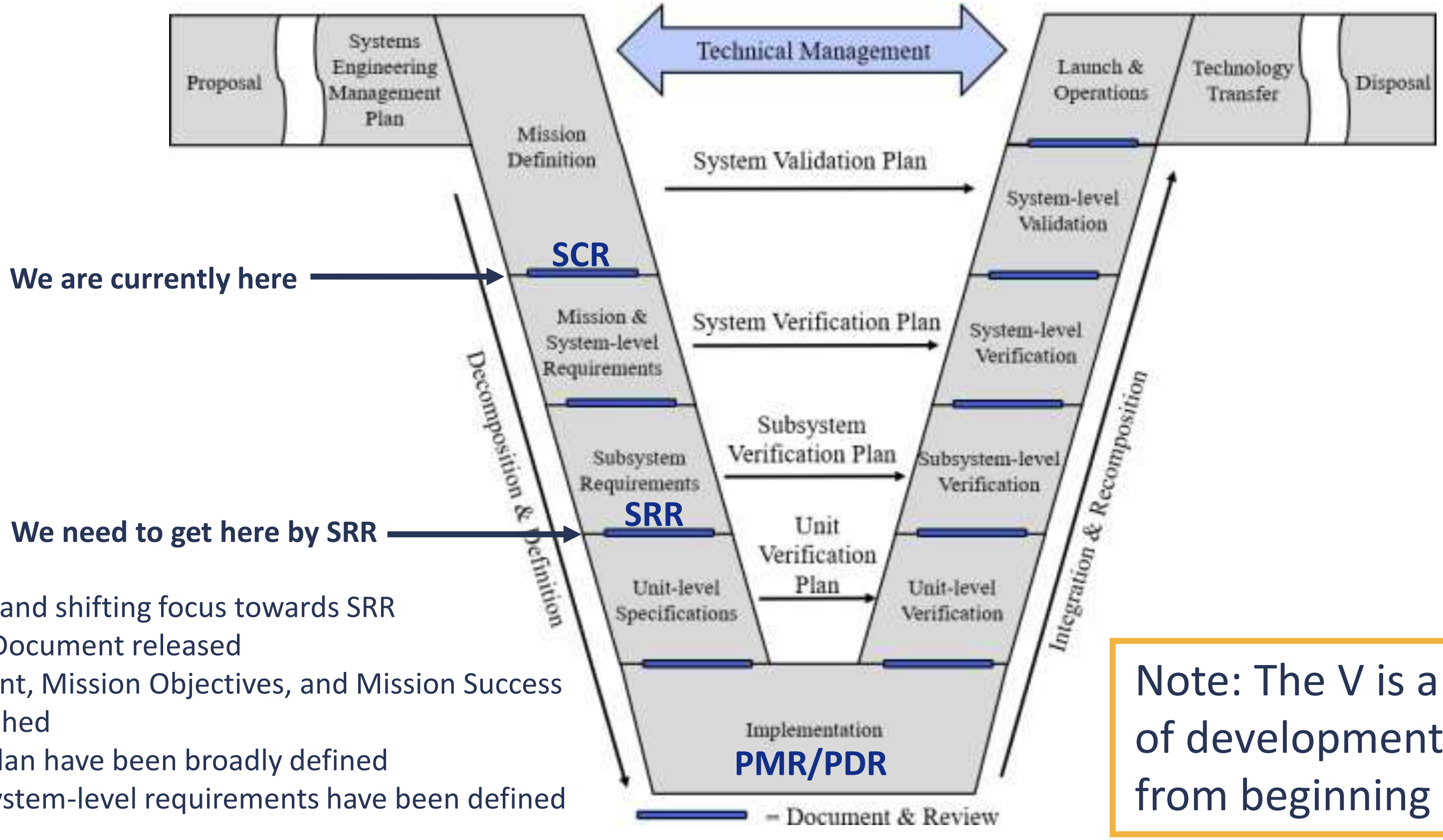
UNP

Mission Design Document

- **Mission Overview** ← Mission Statement, Objectives, and Success Criteria
- **Experiment Plan** ← What data and final results are necessary to answer the fundamental science/technology question(s) of the mission
- **CONOPS** ← How the data will be obtained/downlinked and when that occurs on the mission timeline

By SCR, we ideally have a solid first revision of the Mission Design Document

Where are we?



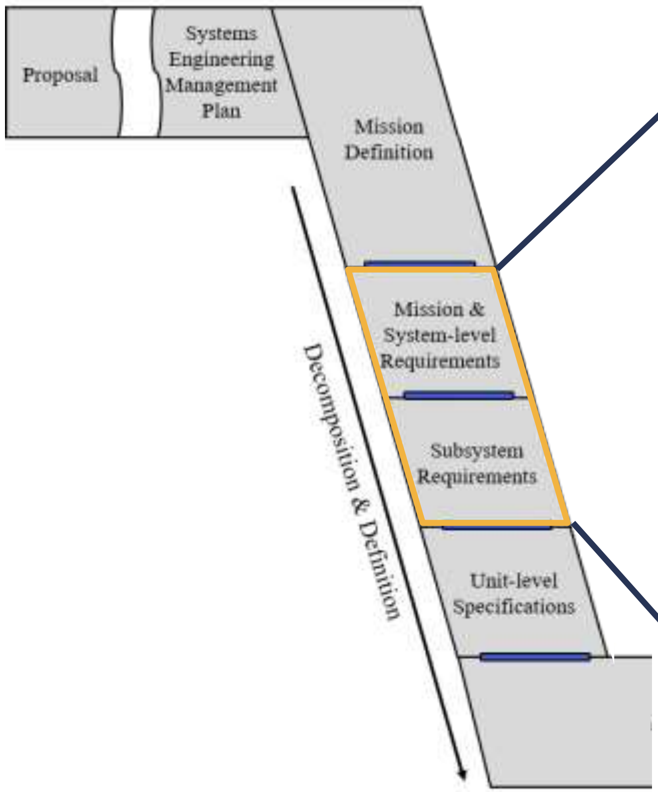
Assumptions:

- Teams will soon be through SCR and shifting focus towards SRR
- First revision of Mission Design Document released
  - A set of Mission Statement, Mission Objectives, and Mission Success Criteria has been established
  - CONOPS & Experiment Plan have been broadly defined
- Perhaps some Mission and/or System-level requirements have been defined

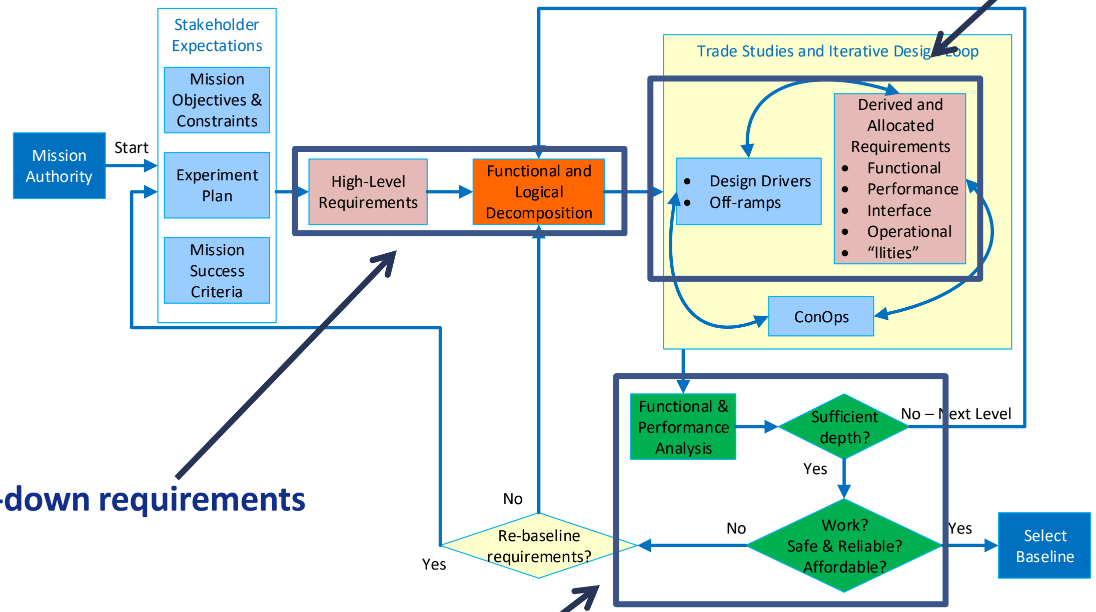
Note: The V is a “waterfall” model of development (i.e. linear flow from beginning to end)

By SCR, you have started to define “how to build the right system?” (validation)
But what about defining “how to build the system right?”(verification). That is what SRR is for…

Transitioning from SCR to SRR



Define the RVM and continuously mature the Mission Design Doc



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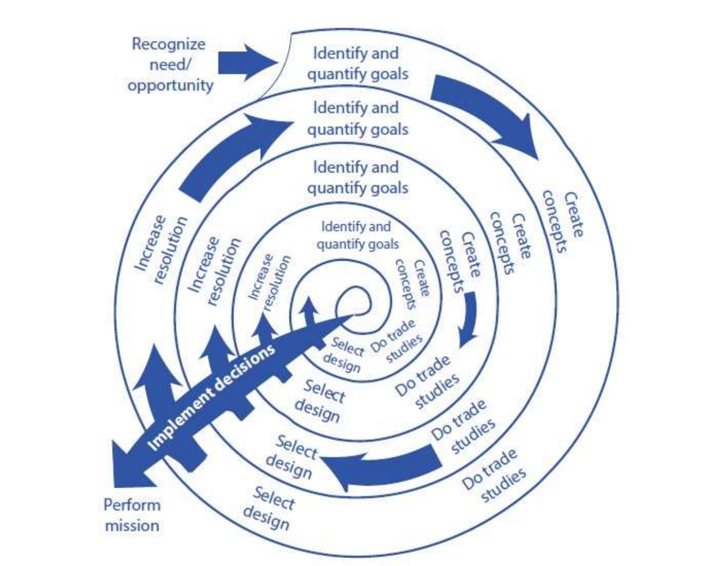
Flow-down requirements

