What are requirements and why they are your friends…

A Benevolent Introduction to Requirements

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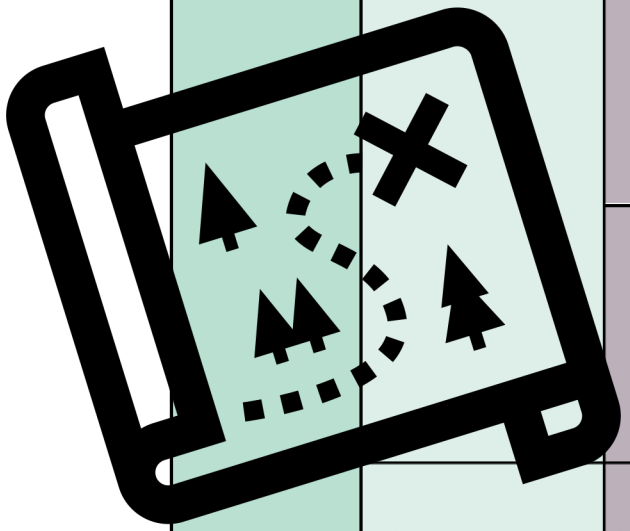
Outline..

- Learning the lingo through a non-science example.
- What the formal structure of requirements are
- Why they are (or will become) your friends…

1. Science Goals	2. Science Objectives (SO #.#)	Scientific Measurement Requirements		Instrument Requirements			8. Top-Level Mission Functional Req's
		3. Physical Parameters	4. Observables	5. Category	6. Threshold Mission	7. Baseline Mission Requirement	



Requirements

I'd like to build a house…

Tell me your requirements…

I require a house for people vs. house music, doll houses, cat houses, dog houses…

Great!
Will be our objective!
Tell me more details!

I require a house for two adults, three children, and two dogs.

Now we're talking!
Let's get into the details!

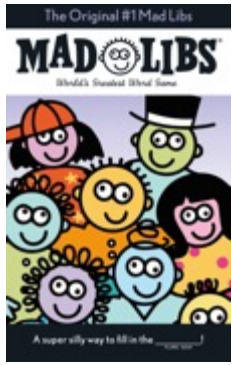
Ooh! I can go on and on here! I need a master bedroom, three non-master bedrooms and 2.5 bathrooms. I'm iffy about a pool—if there is money…

Let's formalize this..

What is a requirement?

They're not mysterious…

Requirement: The *agreed-upon* **need, desire, want, capability, capacity, function or demand** for **instruments, personnel, equipment, facilities, or other resources or services** by specified quantities for specific periods of time or at a specified time **expressed as a "shall" statement**.



General Language:

The [*noun*] **shall** [*quantitative verb*] [*aspect of the physical system*] [*preposition*] [*verification parameter(s)*].

The Language of Requirements…

- Contains a "shall" in it..
- Conveys expectations for what is to be delivered
- A way to clearly communicate
- Contains one thought per statement
- Single interpretation
- **Active Voice:** *"Who" shall "what"?*
- Plain English
- No "and/ors"
- **Stated Positively** *"shall" vs. "shall not"*

System-Level | Subsystem-Level | Component-Level

Objective: The mission is to build a house.

Objective

Level 1: The mission shall build a house for two adults, three children, and two dogs.

Level 1

Level 2 - Project

- Specific flow from L1

Level 3 (L3)

L3 – Room Subsystem Requirements

- Master Bedroom Parameters
- Non-Master Bedroom Parameters
- Bathroom Parameters

L4- Room System Component Level

- Room Component Requirements

Level 2:

- The house shall have one master bedroom.
- The house shall have three non-master bedrooms.
- The house shall have 2.5 bathrooms.

Level 3:

- The master bathroom shall be located on the second floor.

Level 4:

- The master bathroom shall have one shower.
- The master bathroom shall have one sink.
- The master bathroom shall have one toilet.

The [***noun***] **shall** [***quantitative verb***] [***aspect of the physical system***] [***preposition***] [***verification parameter(s)***].

Photo Credit: USDA https://www.nal.usda.gov/afsic/rabbits

Objective:
Your science objective here

Objective

Level 1: The mission shall measure the elevation of at least 90% of the surface with 300 m postings and 10 m height precision

Jared will get into detail here!

Level 1

Level 2 -Project

- Instrument-specific Flow from L1
- Science phase duration

L3 - Flight System

- Spacecraft pointing
- Downlink data rate
- Onboard data stora

L3- Payload System

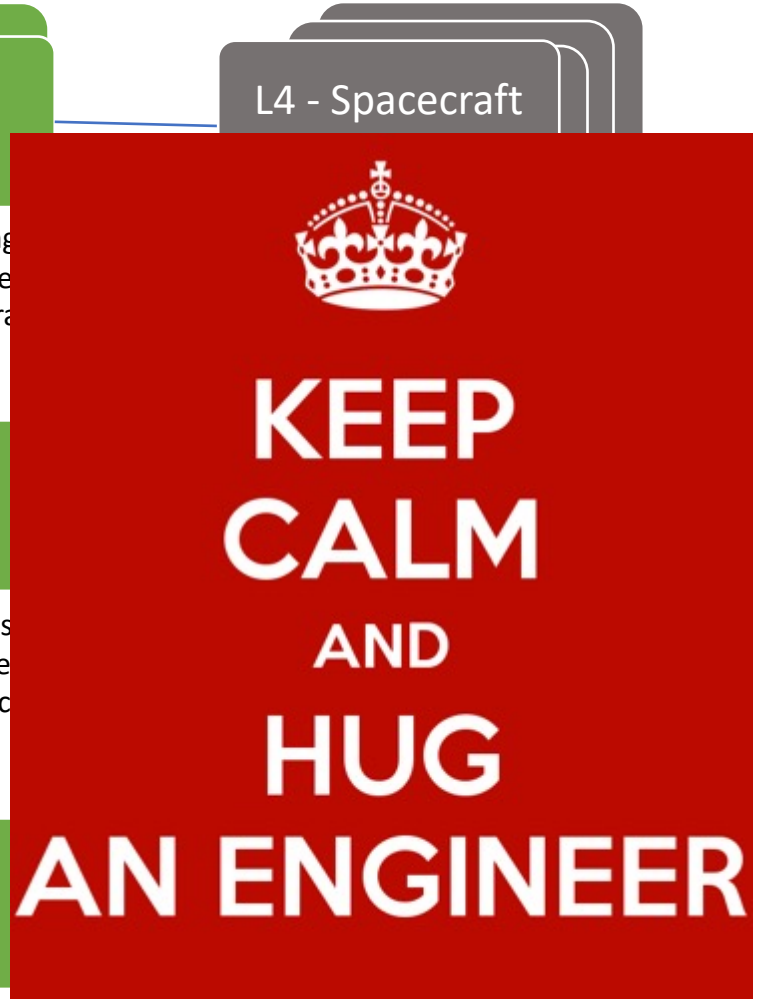
- Instrument settings
- Instrument capture
- Instrument cadenc

