Mission Definition

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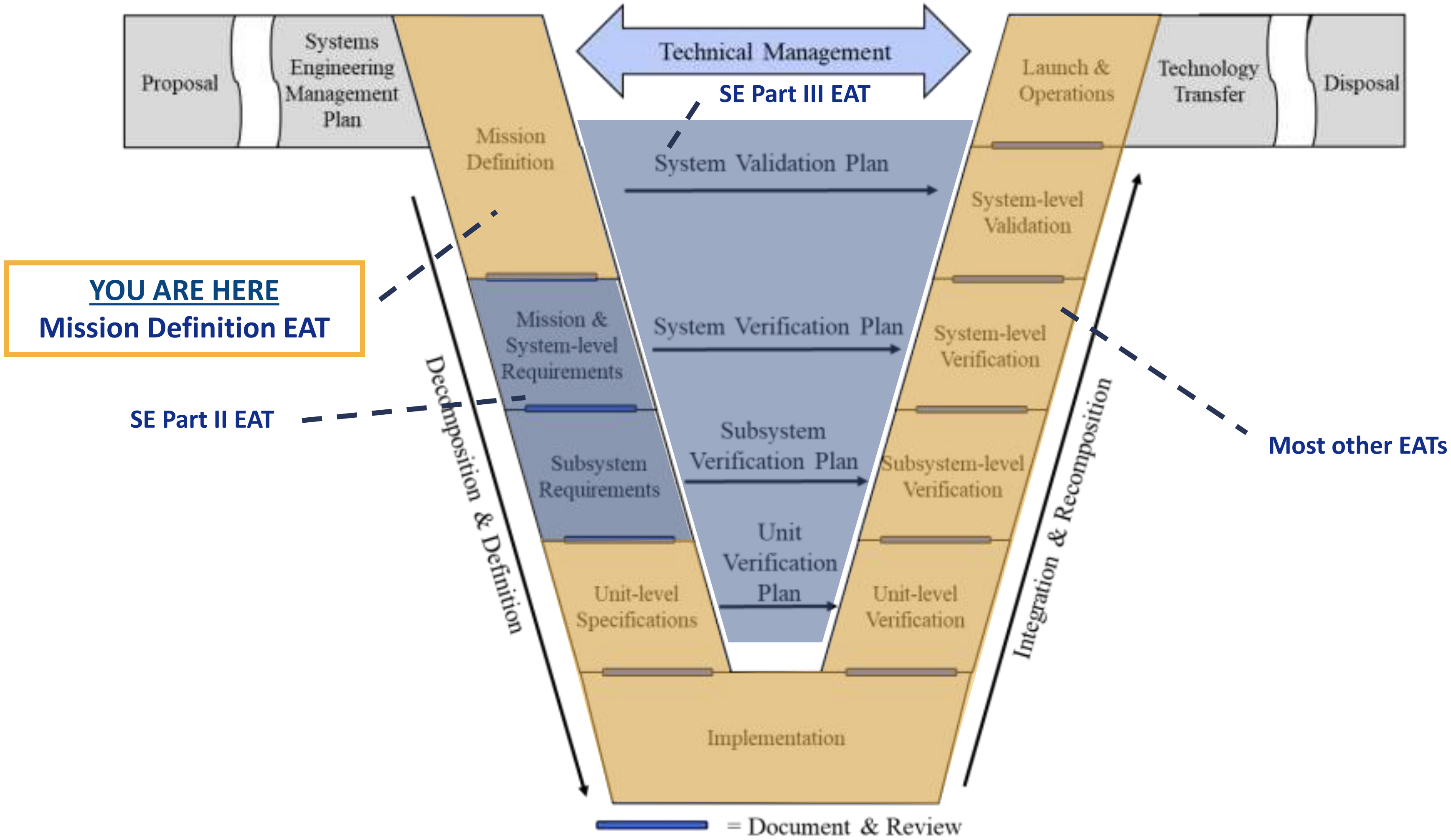
Traditional Systems Engineering



What is Mission Definition?

A process where *stakeholder* needs and expectations are identified and codified into a mission statement, the high level objectives, goals, success criteria, and Level 0 Requirements

- Purpose: <u>define what is being done and what is mission success</u>
  - "When are we done?"

- A *stakeholder* is your lead professor, or the head of the lab + any other people who are interested/driving the need for the mission's data

- References:
  - *UNP User Guide*
  - *NASA/SP-2007-6105, NASA Systems Engineering Handbook*
  - *NPR 7123.1, NASA Systems Engineering Processes and Requirements*
  - *Space Mission Analysis and Design (SMAD)*