- **System budgets (link, power/energy, mass, data, etc.)**
- **Modeling & simulation**
- **Prototyping (if applicable)**

In preparation for SRR, continue cycling through this process; now with a focus on the highlighted areas
Note: remember to continue maturing your Mission Design Doc throughout the process

Transitioning from SCR to SRR



The spiral model is a more accurate portrayal of this process as opposed to the classic waterfall model

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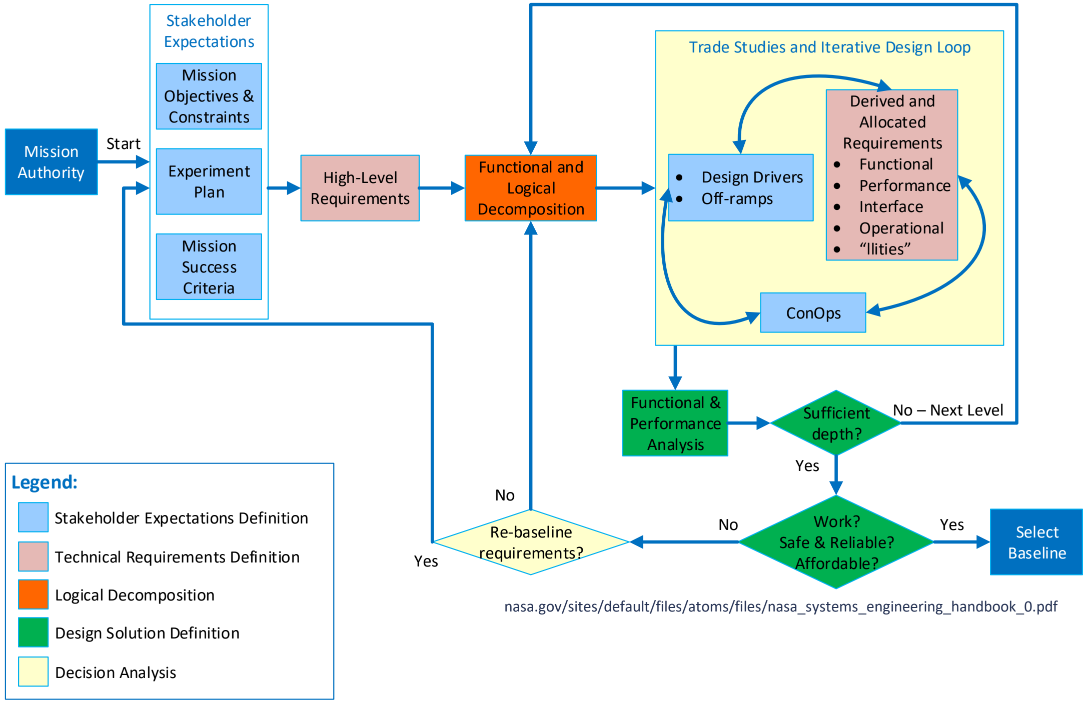

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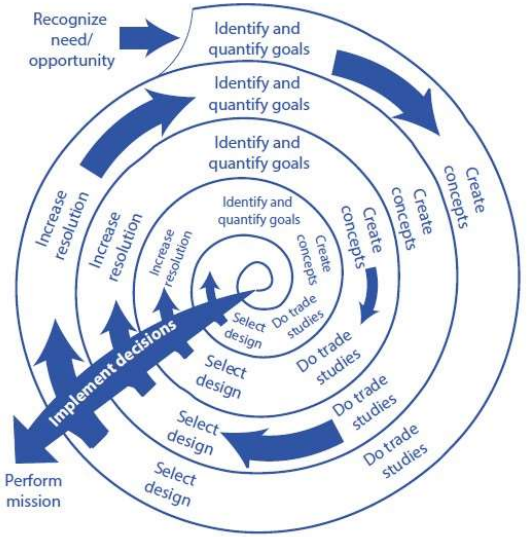
In preparation for SRR, you should have a solid baseline, meaning you can choose "no" to re-baselining each cycle. For SRR, the focus should be on repeatedly iterating through the right-side of this diagram for each level of mission hierarchy (i.e. mission, system, and subsystem-level)

When are you done?

Teams should aim to have their requirements defined down to the subsystem-level by SRR

Transitioning from SCR to SRR



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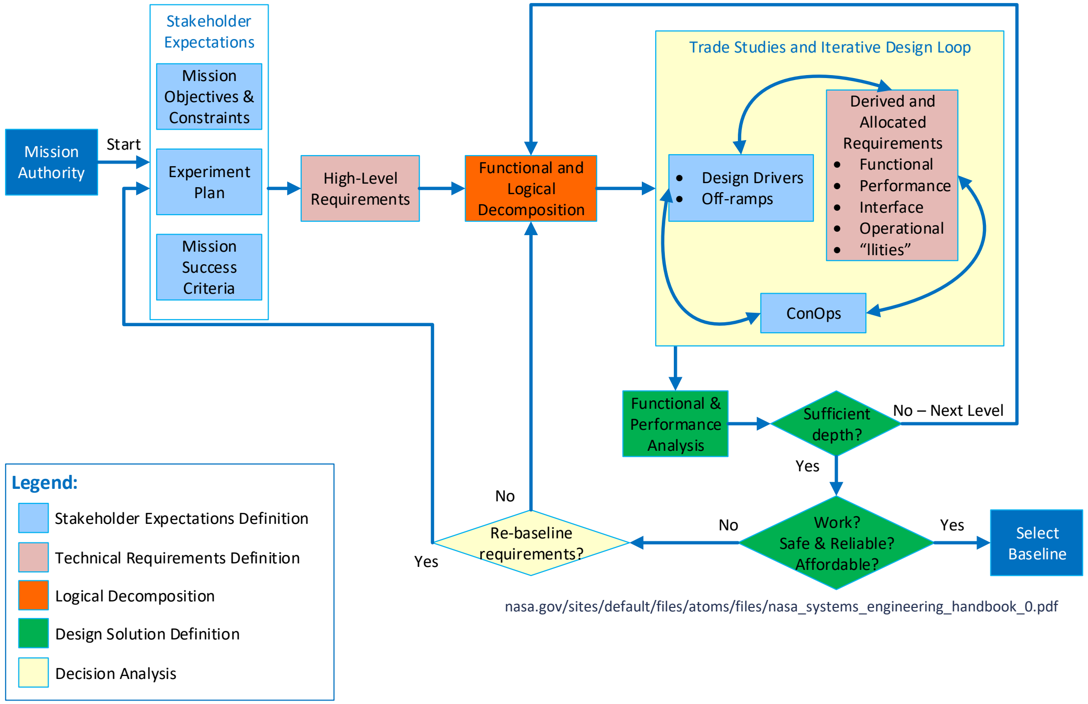

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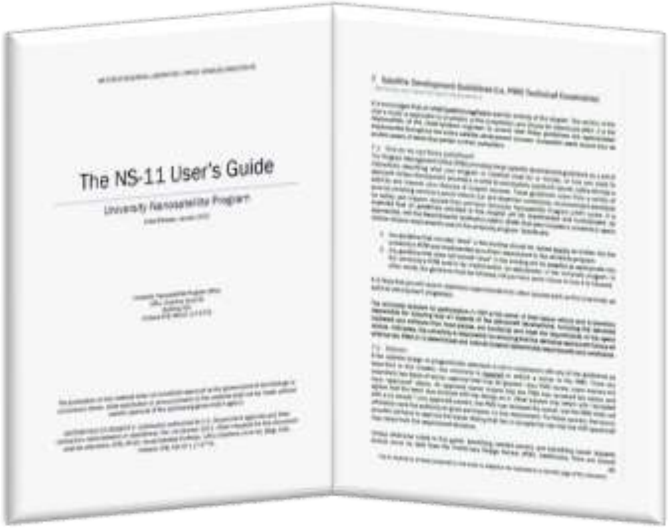
What does this even mean?

When are you done?

Teams should aim to have their requirements defined down to the subsystem-level by SRR

UNP Constraints and Guidelines



The UNP User Guide is full of constraints/guidelines critical to the Requirements Definition process. Much of this content should appear in your RVM verbatim (anything using the word "shall" must be copied exactly into your RVM). Here are examples of both possible situations:

- UNP-3: "The CubeSat **shall** be designed to meet the selected dispenser specifications and requirements."
- UNP-21: "All primary structure fasteners **should** be #4 or larger."

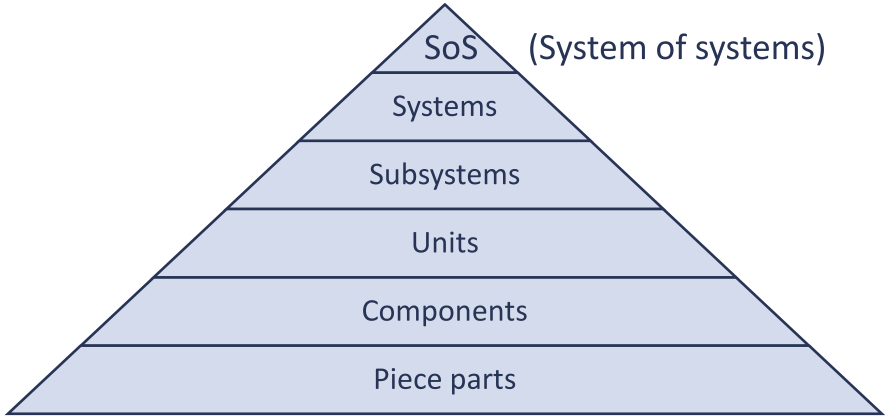
Read, interpret, and implement all content in Chapter 7 in preparation for SRR

What is a Requirement?