L3- Mission System

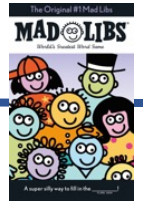
- Ground system architecture
- Data archive size
- Uplink/downlink frequency

L4 - Spacecraft

- DSN Schedule
- Ground Antenna size



Level 2:
The project shall acquire single-pass interferometric synthetic aperture radar height measurements (≤10 m accuracy) over ≥95% of Earth's surface.



Level 2s guide instrument function and performance details

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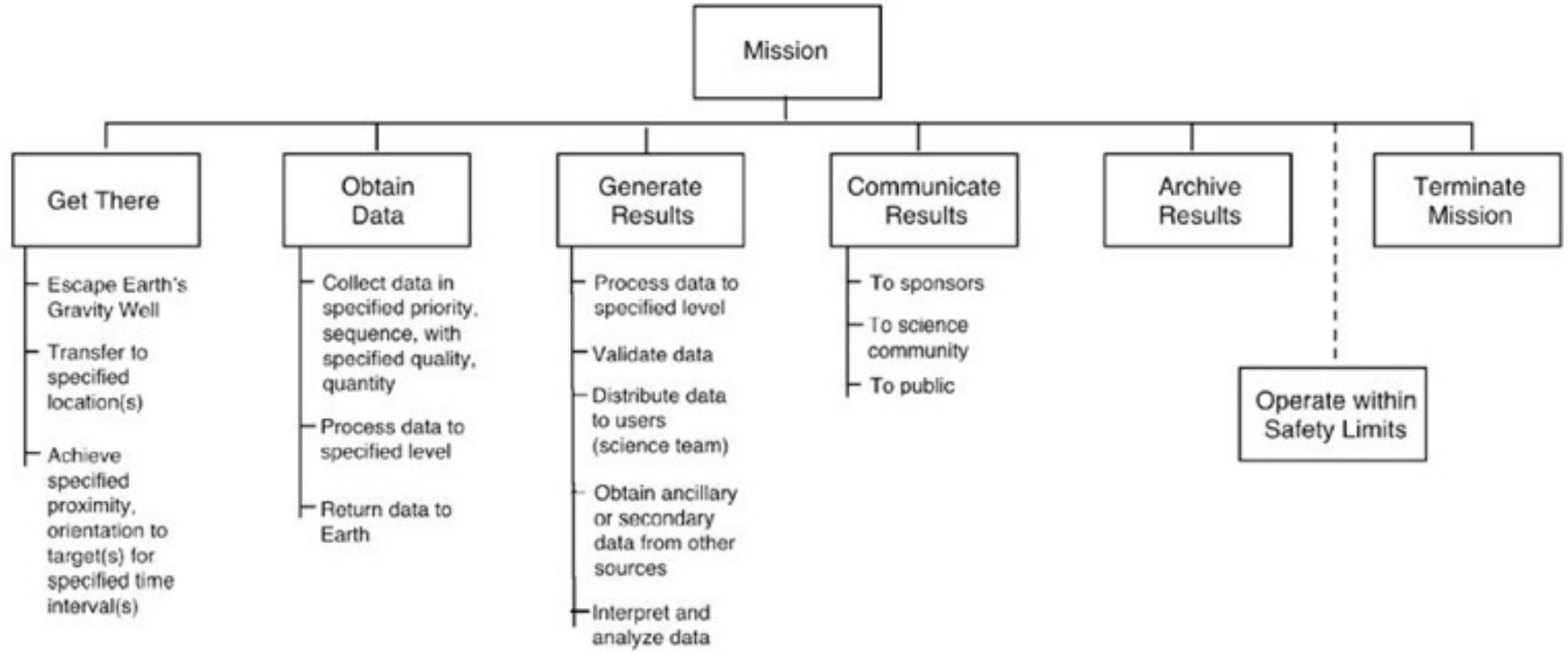
Logical Decomposition of Science in a Standard Mission



Applicable to:

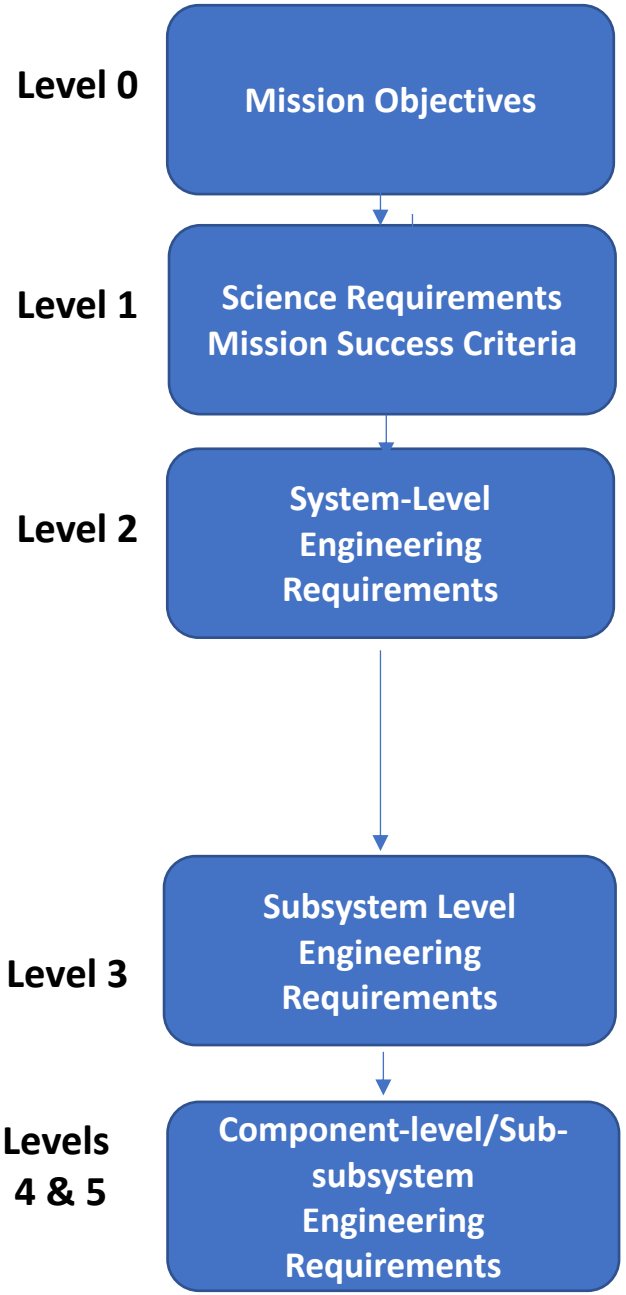
- Flybys
- Orbiters (Earth and Planetary)
- In situ missions
- Constellations
- Heliocentric observers
- Sample return missions
- Occultation experiments