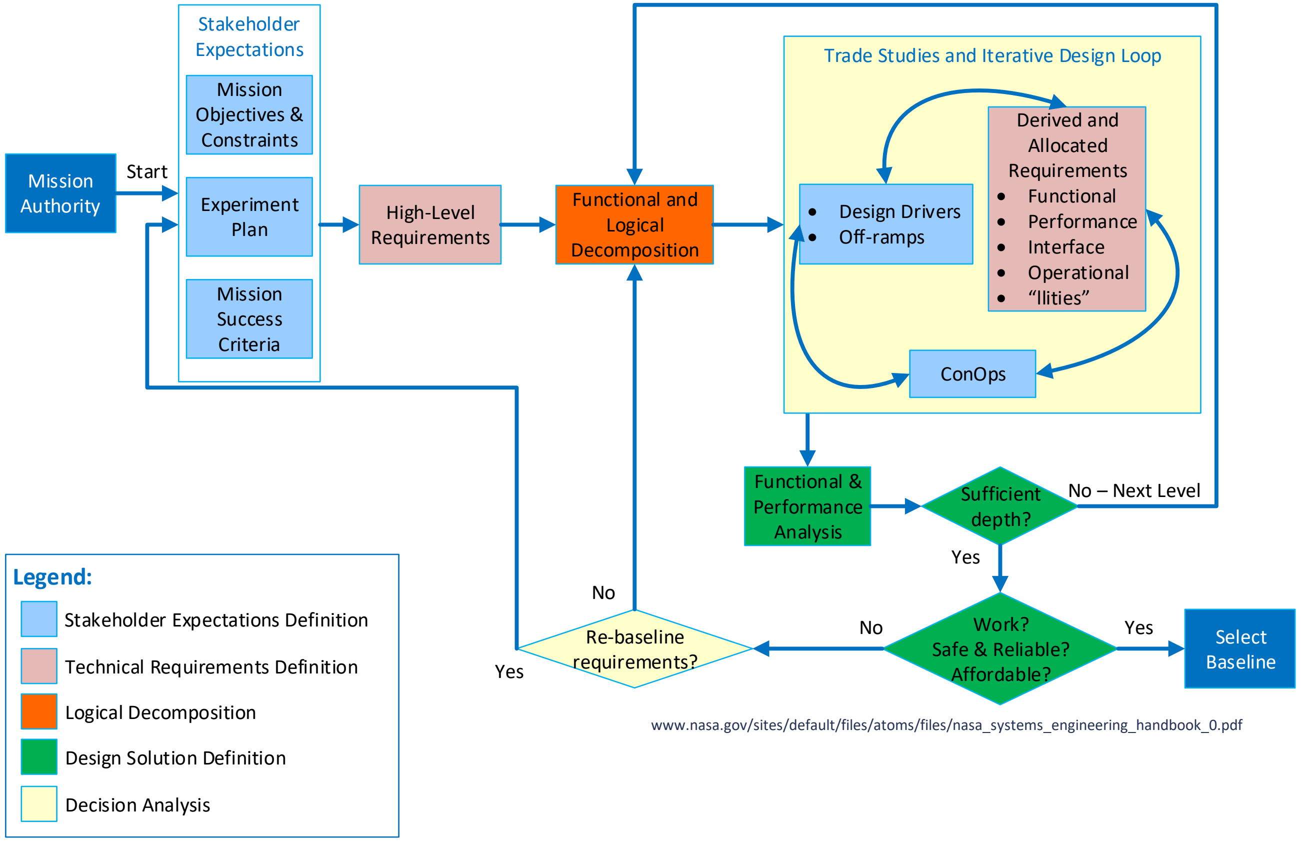
What is Mission Definition?

- Technically
  - Defining what is challenging/what will drive your design the most
  - Convincing yourself, and stakeholders, that the mission is possible and how it is possible
  - Specific metrics that the team can evaluate against to know when the design is acceptable
    - “Better is the enemy of good enough”
  - Constraints: programmatic and/or technical items that bound Mission

- UNP end product: Mission Design Documents (overview, experiment plan, CONOPS)
  - Often convincing argument that this is important and worth doing
  - Contains the above Technical attributes
  - Contains Programmatic attributes
    - Duration + staff + specialty features -> cost
    - Constraints
    - Roles & Responsibilities (stakeholders, team, other involved groups)

Fundamentals of Mission Definition

Traditional Definition Steps



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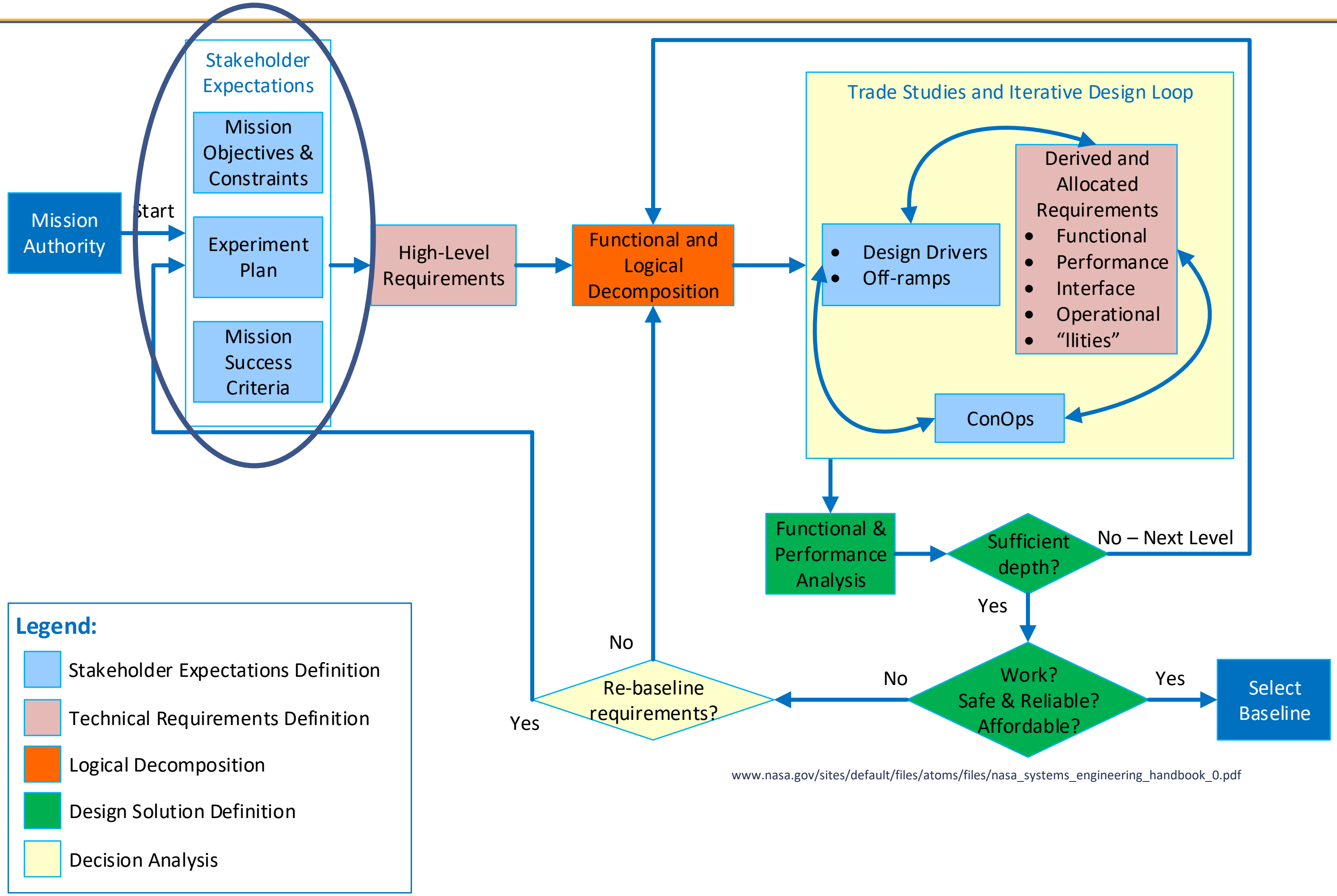
By SCR, your team should have gone through this loop at least once and have a first baseline