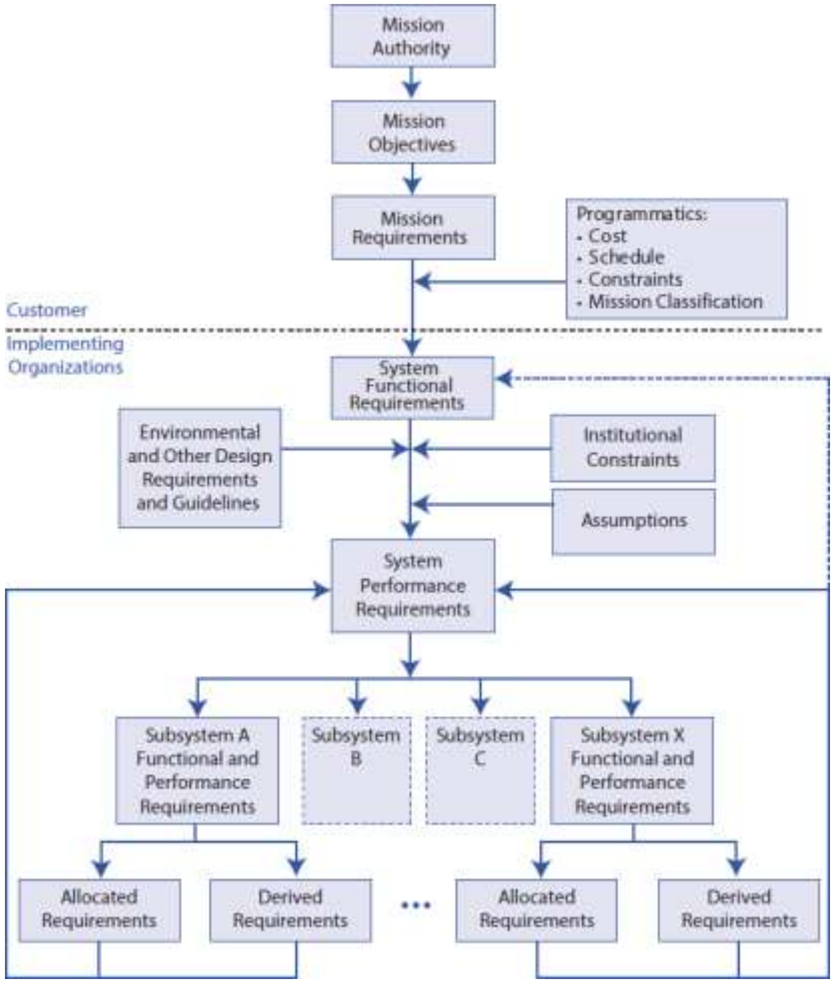
[Mission/system/subsystem] **shall** [perform some action] [in some quantifiable, measurable manner]

- "The communication link between stakeholders, the developer/designer, and the integrator/tester to ensure we build the *system right*." [ASSE]
- "A condition or capability necessary to achieve a mission objective" [BSE]
- **Must be verifiable, preferably quantitatively (do not use words such as "sufficient", "enough", "easy", "fast", "flexible", etc.) – always ask "how can we verify this requirement?"**
- Almost always utilizes the verb "shall" (not "will", "might", "maybe", etc.
  - Shall = it is required and must be verified
  - Will = it is required, but does not need to be verified
  - Should = it is recommended but not required
- Must be achievable – must reflect a need for which a solution is reasonably available
- Must be unambiguous – it can only have one possible meaning
- Must be consistent with other requirements
- Must be expressed in terms of a need, not in terms of a solution
- Be necessary – always ask "what would happen if we left this requirement out?"

What is a Requirement?



- A requirement must be appropriate for the level of system hierarchy (e.g. Mission-level vs. System-level) – a typical hierarchy decomposition for UNP small satellite missions is as follows:
  - **Mission:** includes the space system(s) and ground system(s) (some teams put their payload/science requirements at this level)
  - **System:** the spacecraft, GSE, ground station, etc.
  - **Subsystem:** ADCS, EPS, CDH, etc.
  - **Unit:** torque rod, battery, EPS regulation PCB, reaction wheel, etc. (UNP does not usually write requirements at this level)
  - **Component/Part:** resistor, capacitor, connector (UNP does not usually write requirements at this level)



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What is a Requirement

There are a few different flavors of requirements

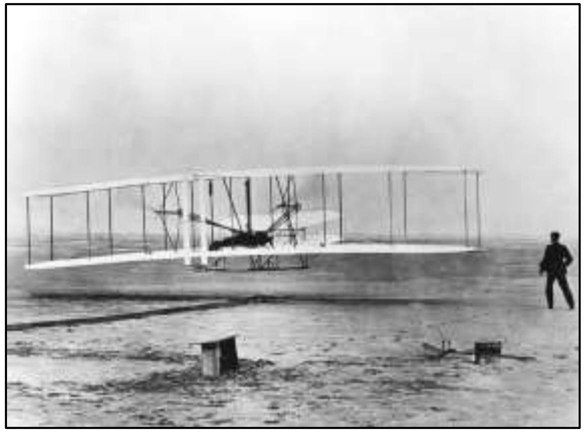
- **Functional:** what does the mission/system/subsystem need to do
- **Performance**: how well does the mission/system/subsystem need to do it
- **Operational:** how must the mission/system/subsystem be utilized in meeting requirements/objectives
- **Interface:** defines how the mission/system/subsystem will interface with other missions/systems/subsystems
- **"ilities"**
  - Operability: can the mission/system/subsystem actually be used?
  - Availability: what frequency and duration should the mission/system/subsystem operate?
  - Sustainability: how will the mission/system/subsystem be maintained on ground and in-flight?
  - Reliability: piece parts but can be expanded to worst-case analyses, failure probability
  - Survivability: environmental and other drivers to system

leonardodavinci.net

britannica.com/technology/ornithopter

Physical decomposition

- Brain, eyes, legs, wings
- Da Vinci and other early dreamers of flight extensively studied and mimicked the composition of birds. All of their inventions were impractical and failed.



kids.nationalgeographic.com/history/article/wright-brothers

Functional/Operational decomposition

- Takeoff, thrust, lift, navigation, landing, etc.
- The Wright Brothers understood thrust and lift, in addition to other functional/performance requirements for flight, thus resulting in their success

What is a Requirement?

Beware of:

- "Gold-Plated Requirements"
  - **Rationale:** A stakeholder has directed that all battery voltage telemetry downlinked from the spacecraft be "very accurate". The mission developer has concluded that, although this is not necessary in meeting mission objectives/success criteria, they will heed to the stakeholder's directive
  - **The resulting requirement:** Spacecraft battery telemetry shall be measured to within 20 significant digits
  - **Why this is bad:** The difference between 20 or 5 significant digits for a battery voltage measurement likely does not add any value to the mission. The technical effort necessary to achieve such a measurement is tremendous and unnecessary
- "The Good Idea Fairy"
  - Always remember to separate requirements from desires. Requirements are for defining a need, not to describe enhancements or nice- to-have features.
  - Remember that every requirement adds programmatic burden (cost, schedule, personnel, etc.)
- Conflicting Requirements
  - Typically occurs in an over-constrained system
  - **Example:** thrust, mass, and speed needs are defined in separate requirements, but taken together they describe an impossible flight trajectory
- "Compounded Requirements"
  - Each requirement must reflect only a single requirement – as opposed to multiple requirements in a single statement or a statement that contains both requirement and rationale

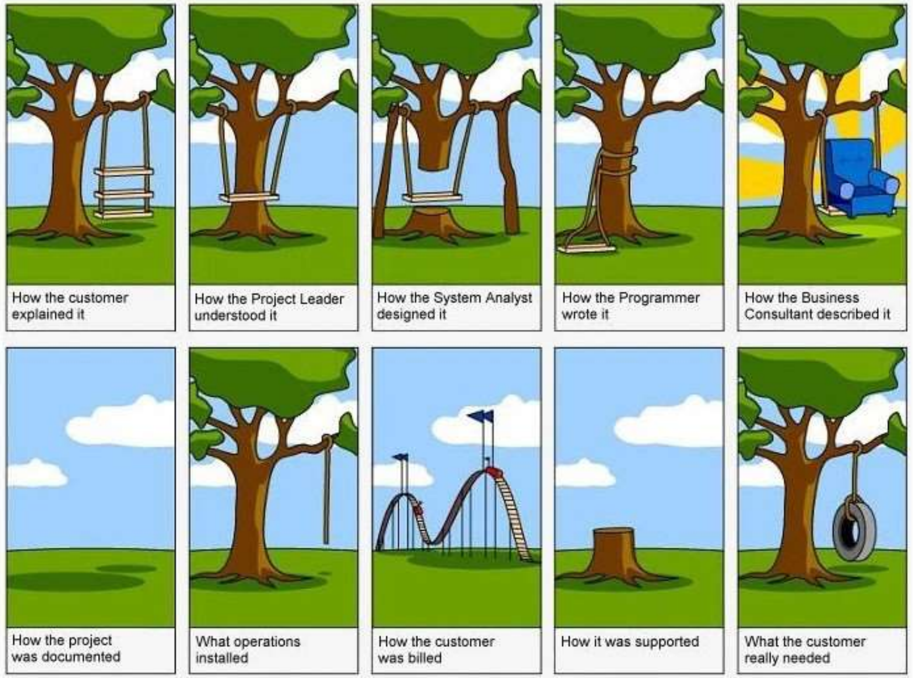
What is a Requirement?

A way to validate requirements is using the VALID method.