Requirement Decomposition

- The process by which requirements defined at one level are allocated or derived into implementable elements.
- It is **NOT** writing the same requirement at the next lower level as a child of a higher level requirement.
- It is **NOT** writing parents for lower level requirements.

Allocating = Distributing a resource or functional requirement

Deriving = Distributing a requirement by analysis or modeling



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Level 1: The mission shall build a house for two adults, three children, and two dogs.

Level 2:

- The house shall have one master bedroom.
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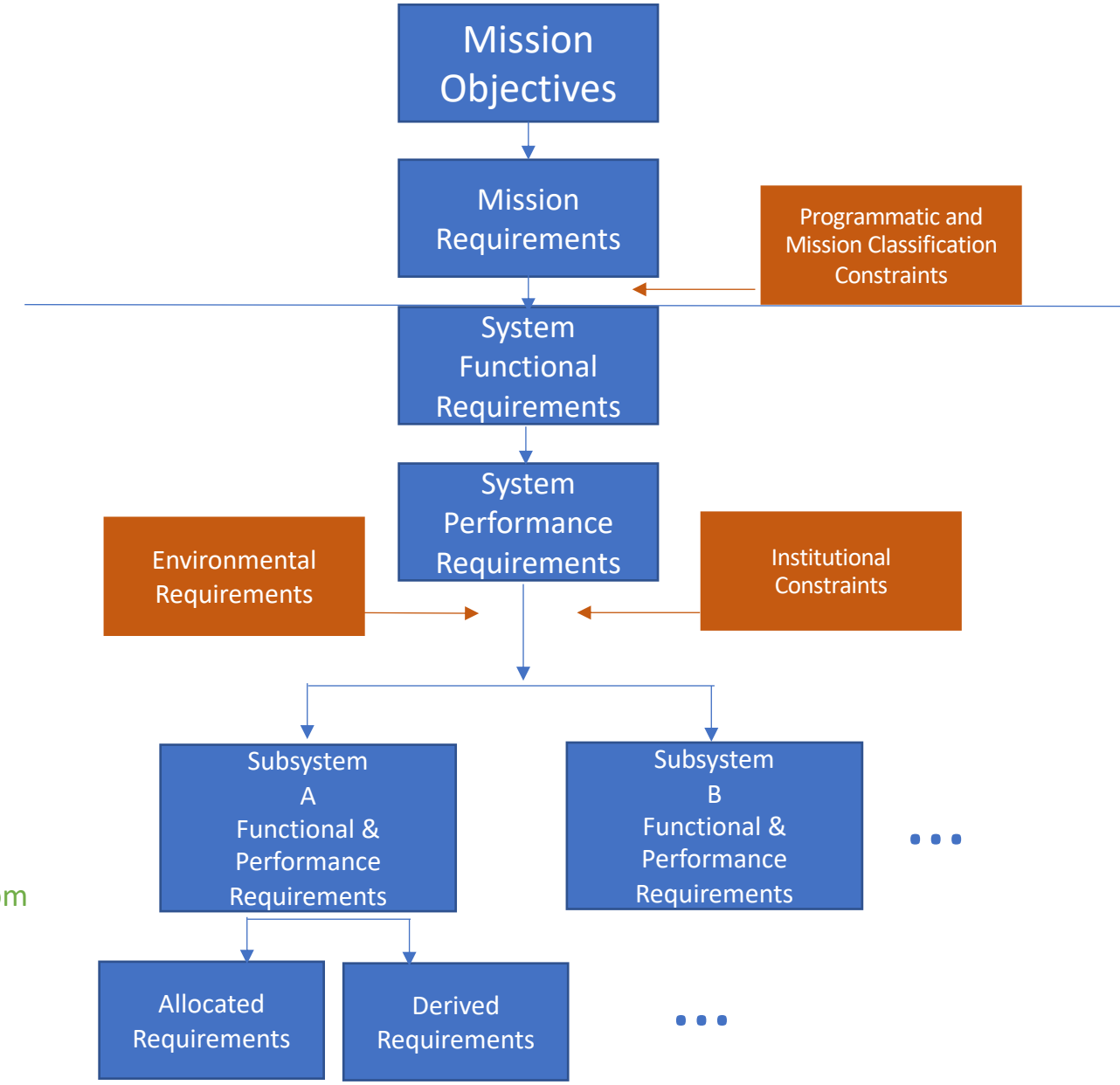
- The house shall have 2.5 bathrooms.

Level 3:

- The house shall have the master bedroom on the 2nd floor.
- The house shall have one bathroom attached to the master bedroom.
- The house shall have one full bathroom on the second floor.
- The house shall have a half bathroom on the first floor.



https://www.nasa.gov/sites/default/files/atoms/files/nasa_systems_engineering_handbook.pdf

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Level 1
Program Level
Science Requirement

Level 2
Project Level
Science Investigation

Level 3
Project Level
Instrument System

Level 3
Project Level
Mission System

Critical Requirement

A requirement where the consequence of not meeting the requirement ***has significant impact or high sensitivity on the mission's ability to meet negotiated success criteria,*** as assessed by the requirement owner.