Traditional Definition Steps



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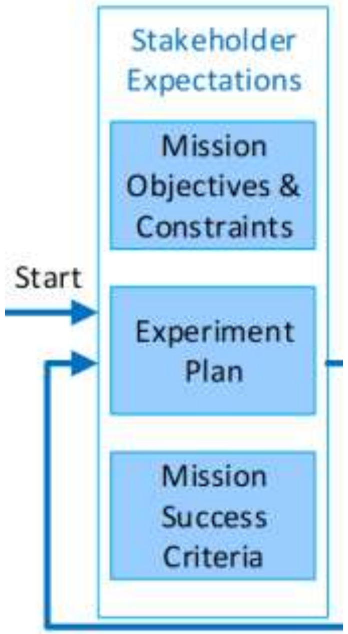
How do you go from flow chart to actual answers?



Mission Statement

UNP: "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 Objective

SMAD: "Broad statements of what the system must do to be useful"

Mission Success Criteria

While Mission Objectives state "what the system must do", Mission Success Criteria state "how well the system must do it" for the stakeholder to consider the mission a success

Your mission's pass/fail criteria, all minimum success criteria must be met to "pass" your mission

Constraint

NASA: "A condition that is to be met. Constraints, in conjunction with the CONOPS, help identify how the system should be operated to achieve the mission's objectives."

Related to "Design Drivers"

Focusing Questions for Identifying and Translating Stakeholder Needs into Mission Definition

What is the question you are trying to answer? / What is the nature of the demonstration you want to achieve?
- What do we already know about it?

What do the physics of the question tell you about how you might answer this question?
- What data and/or information do you need/desire to answer this question?
- What can we say about acceptable error/uncertainty? (i.e. sensitivity study of how well measurements need to be made and trade space between how varying error/uncertainty in various measurements affect the overall mission)
- What are the critical elements you need to obtain that information? (ideal case: an equation with which to solve for certain parameters)

What indications tell you this must be in part, or in whole, accomplished with a space experiment?

SCIENCE/IDEA BASICS

Who is your customer?

What are your customers' requirements?
- What requirement does the user place on the system that drives the mission?
- Does the user care about the way the mission is being performed?
- Does the user care about the way the data is being collected?
- Does the user care about the type of data?
- Does the user care about the accuracy of the requirement?

How will you demonstrate that you have met your customers' requirements?
- How do you know that you have met what your customer needs?

CUSTOMER DISCUSSIONS / CONSTRAINTS

What are the technology options?
- What option(s) do you have for your primary payload?
- What other payloads or capabilities are available and why did you select your approach?

What are the risks associated with using the selected technologies?
- What Technology Readiness Level (TRL) does your primary payload have?
- What are the technical performance risk drivers?
- Describe the schedule and cost risk drivers.

What high-level satellite Concept of Operations (CONOPS) options support the technology options / mission needs?

What's the simplest approach we could take to get the information we need?

TECHNOLOGY OPTIONS

Mission Definition

SCIENCE / IDEA BASICS

CUSTOMER DISCUSSIONS

TECHNOLOGY OPTIONS

Mission Overview

UNP: An expression of the intent of the mission.

Includes: high-level introduction to the mission and supporting satellite system, mission objectives, minimum/full success criteria

CONOPS

UNP: The process and procedure by which the fully developed satellite will fulfill its mission.

IEEE: "A document describing the characteristics of a proposed system from the viewpoint of an individual who will use the system. It shall communicate quantitative and qualitative system characteristics to all stakeholders."