- *Validated Requirements* are:
  - well-formed (clear and un-ambiguous)
  - complete (agrees with customer and stakeholder needs and expectations)
  - consistent (conflict free)
  - individually verifiable and traceable to a higher-level requirement or goal

Letter	Word	Definition	Notes
V	**Verifiable**	Possible to ascertain correctness of	Words like “excessive” “sufficient” “resistant” are not easily verifiable
A	**Achievable**	Possible to do	Likely require calculations, simulations, etc to ensure achievability
L	**Logical**	Reasonable, to be expected	Traceability between system and subsystem requirements
I	**Integral**	Necessary to the completeness of the whole	RVM should be all encompassing, nothing missing
D	**Definitive**	To clarify with a definitive statement	Unambiguous

Importance of Effective Requirements Definition



endigit.com/2019/1/how-create-requirements-document-and-nail-your-project

slideplayer.com/slide/6653912/

Poor definition and understanding of requirements may result in:

- Programmatic cost overruns (cost, personnel, schedule)
- Not developing the *system right* (your Mission Design Doc negotiates with stakeholders how to build the *right system*)
- And many more bad things…..

Requirement Tracking and Documentation

Classic Approach: **Requirements Verification Matrix (RVM)**

- THE formal method to document and track all requirements related to a mission
- Usually in Excel format
- Usually organized in a top to bottom flow down hierarchy (mission-level down to subsystem-level)
- How RVMs are organized are up to each team, but some basic critical elements must be present in all RVMs (see next few slides). They must always remain a LIVING document.

Requirements			Compliance			
Para. No.	Item	Requirement	Value	Margin	Compliant	Comments
4.0	Switch Module	The switch module shall switch a 3 volt supply on and off				
4.0.1	Volume	The size shall be 1 x 1 x .25 cm +/- 0.05 cm	0.95 x 0.98 x 0.27	(-.05 x -.02 x +.02)	Yes	
4.0.2	Mass	The mass shall be < 1 oz	0.96	0.04	Yes	
4.0.3	Power	Power dissapation in the on position shall be < 0.03 watts	0.029	0.001	Yes	Test conducted at 20 C
4.0.4	Postions	The switch shall have two postions; on and off	Yes		Yes	
4.0.5	On/Off Identification	The on and off positions shall be visible to an operator at 100 lumans light level		Yes	Yes	Demonstrated at 90 lumens
4.1.6	Contact Pressure	The force to make or break contact without switching shall be > 1.5 lb	1.9	0.4	Yes	Per test procedure TP 23.4
4.1.7	Off Resistance	The resistance in the off position shall be > 10E6 Ohms	1.65 x 10e6 at 35 C	5 e5 at 0 C .65 e5 at 35 C	Yes	
4.1.8	On Resistance	The resistance in the On position shall be < 0.1 Ohms	0.098 at 0 C 1.000 at 35 C	.002 at 0 C; 0 at 35 C	Yes	
4.1.9	Switching Force	The force to move the switch from either on or off shall be 1 +/- 0.1 lb	1.13	0.03	No	
4.1.10	Operability	The switch shall be operable by user wearing cotton gloves	Yes		Yes	Female Operator wearing jersey gloves

Example Only
Not representative of UNP expectations

themanagersguide.blogspot.com/2011/07/summarize-verification-results-in.html

Requirement Tracking and Documentation

	Requirement	Source	Verification Method	Verification Status	Verification Document
ADCS-3	The ADCS shall be capable of attitude control equal to or less than 1° per axis	COM-2	Analysis	Not Complete	ADCS-D-003

Every requirement in an RVM must have a source to track how it "flowed down":

- If it is later determined the requirement is bad, we can track if its source is the issue
- If the source is changed, we can easily track what requirements further down the flow will be affected
- If the requirement/constraint is sourced by the UNP User's Guide, just list the source as UNP User's Guide (or something similar, whatever works for your team)
- If the requirement/constraint side-loads your team (i.e. your team is restricted to only using an S-band COM subsystem for your spacecraft since all your university has is an S-band Ground Station), just list the source as "constraint" (a document to point to in special situations like this is helpful)

Requirement Tracking and Documentation

#	Requirement	Source	Verification Method	Verification Status	Verification Document
ADCS-3	The ADCS shall be capable of attitude control equal to or less than 1° per axis	COM-2	Analysis	Not Complete	ADCS-D-003

Every requirement in an RVM must at some point be verified:

- Proof you built the system right

Requirement Tracking and Documentation

#	Requirement	Source	Verification Method	Verification Status	Verification Document
ADCS-3	The ADCS shall be capable of attitude control equal to or less than 1° per axis	COM-2	Analysis	Not Complete	ADCS-D-003

Verification Method: How you plan to prove you've met the requirement.

TEST →	**CDH shall collect thermal telemetry at a rate equal to or less than 1 Hz.**
ANALYSIS →	**The ADCS shall be capable of attitude determination equal to or less than 1°/axis.**
INSPECTION →	**The satellite shall use copper wiring**

Requirement Tracking and Documentation

#	Requirement	Source	Verification Method	Verification Status	Verification Document
ADCS-3	The ADCS shall be capable of attitude control equal to or less than 1° per axis	COM-2	Analysis	Not Complete	ADCS-D-003

Every requirement in the RVM must have a means in which to track its status:

- How your team handles this is up to you, but keep it reasonably simple

Possible Statuses (not all-encompassing)
Not Designed
In Progress
Engineering-unit Verified
Flight-unit Verified

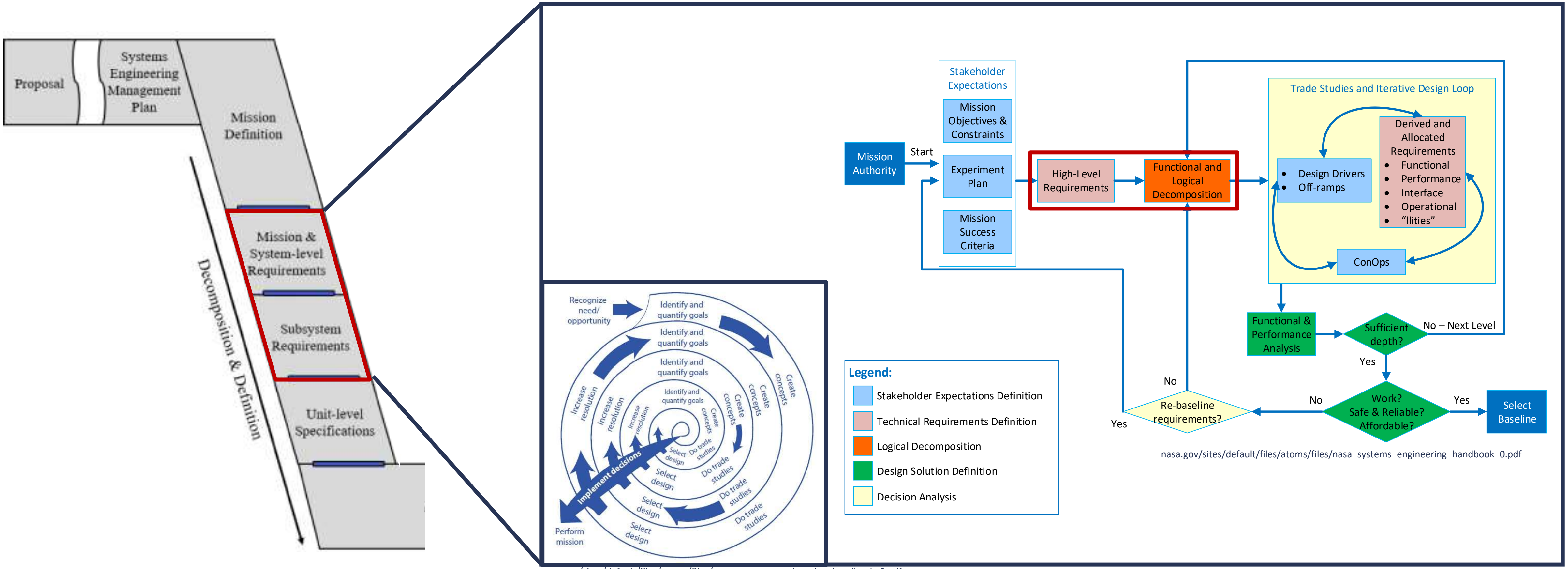
Requirement Tracking and Documentation

#	Requirement	Source	Verification Method	Verification Status	Verification Document
ADCS-3	The ADCS shall be capable of attitude control equal to or less than 1° per axis	COM-2	Analysis	Not Complete	ADCS-D-003

Every requirement in the RVM must have a document to prove its status:

- Always remember– “If it is not documented, it did not happen.”

High-Level Decomposition and Req. Definition



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Okay, so how do we actually do "Requirements Definition"?
I'll give some examples to get you started, but the best way to learn is to just do it!