If the number of bedrooms is not built, this will impact the ability to meet the level 1 requirement

Level 1: The mission shall build a house for two adults, three children, and two dogs.

Driving Requirement

A requirement where ***compliance is deemed particularly difficult or the likelihood of needing additional resources to meet the requirement is significant***, as assessed by the requirement implementer.

Meeting a requirement, like having the majority of the bedrooms and bathrooms on the second floor in an environment with earthquakes may introduce additional challenges.

I would like to build a house.

Based on the budget and schedule, what can you live without and still achieve your mission?

DESCOPES: Baseline vs. Threshold?

- Number of Bedrooms
- Number of Bathrooms
- Number of Floors
- Backyard?
- Basement?
- Patio?
- Pool?
- Garage?
- Energy Source: Electrical/Solar/Geothermal?
- Other?

Baseline science requirements are the mission performance **requirements necessary to achieve the full science objectives of the mission.**

I want it all, I want it all, I want it all...

Threshold science requirements are those mission performance **requirements necessary to achieve the minimum science acceptable for the investment.**

You can't always get what you want, but if you try sometimes, you just might find, you get what you need...

Photo - https://www.loc.gov/exhibits/british/brit-7.html

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Science Goals & Objectives

Observable 1 — Variable 1A , 1B, 1C, …

Observable 2 — Variable 2A , 2B, 2C, …

… — …

Variables measured on

Instrument 1 … Instrument n

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Requirements tidbits for after your project gets going.

Requirements are not always static during development

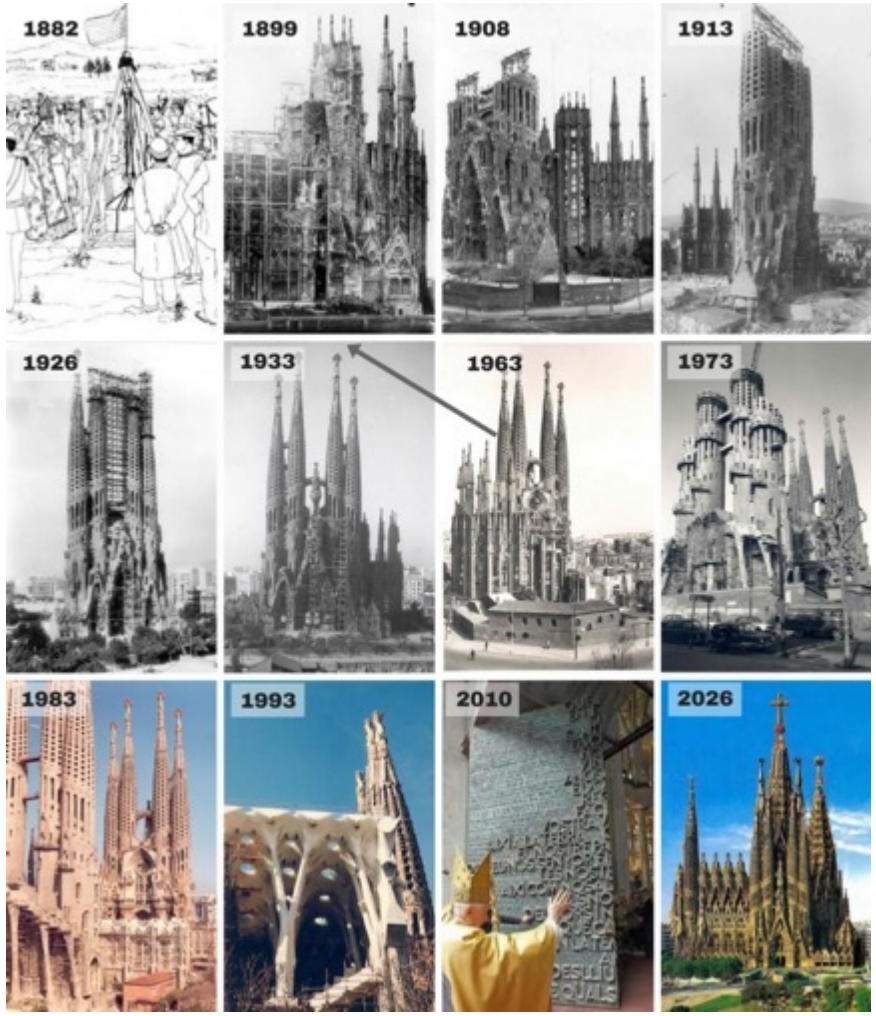
Requirements may need to be added.

Requirements are eventually "frozen"

…they won't change much, if at all, after that…

Requirements can "creep"

Think Antonio Gaudi's Sagrada Familia…



- Adding in capabilities almost always costs resources: money, schedule, labor
- Do you really need that capability or is it a "desirement" (a desired capability)?

Why should they become my friends?

- **The power to define your own path and prove it.** You're not surprised by what you get ("deliverables") or what your deliverables will do (and your stakeholders aren't either).

- **Mission Flexibility** When your requirements are written with baselines/thresholds and in a flowed down manner, you'll have the ability to adapt when situations change (and they will!)

- **Verification and Validation** Did you do (in a unique and quantitative way) what you said you were setting out to do?