Includes: mission timeline, possible functions (typically described within satellite modes), flight rules, and possible transitions between functions in a satellite's lifetime. CONOPS should describe phase/mode entrance and exit criteria, hardware states, expected operation and experiments, and ground station operations

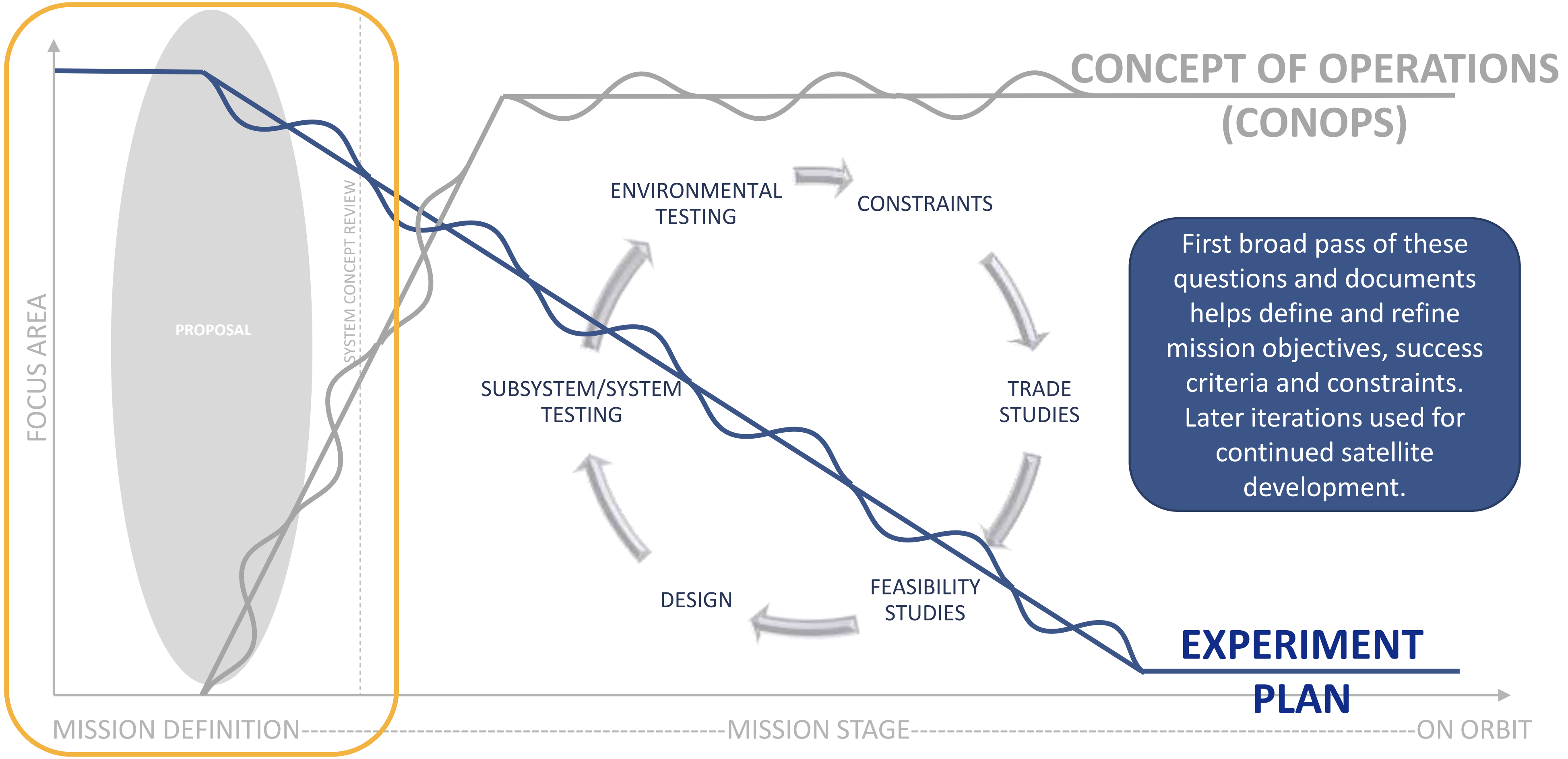
Experiment Plan

UNP: A discussion of the experiments that will be performed.

Includes: what is it measuring/performing, goal/final result of experiment, in what order the experiment occurs relative to other experiments), timeline (quantitative timelines), component on/off, data products, data transfer, satellite configuration, experimental preparation (ground/on-orbit)

First broad pass of these questions and documents helps define and refine mission objectives, success criteria and constraints. Later iterations used for continued satellite development.

When am I done?