A Simple Example

Start with the mission statement

Sputnik: Soviet Union shall develop the first artificial satellite

Develop mission objectives

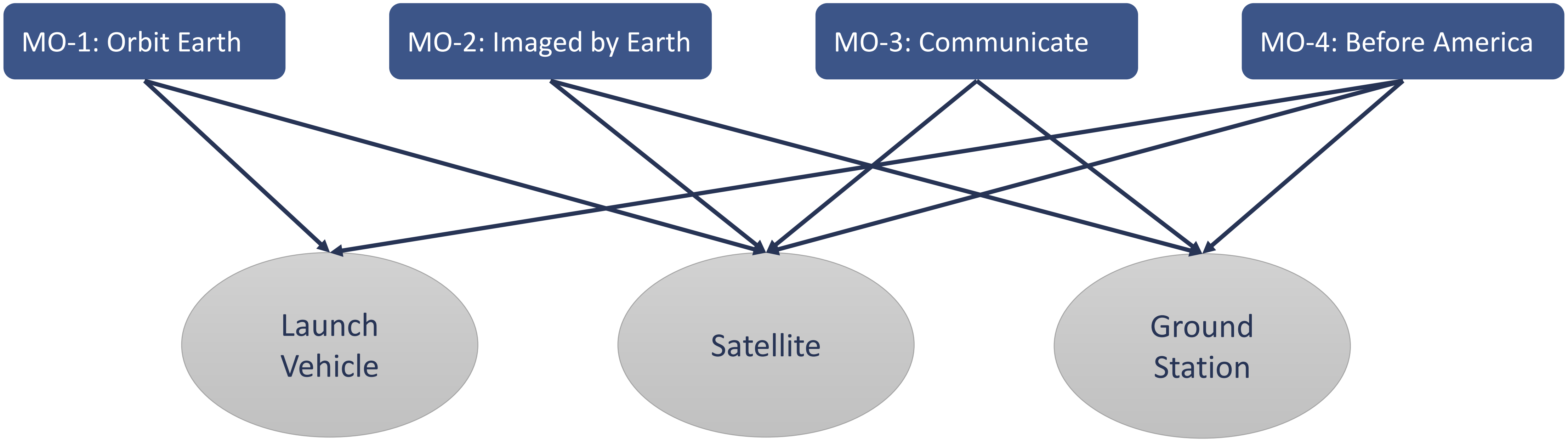
MO-1: Sputnik shall orbit the earth

MO-2: Sputnik shall communicate with the ground

MO-3: Sputnik shall be imaged by the ground

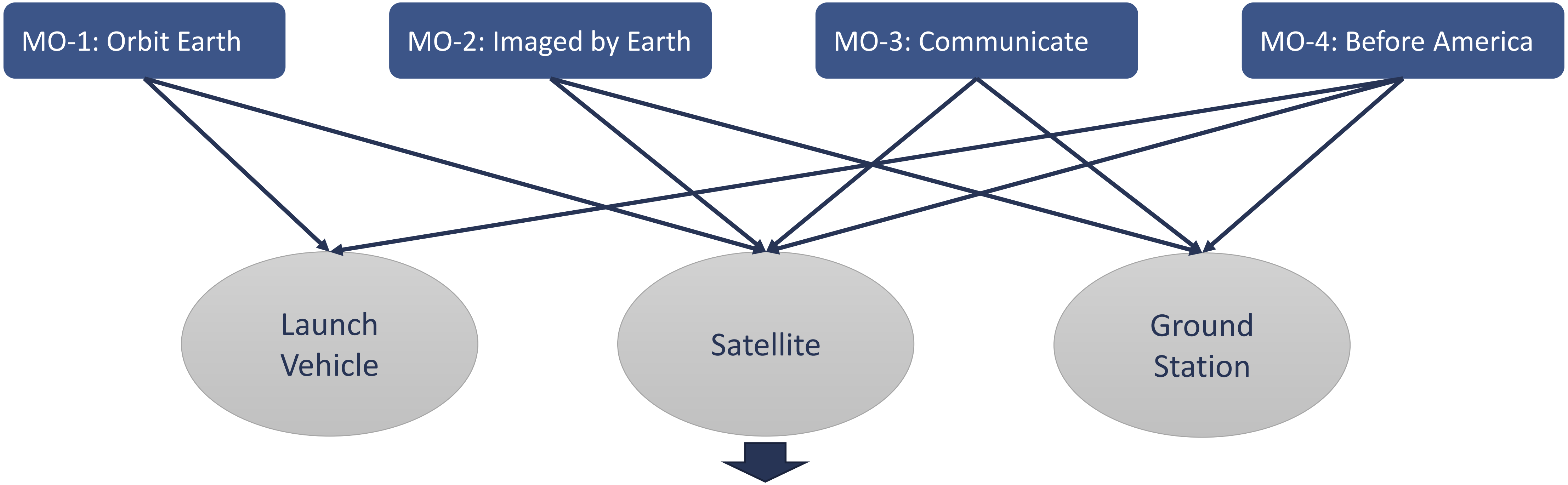
MO-4: Sputnik shall be in orbit before the United States puts anything in orbit

A Simple Example



Flow down to discover what systems the mission needs

A Simple Example



A satellite ***system-level*** requirement is a requirement that applies to the **entire** satellite.

Flow down system-level requirements

A Simple Example

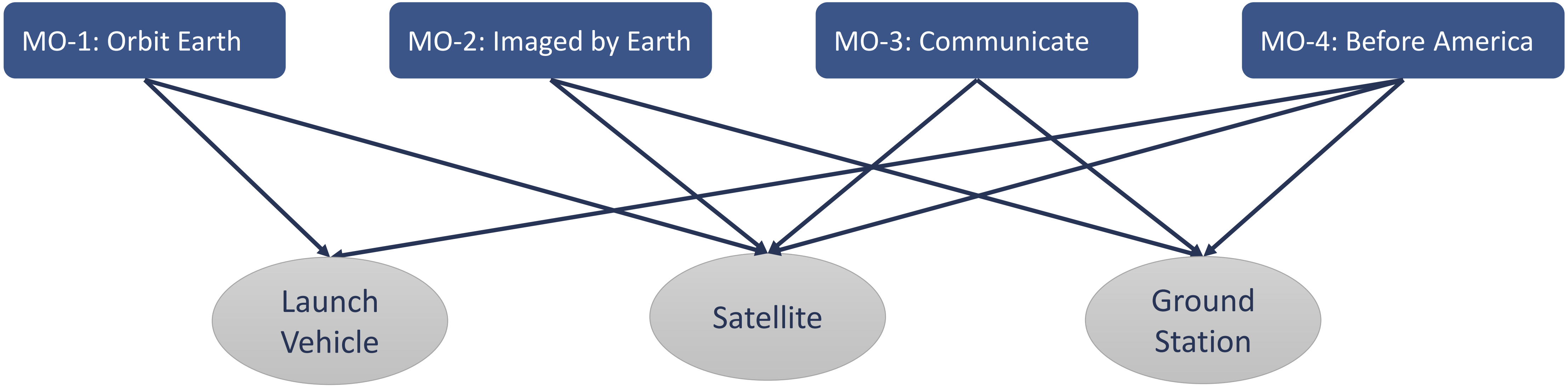
A satellite ***system-level*** requirement is a requirement that applies to the **entire** satellite.

- Sputnik is going to space. The only way to get to space is via a rocket. Therefore, Sputnik needs to survive a rocket ride to space.
- Sputnik is going to space. Therefore, Sputnik needs to survive the space environment.

This is UNP11-1

The smallsat shall be designed to withstand the launch and on-orbit environments of the launch vehicle without failure, leaking fluids, or releasing anything.

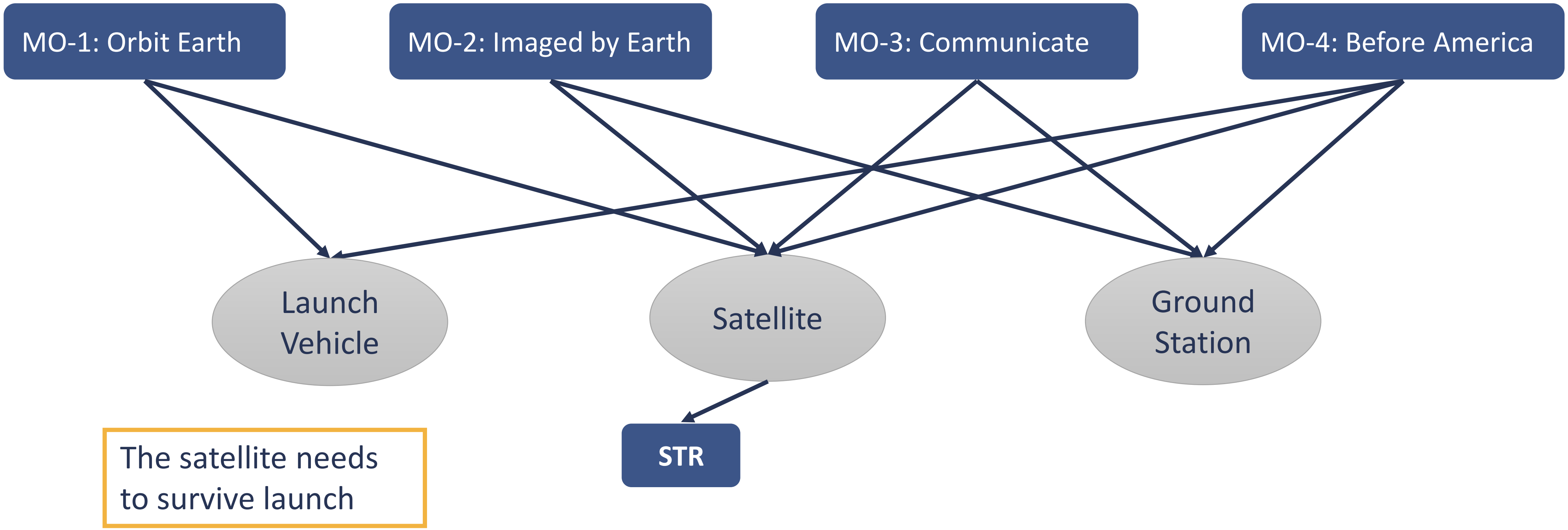
A Simple Example



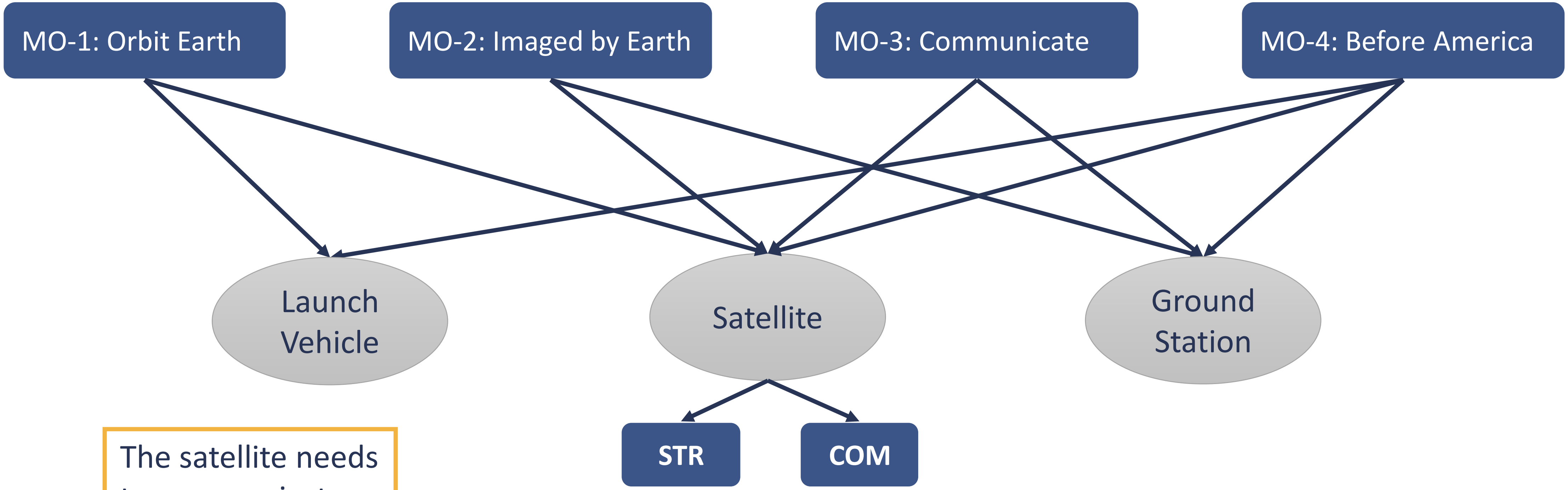
The need for subsystems should flow down from mission and system-level requirements