- **Clear communication to your team, your stakeholders and the community.**

Types of Requirements

Functional Requirements

Defines the function that needs to be performed

Performance Requirements

Defines how well the functions need to be performed

Interface Requirements

Define how design elements relate to one another or to other systems

Environment Requirements

Define internal and external environments for flight segment elements

Reliability Requirements

Define probability of failure under specified operating conditions

Safety Requirements

Define human, environmental and asset safety needs

What the initial focus is for most science teams…

Functional Requirements

Performance Requirements

Interface Requirements

Environment Requirements

Reliability Requirements

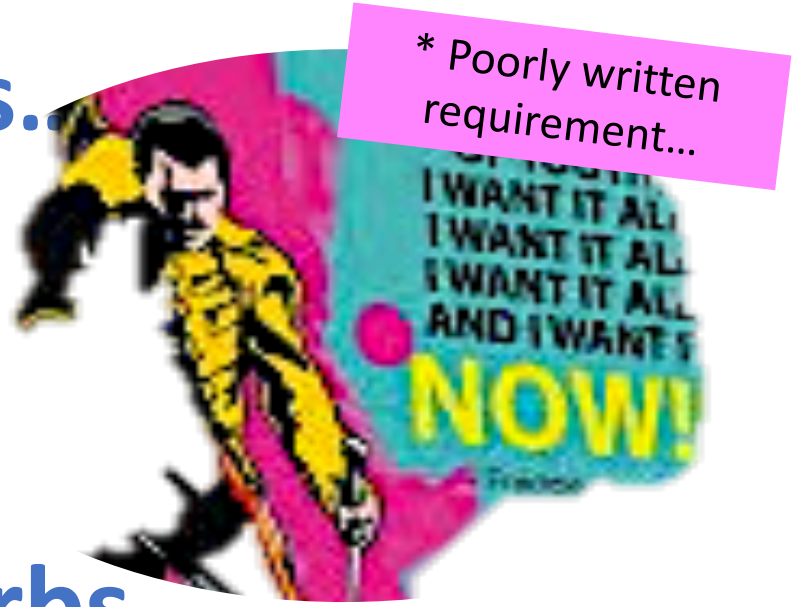
Safety Requirements

…your engineering colleagues usually get to work the rest, so…

Meme generated at https://fontmeme.com/keep-calm/

How to write ambiguous requirements…

- And/or in the requirements statement
- Multiple requirements in one sentence.
- Use of vague adjectives/adverbs



Vague phrases, adjectives and adverbs

- About
- Acceptable
- Appropriate
- Applicable
- Average
- Adequate
- Adjustable
- Affordable
- Average
- Optimum
- Normal
- Effective
- Immediate
- Major
- Stable
- Sufficient
- Significant
- Various
- Variable
- Typical
- Necessary
- Possible
- Known
- Approximate
- TBD
- TBR
- Easy
- Safe
- Flexible
- But not limited to
- Be able to
- As appropriate
- Be capable of

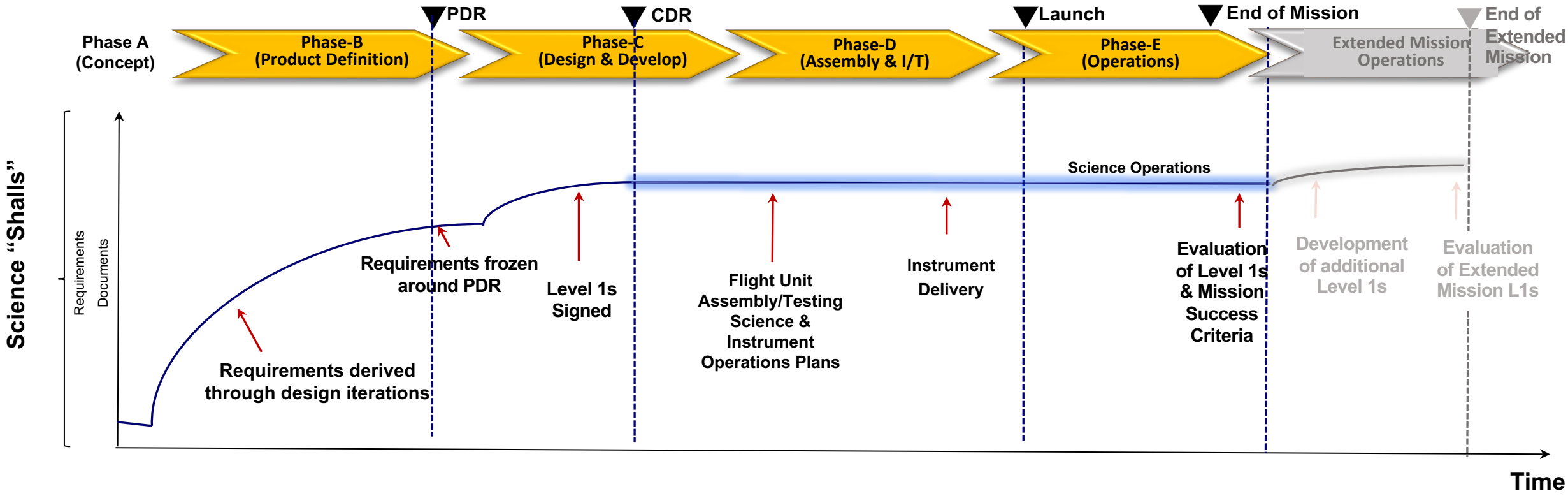
Potential Resources

Movies:
Mr. Blandings Builds His Dream House
The Money Pit

Texts:
The NASA Systems Engineering Handbook
Exploring Requirements Before, Gause and Weinberg
Visualizing Project Management by Forsberg, Mooz and Cotterman
Practical Project Management for Engineers by N. Patel=

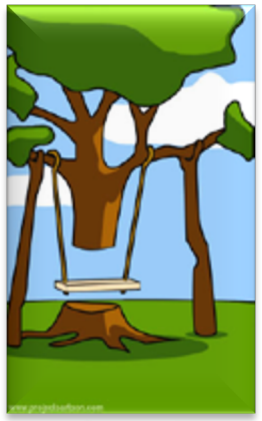
BACKUP

The Science “Shalls” Through the Life Cycle



What the scientists wanted

What the PM envisioned

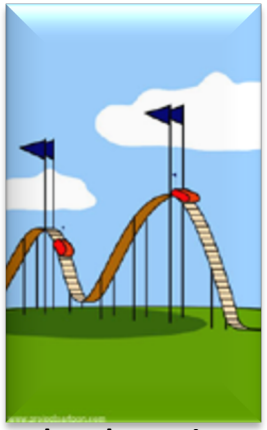


How the engineer saw it

How the requirements were documented

After PDR...

After CDR...