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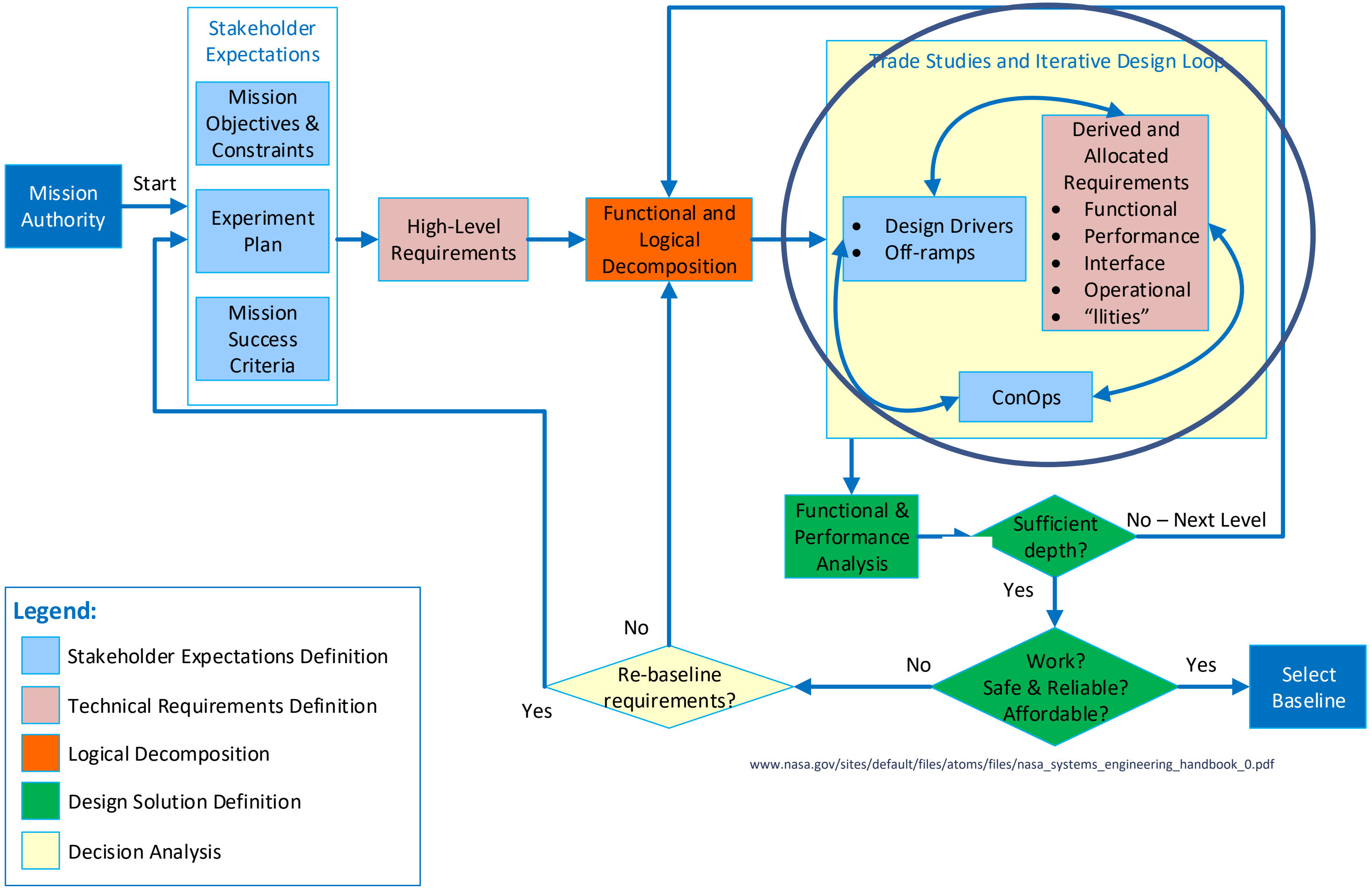
Traditional Definition Steps



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Off-Ramps

- As designs evolve and mature, it may become apparent that the identified solution is too difficult, expensive, time consuming, etc. to accomplish… off-ramps are identified alternatives to accomplish the mission
  - Off-ramps are often not "ideal" solutions & may preclude meeting goals or full mission success
- Should be identified early in the program when possible to allow for quick revectoring; often require inventive thinking
- Example Galileo (to Jupiter):
  - High gain antenna deployment failure led to reliance on low bandwidth command/ telemetry link
    - Was to deploy after Venus & Earth sling shots
    - Went from 135kbps X-band to 10bps S-band!
  - Caused a 100x improvement in data rates*
    - Improved compression schemes and encoding brought data rate to 100bps
    - Ground (DSN) arraying and improvements brought rate to 1000 bps
  - Mission met about 70% of its original objectives!

*Taylor, Jim, Kar-Ming Cheung, and Dongae Seo. Galileo Telecommunications. Article 5. Pasadena: NASA-JPL/ CalTech, 2002. DESCANSO Design and Performance Summary Series.

Matures concept definition, stakeholder understanding, and may inform success criteria

Key Questions:

- What are the technology options for payload/capability?
- What are the technology options for the constraints identified?
- What’s the simplest approach we could take to get the information we need?
- What top-level CONOPS options support the technology options / mission needs?

Derived and Allocated Requirements

- Covered further in EAT: Systems Engineering Part II
- Basically:
  - Functional Requirements: what does the system need to do (not how)
  - Performance Requirements: how well does a system need to make measurements?
  - Interface Requirements: constraining needs for the system (launch, deployer, etc.)
  - Operational Requirements: what does system need to do, when operating, to collect data
  - "Ilities":
    - Operability – can system actually be used?
    - Availability – how often, how long to take measurements?
    - Sustainability – how will vehicle be maintained on ground & in-flight (software uploads)?
    - Reliability – piece parts but can be expanded to worst-case analyses, failure probability
    - Survivability – environmental and other drivers to system

Concept of Operations (CONOPS)