Flow down system-level requirements to subsystem-level requirements

A Simple Example

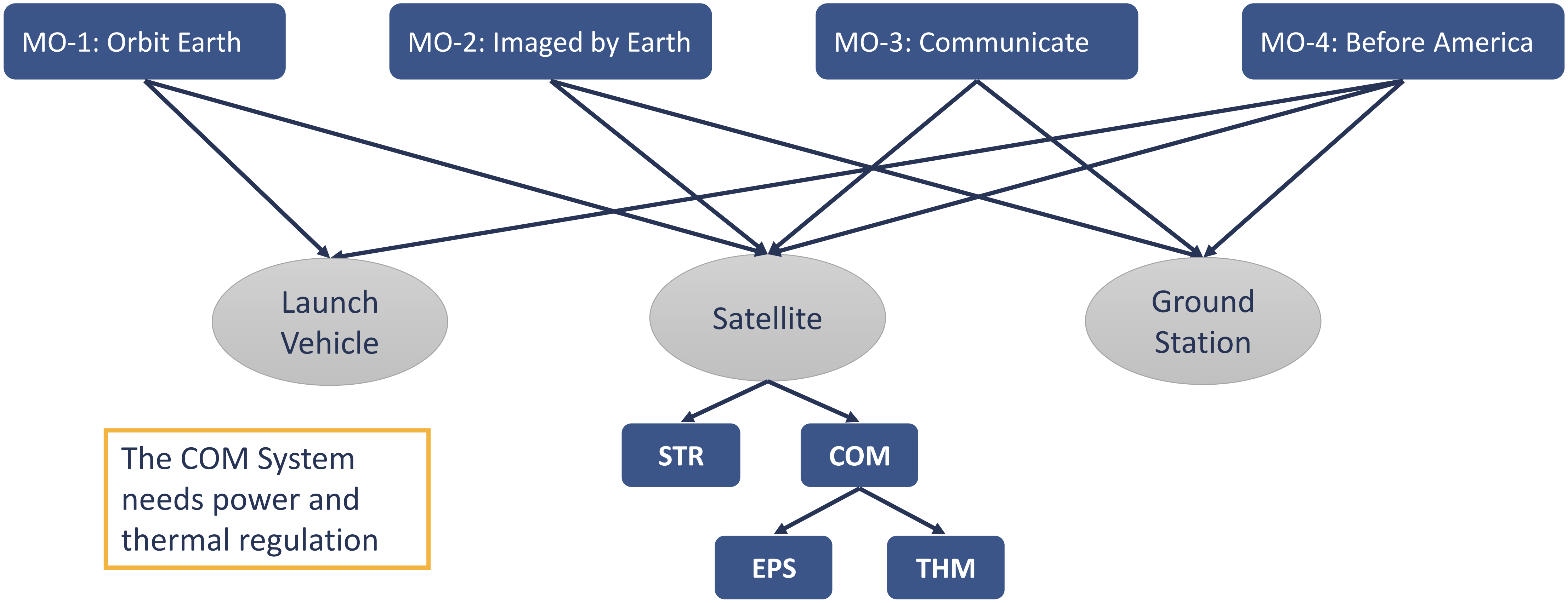


A Simple Example



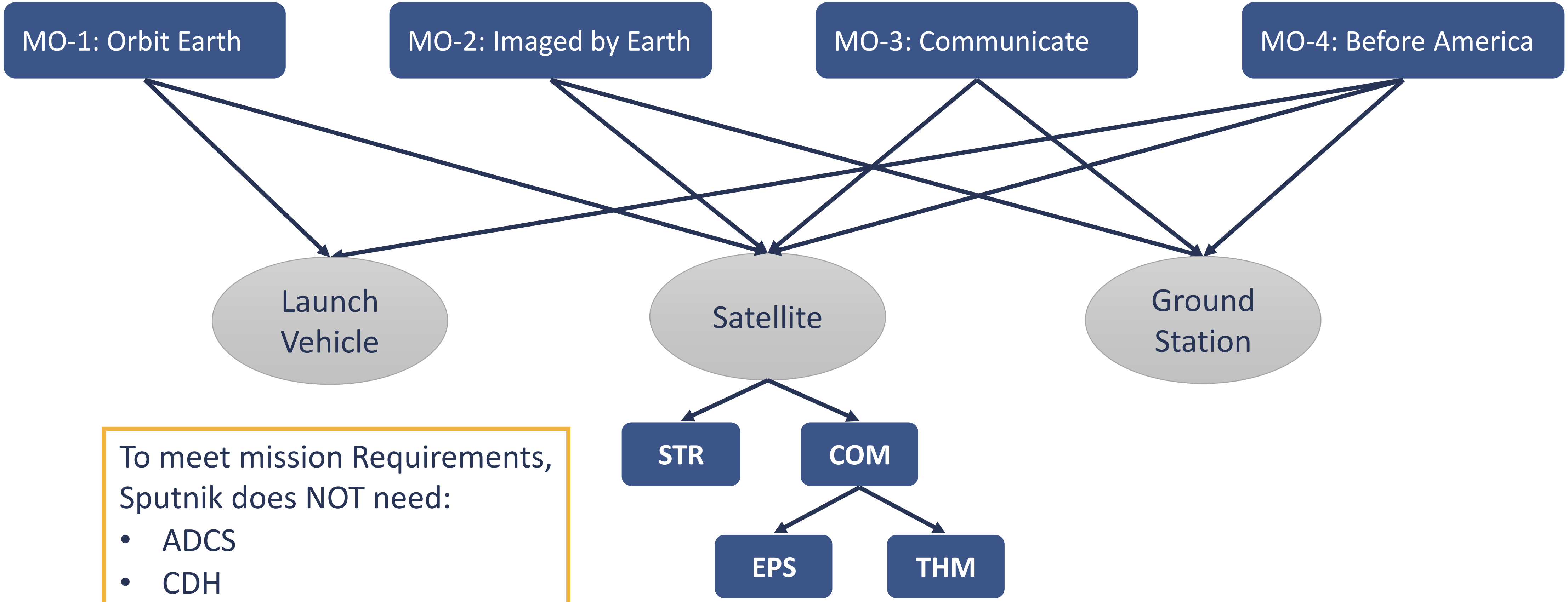
The satellite needs to communicate with the ground

A Simple Example



The COM System needs power and thermal regulation

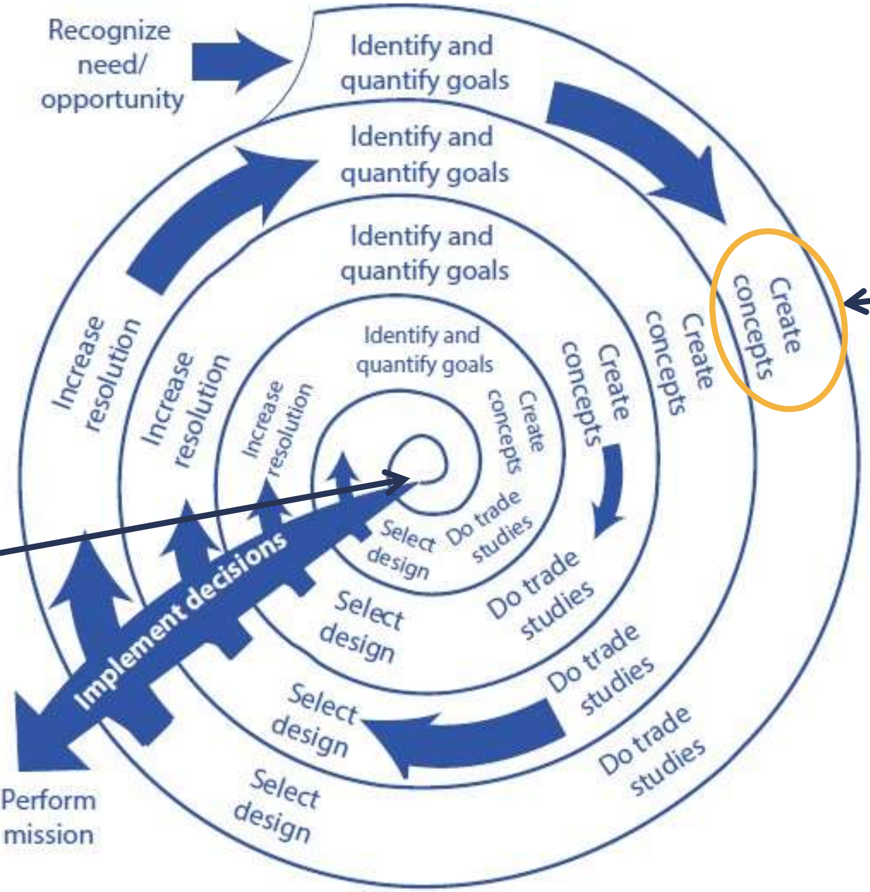
A Simple Example



To meet mission Requirements, Sputnik does NOT need:

