

Introduction: Jared Leisner

- 2014-2017: Program Scientist, Planetary Science Division
 - R&A programs
 - Lead, Cassini Data Analysis Program (80-120 proposals/year)
 - Co-lead, Solar System Workings program (300-400 proposals/year)
 - Program officer, multiple other programs
 - Missions
 - Program Scientist, MESSENGER mission (extended Phase E)
 - Deputy to the Program Scientist, Discovery 2014 AO (28 proposals, 5 Phase A studies)
- 2017-Present: Program Scientist, Heliophysics Division
 - Missions
 - Lead Program Scientist, Solar-Terrestrial Probes program
 - Program Scientist, THEMIS/ARTEMIS
 - Program Scientist, ESCAPE
 - Program Scientist, Geospace Dynamics Constellation
 - Science and Technology Definition Team, 2018-2019
 - Pre-project study team, 2019-ongoing

Goals and Objectives

- NASA missions are formulated and developed based upon the flowdown of requirements.
 - Goal: A broad scientific effort that is part of a larger strategy to address a program's objectives. A mission investigation will make progress towards the mission's Goals, but is not expected to completely achieve them.
 - Objective: A focused scientific effort that is part of a larger strategy to address a mission goal. A mission Objective must be achieved by a mission.
 - Level-1 Requirements: Those scientific determinations and/or results required for successful completion of the mission's Objectives. *Level-1 Requirements do not specify implementation details for the mission.*
 - Level-2 Requirements: The measurement, payload, system, subsystem, mission, or other details that flow down from Level-1 Requirements. *Level-2 Requirements are the first level of implementation details for the mission.*
- The relationship between Level-1 and Level-2 Requirements can be viewed in two ways:
 - Level-1 Requirements are the science that need to be completed. Level-2 Requirements are the mission's way of completing that science. (Flow down)
 - Level-2 Requirements describe the data that will be acquired. The Level-1 Requirements explain why those are the right data. (Flow up)

Level-1 Requirements

- What purpose(s) do Level-1 Requirements serve?
 - Scientific
 - Focus the mission science...
 - ...priorities: Define the *science* needs for each Objective, and the scientific space for descopes.
 - ...proposal: Provide the framework to write your proposal within and around.
 - ...publicity: Informs coherent messaging on the work to be done and the objectives to be achieved.
 - Quantify the science Objectives in terms that can flow into mission requirements
 - Define the requirements that mission success is measured against
 - Assist HQ's portfolio management via understanding synergies, overlap, and gaps
 - Engineering
 - Bound the engineering trade space, and give engineers a framework within which to find solutions
 - Programmatic
 - Serve as the contract between NASA HQ and the mission on work to be accomplished
 - Define the level at which the mission *must* seek HQ approval for changes; and therefore define the levels at which the mission *need not* seek HQ approval

Level-1 Requirements

- Why are Level-1 Requirements based in scientific determinations and/or results rather than mission-specific implementation details?
 - Level 1s are the system-level requirements that reflect the Objectives in the system design process.
 - All mission requirements flow down from those Objectives, through the various requirement levels.
 - All child requirements must also *flow up* to the parent requirement(s).
 - The Level-1 Requirements have no parent requirements to flow up to; therefore they have no products (within the design) to deliver. They are not mission-implementation requirements; they are the Objectives written in requirement form.
 - Objectives are inherently implementation-agnostic.
 - Any Objective can be met multiple ways; remote-sensing, single-spacecraft in situ, and multiple-spacecraft in situ are different implementations but do not capture all of the possibilities.
 - Therefore Level 1s are implementation-agnostic.
- On a pragmatic note, implementation-specific Level 1s make a mission team's life more difficult. As noted on the last slide, having Level 1s be implementation-agnostic leaves the teams flexibility to succeed.

Level-1 Requirements

- Level-1 Mad Libs: The mission shall [quantitative scientific-result verb] [aspect of the physical system] [prepositional phrase] [verification parameter(s)].
- Quantitative scientific-result verb
 - All requirements must lead to a pre-registered, quantified scientific result.
 - “Intent-based” verbs are precluded: “study”, “investigate”, “perform”, “survey”, “search”
 - “Result-based” verbs are required: “determine”, “map”
 - For technology missions, verbs like “demonstrate” or “achieve” may be appropriate.
 - For exploration missions, verbs like “extract” or “transport” may be appropriate.
- Aspect of the physical system
- Verification parameter(s)