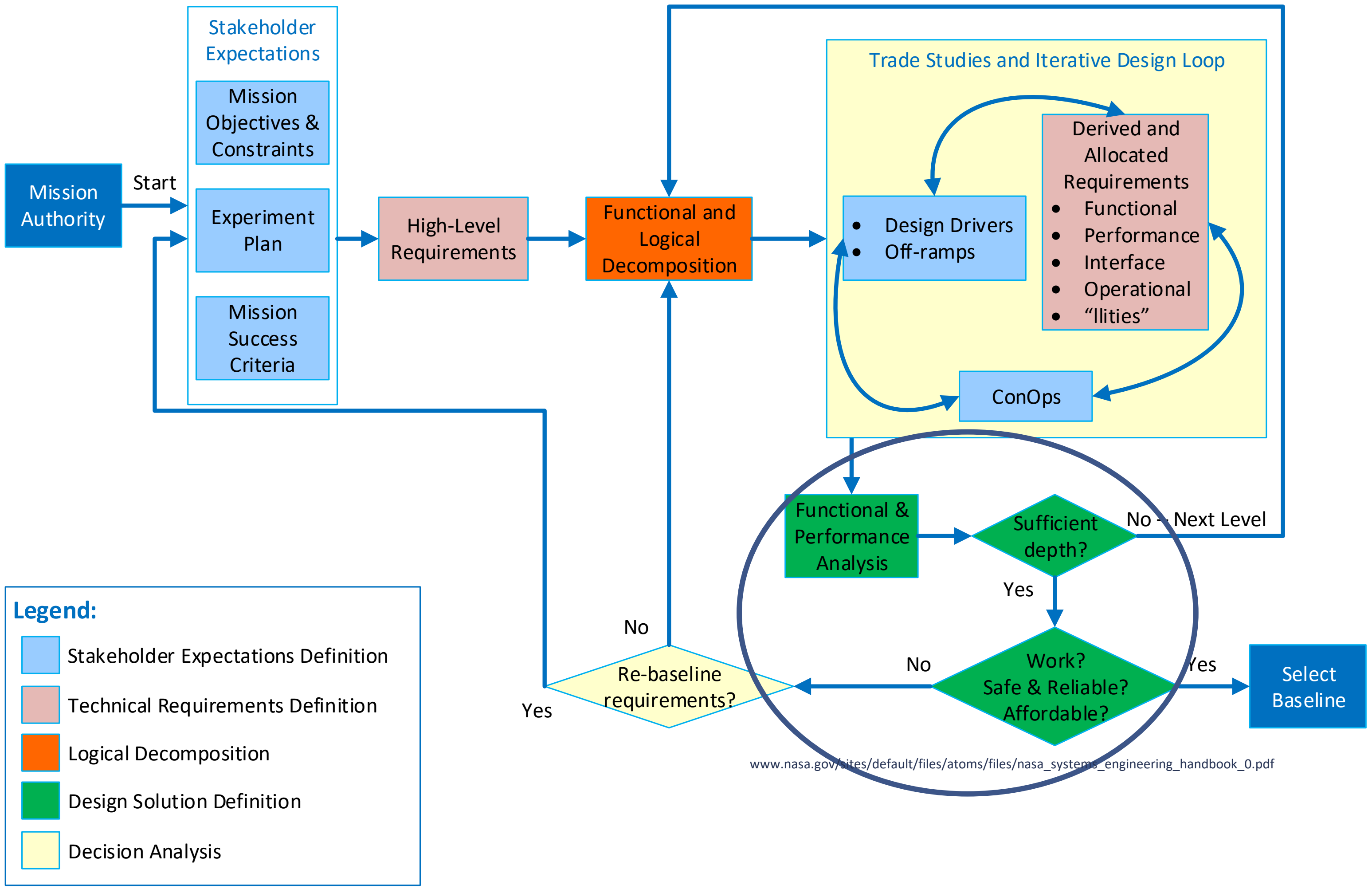
- Describes how the Mission will achieve the objectives including Flight, Ground, and Information Systems
- How does the project get data or carry out the mission to satisfy stakeholders?
- Can be broken into four major elements (see SMAD):
  1. Data delivery
  2. Communications architecture
  3. Tasking, Scheduling, and Control
  4. Mission Timeline
- If the Experiment Plan describes the data and tasking that need to be done, the CONOPS address how that data is created, sent to the ground, and the timeframe it is done within

Trade Studies

- Great to collect & document choices & evolution of mission
  - Can be at any level of design: architectural (6U vs. 12U, Camera vs. LIDAR), subsystem, vendor, part, etc.
- Generally functionality/performance are traded against schedule, cost, or feasibility
  - Should outline MUST HAVE attributes vs. items that can be traded
  - Inputs should be as quantitative as possible; evaluation is often qualitative
- Often requires research, modeling, and programmatic evaluation to collect inputs to create trade

Characteristic	Architecture/Part/Configuration #1	Architecture/Part/Configuration #2	Comments
Interface with other mission elements	Fits all interfaces	Requires some rework	ICD referenced
Performance	Achieves 70% of objectives	Achieves 90% of objectives	Based upon system budget
Lead Time (Schedule)	Integration with FlatSat in month 2	Integration with FlatSat in month 2	Both options meet schedule
Cost	$100	$150 + $TBD for rework of interfaces	Both above desired cost but are possible. Rework is concern on #2

Mission Definition



Feasibility

- "Functional & Performance Analysis" + "Safe & Reliable, Affordable"
  - All of these are Feasibility studies
- Analyzing the Design Drivers is one of the key ways to determine feasibility
- System Budgets are great way to assess (i.e. power, data, link, mass):
  - Iteration 1 = sizing/architecting of system + identifying drivers + feasibility
  - Iteration 2 = analysis tool to track progress/verification of these budgets with test results
  - Iteration 3 = Use as operations tool to ensure system is capable of a given operations profile
- Ideally, physics-based models of the technology or science demonstration exist to inform mission developers of key needs
- Utilize trade studies to compare capability vs. need vs. constraints (time, money, people knowledge)

Summary

We do this process because it helps engineers define and understand stakeholder needs, and therefore mission needs