- ADCS
- CDH

A Simple Example



This example got us here

Fully mature RVM would be here

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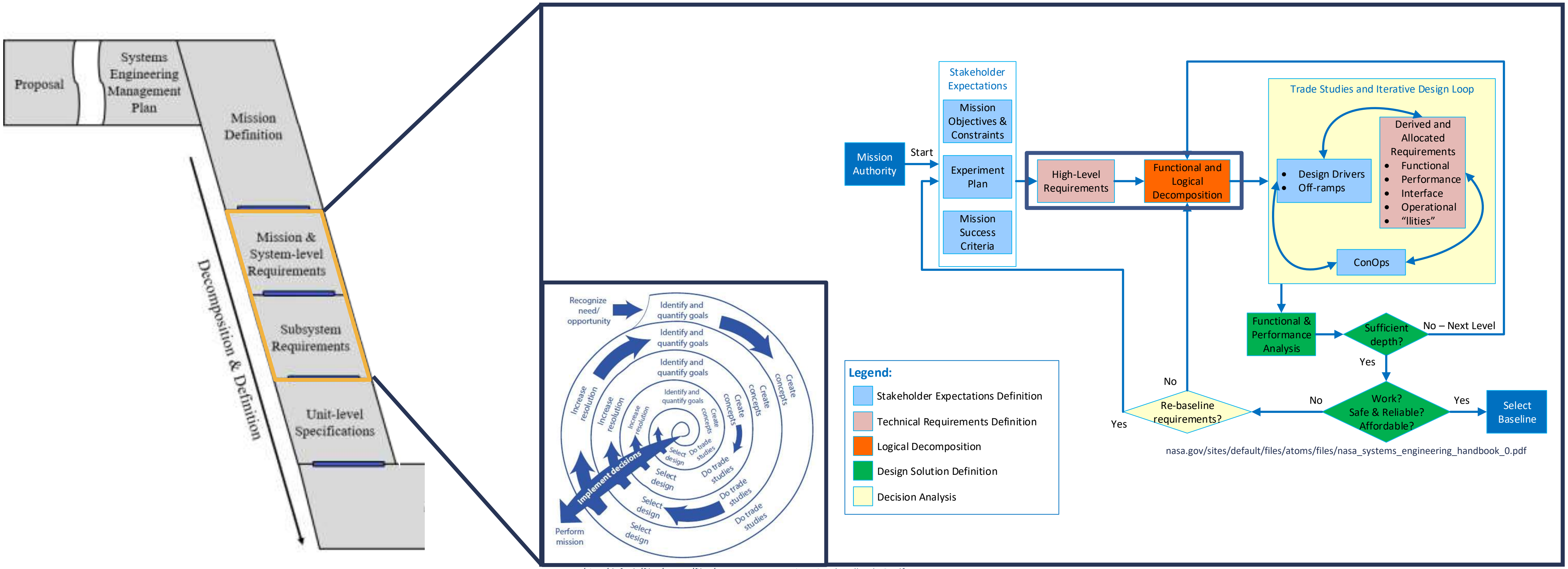
Bringing it all Together



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How can we string all the other parts of the process together?

An Imperfect Example (R3)

Mission Statement: The Rapid Reconnaissance and Response (R3) mission will characterize the radiation environment in low earth orbit and evaluate radiation effects on an uncooled microbolometer thermal imager. Onboard thermal image processing will be used to geolocate thermal features of interest.

Identifier	Requirement	Source
MO-1	R3 shall monitor the radiation environment in terms of total ionizing dose and single event effects.	Mission Statement
MO-2	R3 shall characterize the radiation effects on the performance of an uncooled microbolometer thermal imager.	Mission Statement
MO-3	R3 shall acquire thermal images from low earth orbit, and utilize onboard image processing algorithms to detect and geolocate thermal features having specified signatures.	Mission Statement

An Imperfect Example (R3)

Mission Statement: The Rapid Reconnaissance and Response (R3) mission will characterize the radiation environment in low earth orbit and evaluate radiation effects on an uncooled microbolometer thermal imager. Onboard thermal image processing will be used to geolocate thermal features of interest.

Identifier	Requirement	Source
MO-1	Microbolometers are awesome, because they don’t require cooling, but we want to know how they’ll work in space	
MO-2		
MO-3	We can also do research by taking microbolometer images and using a cool new algorithm that our PI really cares about	

An Imperfect Example (R3)

Mission Statement: The Rapid Reconnaissance and Response (R3) mission will ~~characterize the radiation environment in low earth orbit and~~ evaluate radiation effects on an uncooled microbolometer thermal imager. Onboard thermal image processing will be used to geolocate thermal features of interest.

Microbolometers are awesome, because they don't require cooling, but we want to know how they'll work in space

We can also do research by taking microbolometer images and using a cool new algorithm that our PI really cares about

Mission Statement: The Rapid Reconnaissance and Response (R3) mission will demonstrate the use of an uncooled microbolometer in space and characterize its behavior in the space environment. Onboard thermal image processing will be used to geolocate thermal features of interest.

An Imperfect Example (R3)

Mission Statement: The Rapid Reconnaissance and Response (R3) mission will demonstrate the use of an uncooled microbolometer in space and characterize its behavior in the space environment. Onboard thermal image processing will be used to geolocate thermal features of interest.

Break down the mission statement into it’s clear distinct components

An Imperfect Example (R3)

Mission Statement: The Rapid Reconnaissance and Response (R3) mission will demonstrate the use of an uncooled microbolometer in space and characterize its behavior in the space environment. Onboard thermal image processing will be used to geolocate thermal features of interest.

Break down the mission statement into it's clear distinct components

Identifier	Requirement	Source
MO-1	R3 shall demonstrate the use of an uncooled microbolometer in space.	Mission Statement
MO-2	R3 shall characterize a microbolometer in the space environment.	Mission Statement
MO-3	R3 shall utilize onboard thermal image processing to geolocate thermal features of interest.	Mission Statement

An Imperfect Example (R3)

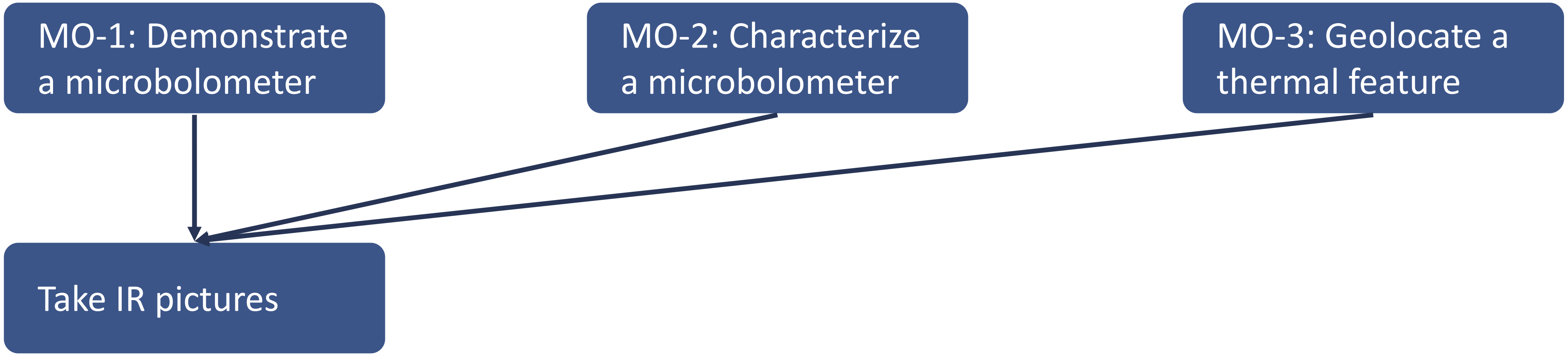
MO-1: Demonstrate a microbolometer

MO-2: Characterize a microbolometer

MO-3: Geolocate a thermal feature

What must be done to meet the mission objectives successfully?

An Imperfect Example (R3)



An Imperfect Example (R3)

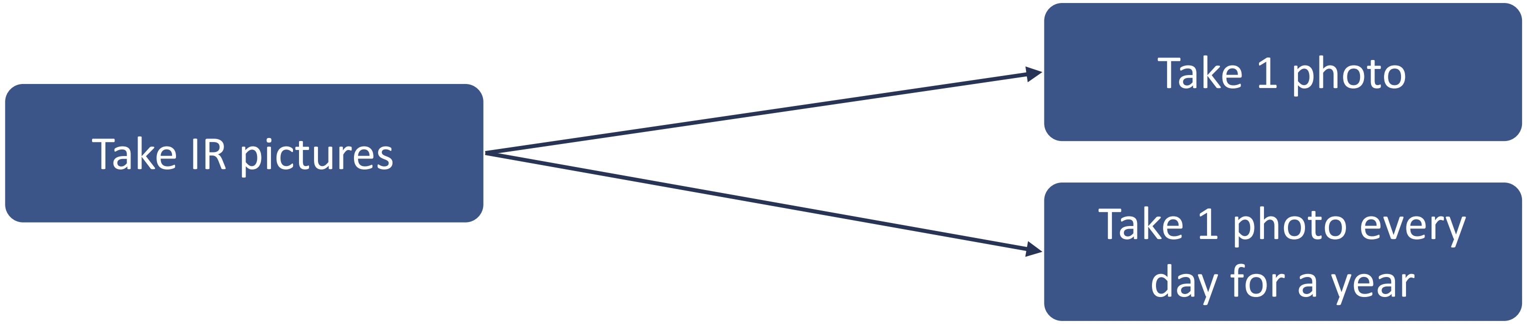
Take IR pictures → How many pictures are enough to demonstrate the use of the microbolometer?