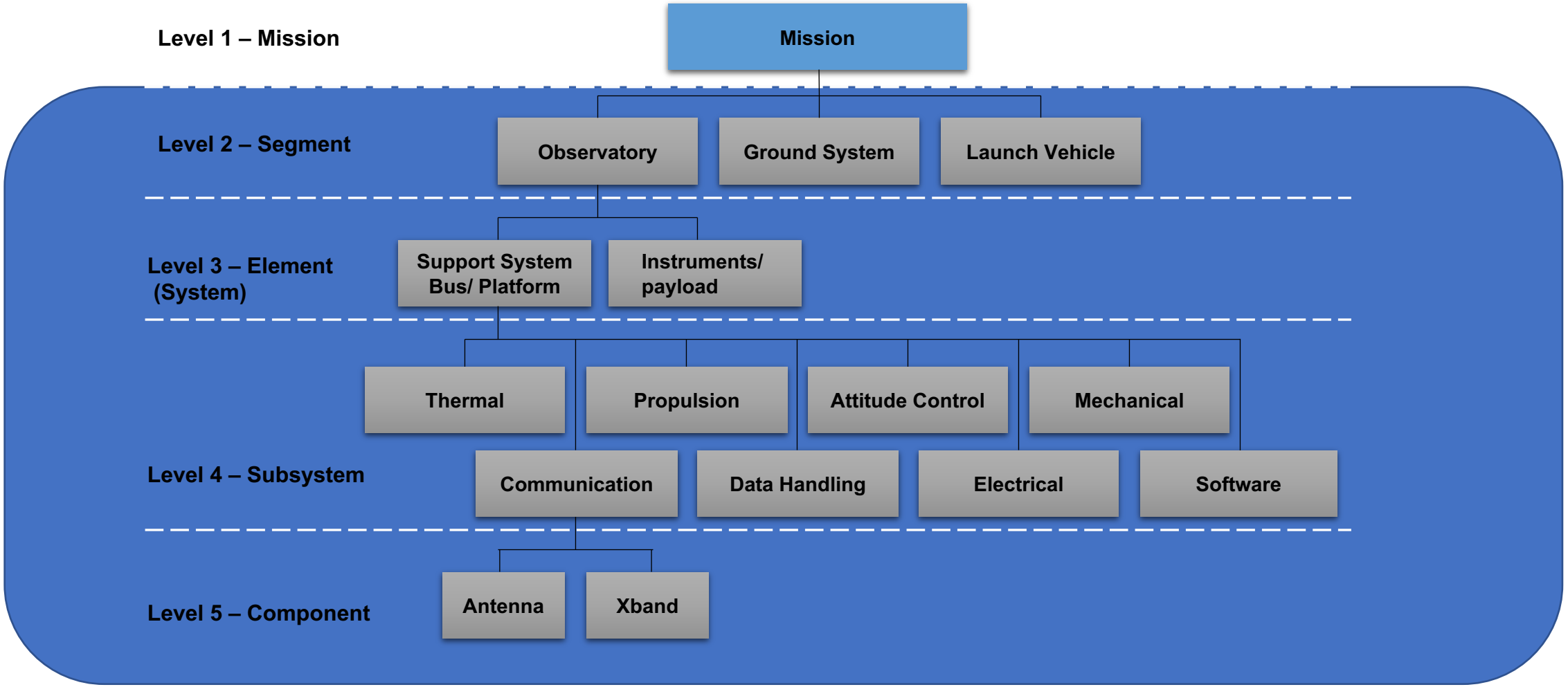
What the project was going to cost

What the project could afford

What the scientists really needed

Notional System Hierarchy for Requirements

Lisa will talk about this more!



Characteristics of Sound Requirements…

- **Unambiguous**-only one interpretation
- **Understandable** –the interpretation of each requirement is clear
- **Correct**-a requirement the system is in fact required to do
- **Concise**-no unnecessary information is included in the requirement
- **Traced**-each requirement is traced to some statement/document
- **Traceable-** each derived requirement must be traceable to an originating requirement
- **Design independent-** does not specify a particular solution or portion of the solution
- **Verifiable** – a finite process can be conducted to check that the requirement has been attained
- **Unique** – requirements are not overlapping or redundant with other requirements
- **Consistent**-(a) internally consistent—no two subsets of requirements conflict and (b) externally-no subset of requirements conflicts with external documents from which the requirement is traced.
- **Comparable**-relative priority of a particular requirement can be compared to other requiremetns
- **Modifiable**-changes to the requirements can be made easily, consistently, and completely
- **Attainable**-solutions exist within cost/schedule/performance constraints

The “Mary Had a Little Lamb” test…

What is the significance of each word in your requirements?

An Example:

“Mary had a little lamb, whose fleece was white as snow.
Everywhere that Mary went the lamb was sure to go. “

Mary **had** a little lamb. *Used to own? Still owns?*
Mary had a **little** lamb. *Little in size? Little in age? Little in weight? How little?*
Mary had a little **lamb.** *A young sheep? A young child? A lamb-orghini?*

Is the requirement free of ambiguities? Unverifiable terms?

Concept of Operations (ConOps/OpsCon)

A description of how the system will be operated during the missions phases in order to meet stakeholder expectations. Timelines and graphics are typical description methods.

Typical ConOps Timeline Elements:

- Launch
- Cruise (and instrument checkout)
- Orbit Insertion/Landing/Flyby
- Instrument Commissioning
- Prime Science Mission
- Extended Science Mission
- Decommissioning/Deorbit/End of Mission activities

Includes command and data transmission sequencing, science operations controls, logistics (resupply