Level-1 Requirements

- Level-1 Mad Libs: The mission shall [quantitative scientific-result verb] [aspect of the physical system] [prepositional phrase] [verification parameter(s)].
- Quantitative scientific-result verb
- Aspect of the physical system
 - Science Objectives require results about the physical system. (Not just measurements.)
 - Written to be agnostic of the research plan that accomplishes them.
 - The aspects are varied and depend on the particulars of a mission.
 - Because these Level 1s are shown to be met at the end of the mission, they are aggregates. For dynamic systems, time-separated events, etc., Level 1s target characteristics of a statistical distribution (e.g. average, 80th percentile).
 - Ex: rise time of a specific signal after a particular event (e.g. auroral radio emission after CIR impacting the magnetosphere), fraction of a specific energy input partitioned into a specific output (e.g. electron heating in a solar coronal event)
- Verification parameter(s)

Level-1 Requirements

- Level-1 Mad Libs: The mission shall [quantitative scientific-result verb] [aspect of the physical system] [prepositional phrase] [verification parameter(s)].
- Quantitative scientific-result verb
- Aspect of the physical system
- Verification parameter(s)
 - The robustness of the results that the mission must achieve.
 - Origin of flow down into implementation requirements.
 - Needs to be sufficient to deliver compelling science for NASA's investment. Should not be the best that the implementation can do.
 - Examples: accuracy (space, time, fraction, etc.), confidence level, coverage (“80% of the surface of Planet Acme”, “75% of the total energy”)
- Many Objectives have more than one Level-1 Requirement. The exact form of the L1s depends on the mission-specific Objectives.

Level-1 Requirements

- Level-1 Mad Libs: The mission shall [quantitative scientific-result verb] [aspect of the physical system] [prepositional phrase] [verification parameter(s)].
- I think of Level 1s as coming in one of two forms:
 - Test: The “aspect of the physical system” is a test whether some specific observable configuration of the physical system is fulfilled. Hypothesis- or search-based Objectives may be able to use one or more test requirements.
 - The mission shall determine whether the abundance of Element X in Astrophysical Structure Y increases with radial distance to a 90% confidence interval.
 - The mission shall determine whether the average magnetopause reconnection rate increases with Earth’s tilt towards the Sun to a 95% confidence interval.
 - Task: The “aspect of the physical system” is a required analysis task to draw scientific conclusions about the physical system. All Objectives can use one or more task requirements.
 - The mission shall determine Planet Acme’s internal magnetic field to degree 2 and order 2 with 10% accuracy.
 - The mission shall determine the average Auroral Emission X rise time after the impact of Solar Wind Structure Y with an accuracy of 5 minutes.
 - The mission shall determine the absolute age for Planet Acme’s geologic units larger than X by Y km with an accuracy of 5 minutes for 80% of the surface.

Level-2 Requirements

- Level-2 Mad Libs: The mission shall [quantitative measurement verb] [parameter of the physical system] [prepositional phrase] [verification parameter(s)].
- Level-2 Requirements are the first level of implementation-specific requirements in a mission design.
 - Level 2s describe the data-product requirements for executing the research plan necessary for completing the Level 1s.
 - Level 2s are not the actual observation made by the instrumentation. (For some observables, however, they may be very close. For instance, the vector magnetic field.)
 - Level 2s are still based in the physical system.
 - In the STM, Level 2s fall between the Physical Parameter (e.g. vertical profile of the horizontal wind) and the Observable (e.g. specific emission line).
- Level 2s have a large amount of variability between implementation centers, between projects, and between individuals in leadership positions.
 - I am wary of suggesting that PSEs change the way they flow down their requirements.
 - Main point is that the Level 1s are based in science and the Level 2s have clear traceability down from the Level 1s.

Common Concerns about Level 1s

- Can the Objectives be written in terms of requirements?
 - All science can be written in terms of properly scoped Level 1s.
 - Level-1 Requirements are the way one can tell that you have succeeded, so any potentially successful investigation can write them.
 - If you don't have science-based Level 1s, you can't clearly demonstrate flow between science Objectives and lower-level requirements.
- Level-1 Requirements restrict scientific creativity.
 - Level 1s provide the framework that your mission must be developed in. When you have that base, you gain the freedom to explore innovative solutions within it while still explicitly showing that they enable success.
- Level-1 Requirements can not capture all of the science that will be done.
 - Level 1s are not intended to capture all science that a mission will do or all science that can be done with the mission data. (Note that the latter is outside of the mission Objectives.)
- Level-1 Requirements are hard to develop.
 - Level 1s are easy. If you have an achievable science objective, you already have your Level 1s in mind in some form.
 - Without Level 1s, you can not clearly demonstrate that your measurement requirements are sufficient and necessary to achieve the science objective.
 - Writing requirements is a skill. Once learned, it becomes a natural part of mission formulation.