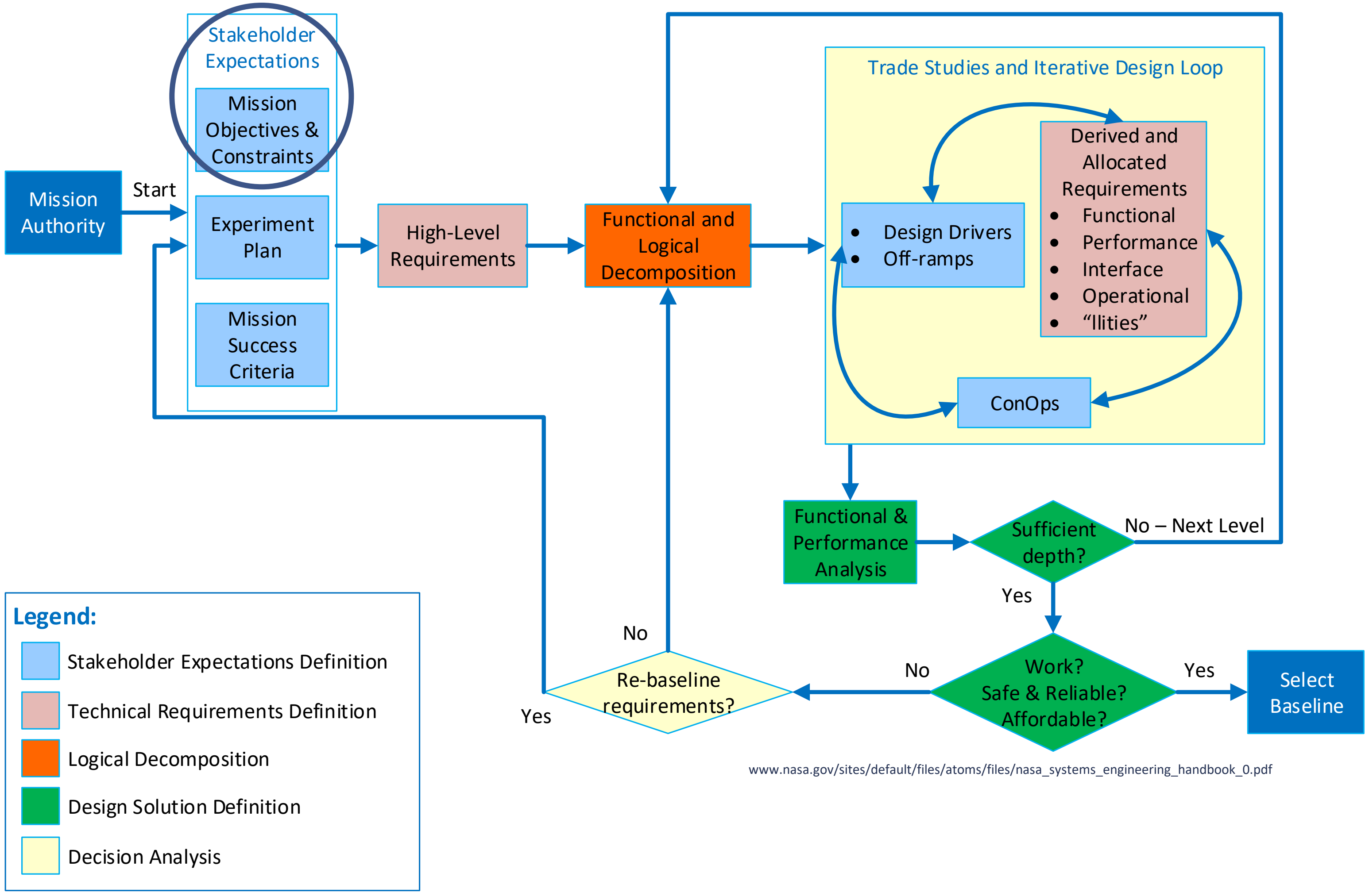
- UNP has defined the Mission Definition Document, and system-level budgets as ways to capture this information

- By the system concept review, you should have gone through this loop at least once and have a baseline. Convince **yourself** that the mission is feasible
  - Often "Stakeholder Expectations" box is an iterative cycle during the concept phase of a mission. Stakeholders also need to understand what is possible
  - Teams are highly likely to revisit all elements in the Mission Definition flow throughout the project's lifetime

Mission Example: An Old UNP Mission (DANDE)

The Drag and Atmospheric Neutral Density Explorer (DANDE)

Mission Definition



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Key Questions: Mission Definition

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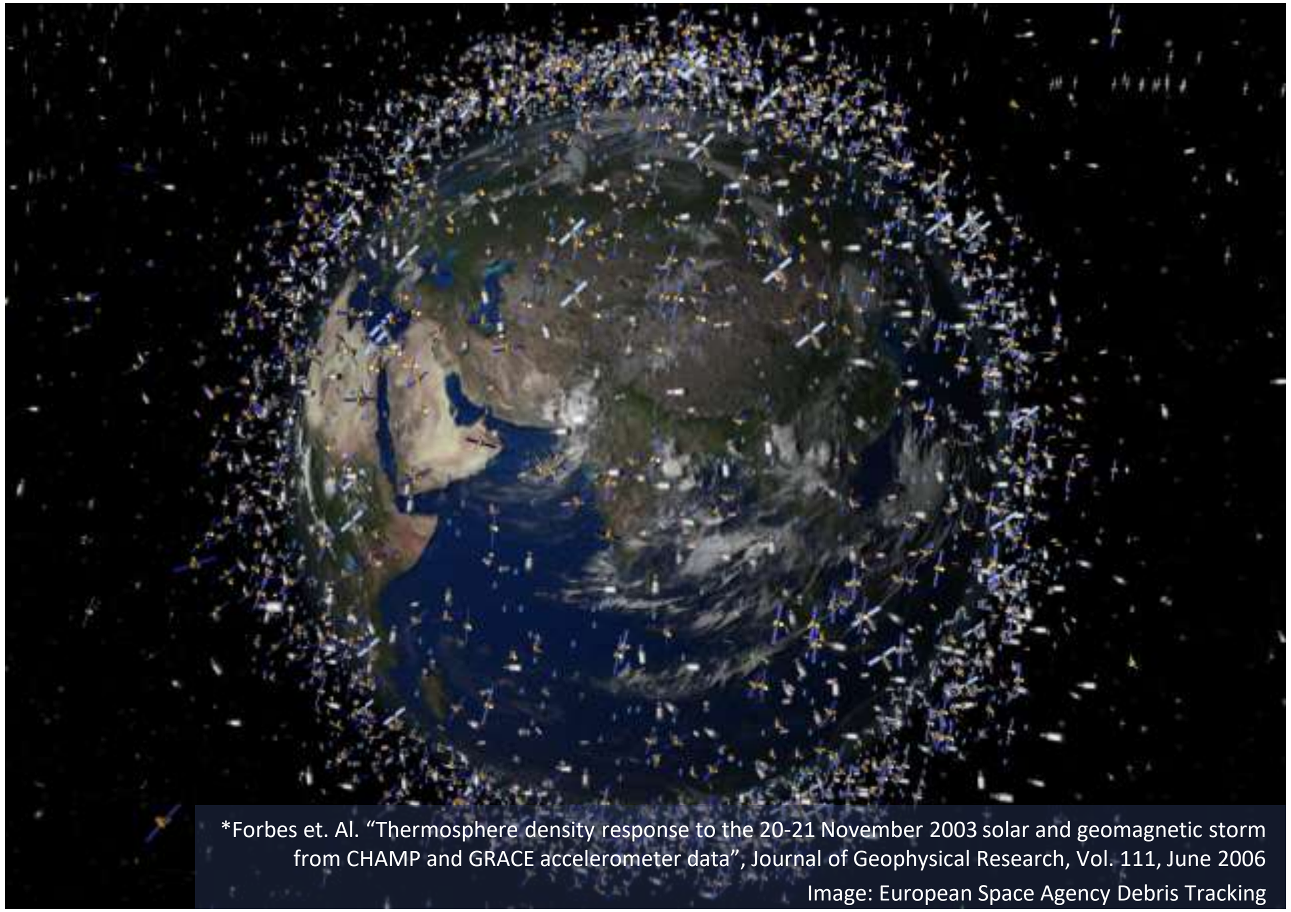
  - What indications tell you this must be in part, or in whole, accomplished with a space experiment?
- Why does this question matter? Who might be a stakeholder or interested party?