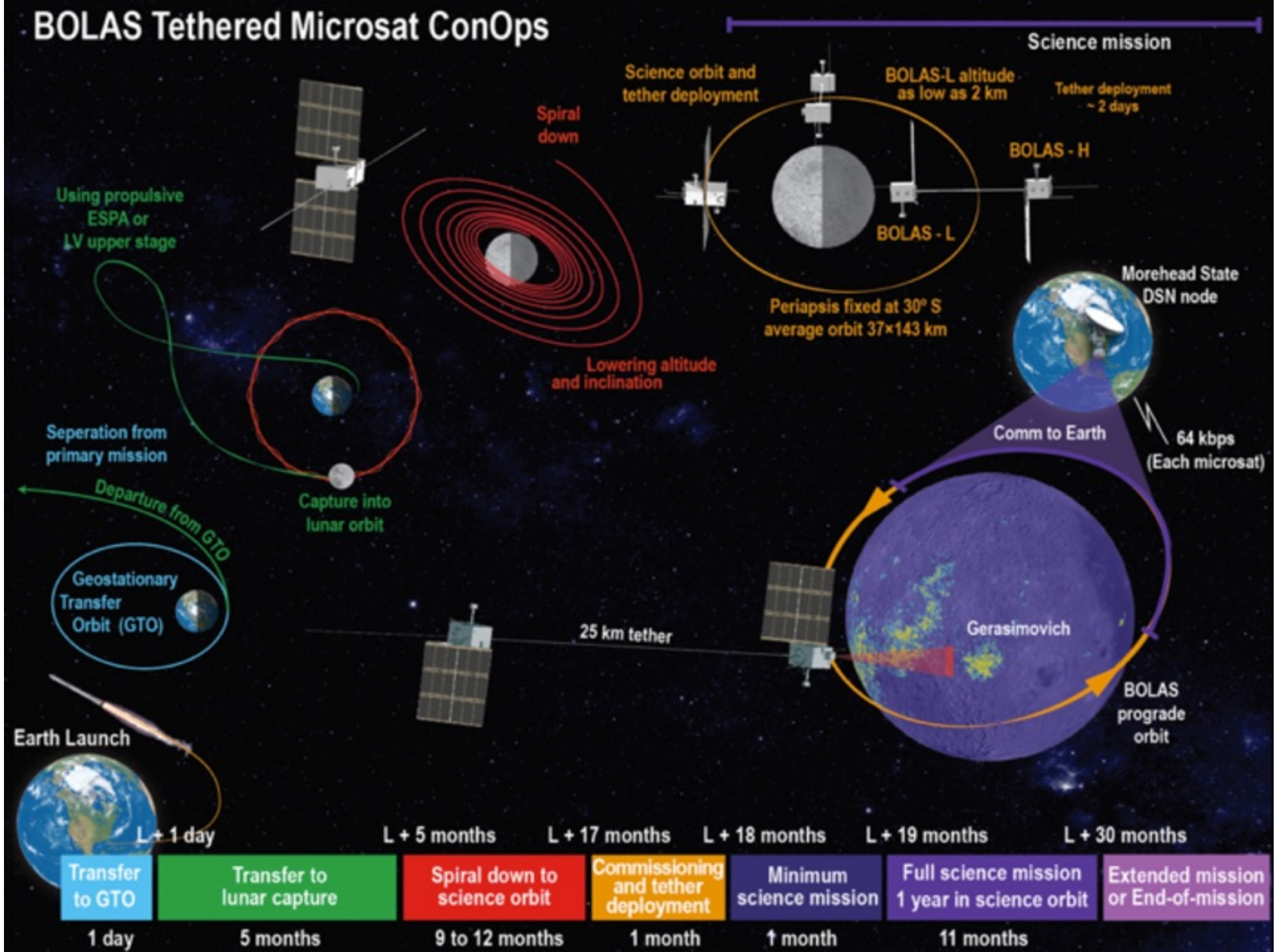
In developing the ConOps, you may make some discoveries….

Requirements Revealed!

Changes In ops Sequences!

New Use Cases!

Requirements Removed!


BOLAS Tethered Microsat ConOps
Science mission
Science orbit and tether deployment
BOLAS-L altitude as low as 2 km
Tether deployment ~ 2 days
Spiral down
BOLAS - H
BOLAS - L
Using propulsive ESPA or LV upper stage
Periapsis fixed at 30° S average orbit 37×143 km
Morehead State DSN node
Lowering altitude and inclination
Comm to Earth
64 kbps (Each microsat)
Seperation from primary mission
Departure from GTO
Capture into lunar orbit
Geostationary Transfer Orbit (GTO)
25 km tether
Gerasimovich
BOLAS prograde orbit
Earth Launch
L + 1 day
L + 5 months
L + 17 months
L + 18 months
L + 19 months
L + 30 months
Transfer to GTO
Transfer to lunar capture
Spiral down to science orbit
Commissioning and tether deployment
Minimum science mission
Full science mission 1 year in science orbit
Extended mission or End-of-mission
1 day
5 months
9 to 12 months
1 month
1 month
11 months

Verification and Validation

VERIFICATION

Is the system built right?

Verify design and implementation against requirements

Process for Verification:

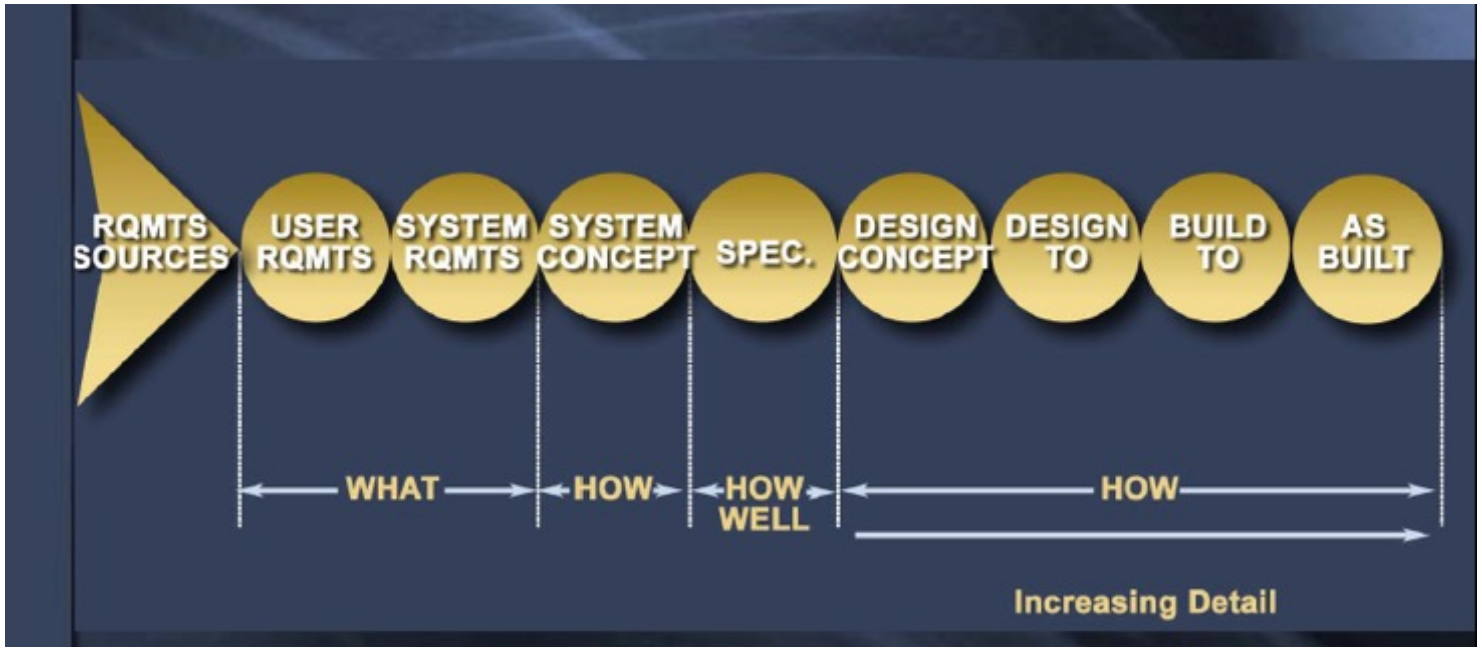
[ID verification item] +
[Method of verification] +
[Review of verification results]