Minimum vs Full Mission Success

Take 1 photo → Minimum Mission Success is the absolute minimum of what must be done to claim the mission has passed.

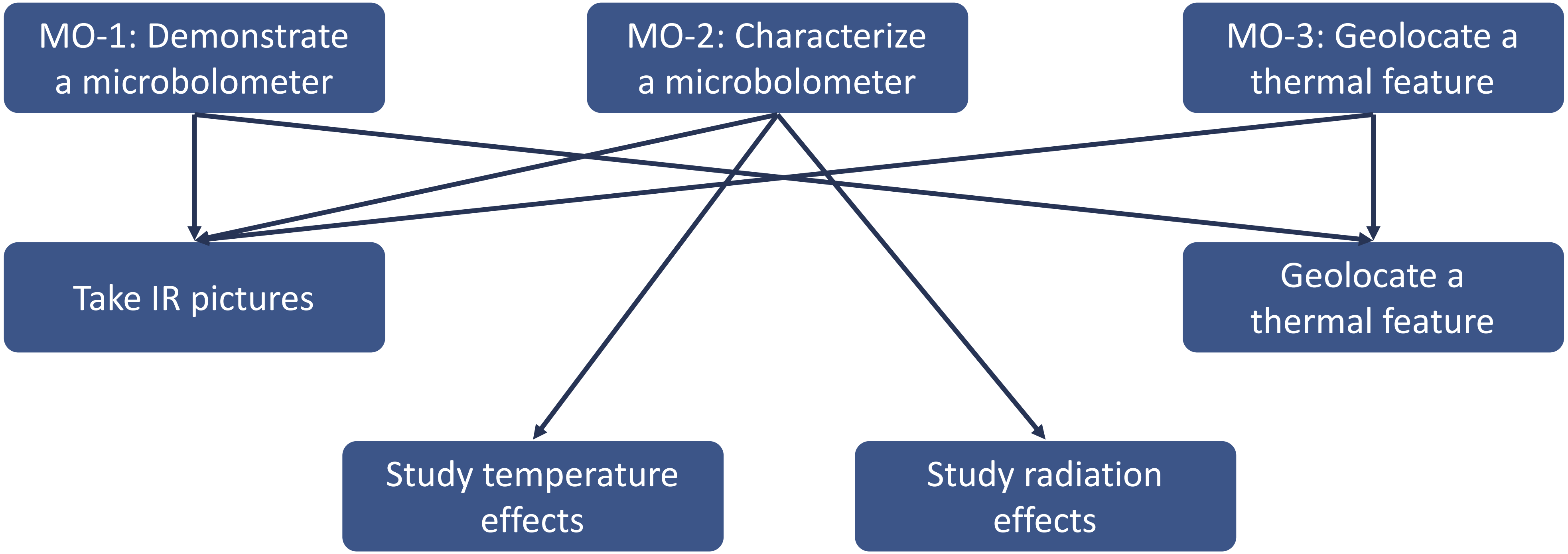
Take 1 photo every day for a year → Full Mission Success is if the satellite could do everything you wanted it to do

An Imperfect Example (R3)



Identifier	Level	Requirement	Source
MSC-1	Min	R3 shall take one image of the Earth	MO-1
	Full	R3 shall take at least one thermal image of the Earth every day for a year	MO-1, MO-2

An Imperfect Example (R3)



An Imperfect Example (R3)

Identifier	Requirement	Source
MSC-2	R3 shall take enough data to characterize how radiation affects the microbolometer	MO-2

What is enough?

Study Radiation Effects

An Imperfect Example (R3)

Identifier	Requirement	Source
MSC-2	R3 shall take enough data to characterize how radiation affects the microbolometer	MO-2

What does this even mean? How are we doing this?

Study Radiation Effects

An Imperfect Example (R3)

Identifier	Requirement	Source
MSC-2	R3 shall take enough data to characterize how radiation affects the microbolometer	MO-2

We want to know how radiation effects the microbolometer

In order to do that, we want to see if bit-flips or dead pixels correlate to the radiation environment

Therefore, we want to get radiation readings (dosimeter) and compare radiation levels to defects in the IR images

What are we trying to say?

An Imperfect Example (R3)

Identifier	Requirement	Source
MSC-2	R3 shall take enough data to characterize how radiation affects the microbolometer	MO-2

We want to know how radiation effects the microbolometer

In order to do that, we want to see if bit-flips or dead pixels correlate to the radiation environment

Therefore, we want to get radiation readings (dosimeter) and compare radiation levels to defects in the IR images

We need to take a thermal image and compare defects to the radiation environment

An Imperfect Example (R3)

Identifier	Requirement	Source
MSC-2	R3 shall compare (TBR number) of thermal images to the radiation environment	MO-2

How many image comparisons are enough to characterize the microbolometer?

We need to take a thermal image and compare defects to the radiation environment

An Imperfect Example (R3)

Identifier	Level	Requirement	Source
MSC-1	Min	R3 shall take at least 1 thermal image of the Earth	MO-1
	Full	R3 shall take at least 1 thermal image of the Earth every day for 1 year	MO-1, MO-2
MSC-2	Min	R3 shall compare (TBR small number) of thermal images to the radiation environment	MO-2
	Full	R3 shall compare (TBR big number) of thermal images to the radiation environment	MO-2
MSC-3	Min	R3 shall compare (TBR small number) of thermal images to the thermal environment	MO-2
	Full	R3 shall compare (TBR big number) of thermal images to the thermal environment	MO-2
MSC-4	Min	R3 shall geolocate at least 1 thermal feature (to some level of precision/accuracy)	MO-3
	Full	R3 shall geolocate (large number that verifies the algorithm works in a statistically important variety of cases) thermal features (to some level of precision/accuracy)	MO-3

All minimum mission success criteria must be met to “pass” your mission

An Imperfect Example (R3)

Words to Avoid

- Enough/Sufficient: i.e., words meant to take place of quantities
- Sometimes/Frequently: i.e., words meant to take place of time periods
- Characterize
- Accurately
- Precisely

An Imperfect Example (R3)

Mission Statement: The Rapid Reconnaissance and Response (R3) mission will demonstrate the use of an uncooled microbolometer in space and characterize its behavior in the space environment. Onboard thermal image processing will be used to geolocate thermal features of interest.

MO-3	R3 shall utilize onboard image processing to geolocate thermal features of interest	MS

MSC-1	R3 shall take at least one thermal image of the Earth	MO-1
MSC-4	R3 shall geolocate at least one thermal feature	MO-3

ADCS-1	The R3 satellite shall be capable of controlled slew rates equal to or less than [TBR]°/sec	MSC-1, MSC-4

An Imperfect Example (R3)

UNP11-59 There shall be a minimum of 6dB margin in the telecommunications link analysis both for the uplink and the downlink at 10-degree elevation mask

COM-2	The COM Subsystem shall maintain a link margin of at least 6 dB	UNP

Why pointing from COM? Perhaps this mission's data budget called for an S-band radio – which leads to such pointing reqs.

ADCS-3	The ADCS shall be capable of attitude control equal to or less than 10°/axis	COM-2
ADCS-3.1	The ADCS shall be capable of attitude determination equal to or less than 1°/axis	ADCS-3

The quantitative figures of merit for these reqs. came from a combination of mod&sim, data budget, and pointing budget efforts

Remember, requirements are what you NEED

An Imperfect Example (R3)

- Will your ADCS control/determination reqs. conflict with the slew rate req?
- The data budget indicated a need for an S-band radio, is this affordable? Will the required ADCS to use this S-band radio be too complicated?
- Will the EPS be able to provide all the energy necessary to power all these subsystems?
- Now that we defined some subsystem reqs., does this agree with the Experiment Plan? What does the CONOPS need to look like now?

This is the nature of the trades your team will need to do while defining requirements!

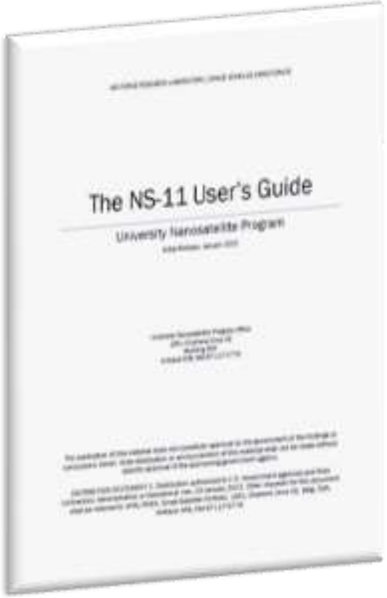
An Imperfect Example (R3)

What happens with the RVM now that it's filled out? We're done with it, right?

NO!

The RVM is a living document that will be used throughout the entire mission life

Want to Learn More?


The NS-11 User's Guide
University Nanosatellite Program

Read the UNP User's Guide!

Stick around for future EATs!

Ask questions!

Read the supporting material

Supporting material

- Most of this presentation copied from "UNP NS10 Systems Engineering Part1 EAT" by Sam Baxendale
- "UNP NS11 User's Guide", AFRL/RV, 2022
- "Applied Space Systems Engineering", Larson/Kirkpatrick/Sellers/Thomas/Verma, 2009
- "Space Mission Engineering", Wertz/Everett/Puschell, 2011
- "The NASA Systems Engineering Handbook", NASA, 2007
- "INCOSE Systems Engineering Handbook", INCOSE, 2010
- "Michigan Tech MEPIV Lecture: An Introduction to Systems Engineering", King, 2019
- "UNP NS9 EAT: Systems Engineering", Straight, 2016
- "ISO/IEC 15288 IEEE Systems Engineering Standard", IEEE, 2015
- "ECSS-E-10A European Systems Engineering Standard", ESA, 2018
- And more! *Not an exhaustive list*

Questions?