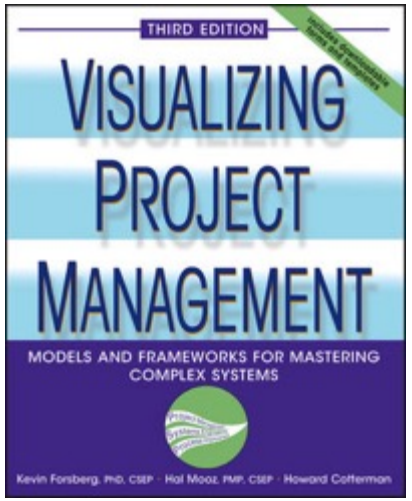
- Methods of Verification: Analysis, Inspection, Test
- If Testing: test in exposure environments (launch, cruise, landing) and requirements for functional, aliveness and comprehensive testing.

VALIDATION

Has the right system been built?

- Some Phrases You Might Hear:
  End to End Testing: Testing from the science input to the science data output
  Test as you Fly and Fly as you Test: ID anything that may not be tested in flight configuration and assess and mitigate risk.





Forsberg, Mooz & Cotterman

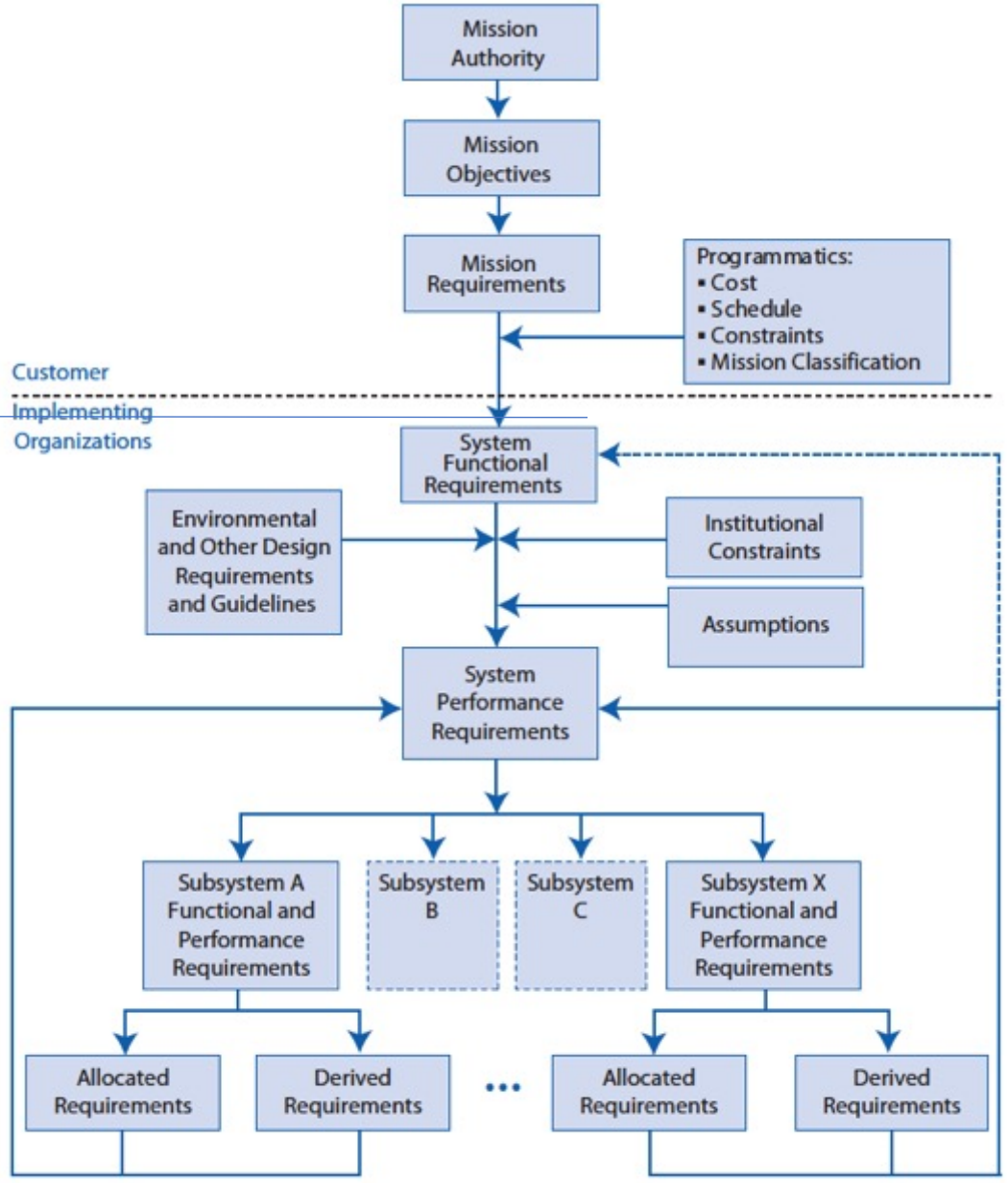


Figure 4.2-3 The flowdown of requirements

https://www.nasa.gov/sites/default/files/atoms/files/nasa_systems_engineering_handbook.pdf