DANDE Mission Narrative

Operational Importance of Drag

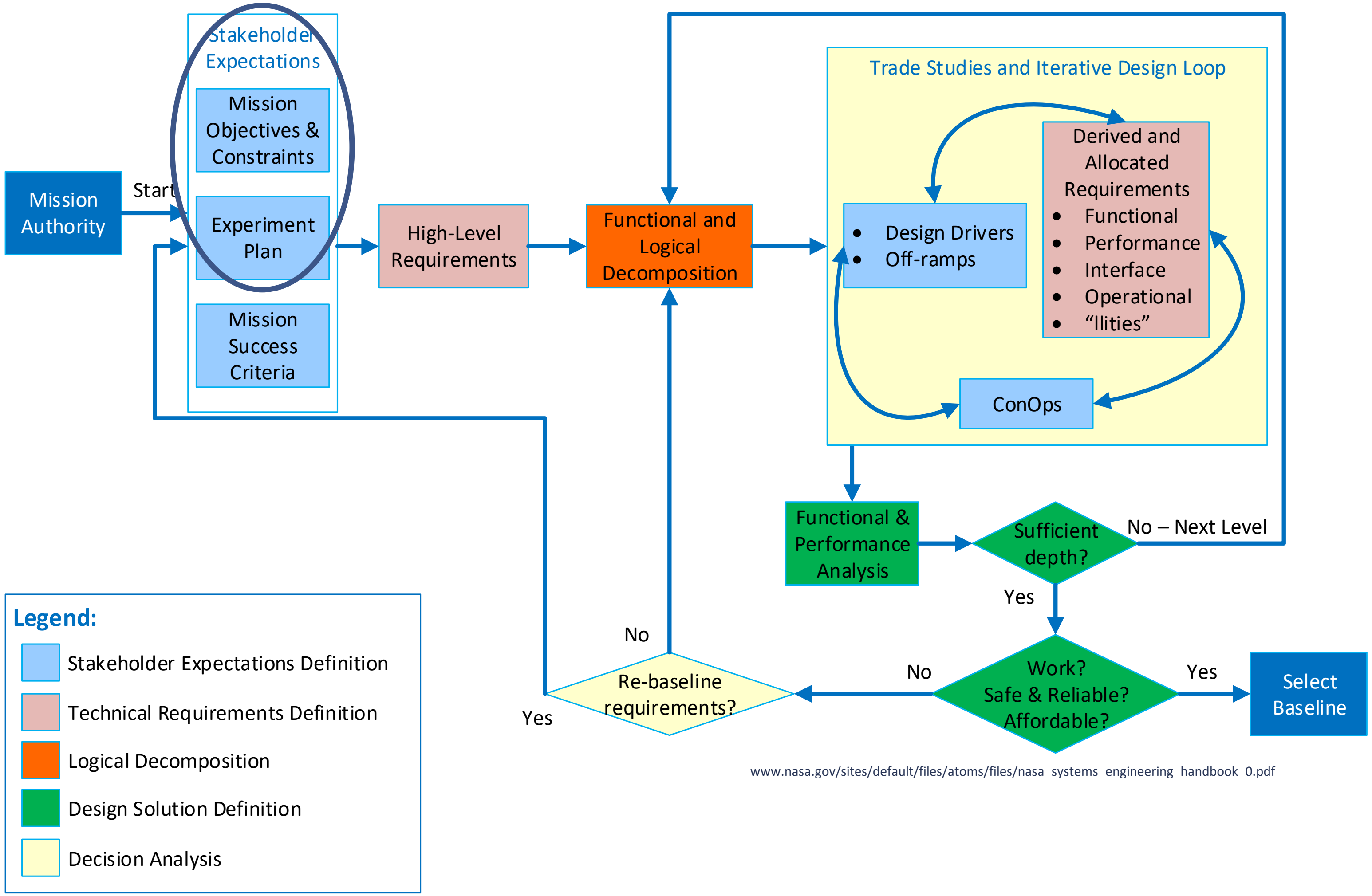
The density of the atmosphere in this region [the thermosphere] varies greatly (300% to 800%*) due to space weather and not yet understood coupled processes.



*Forbes et. Al. “Thermosphere density response to the 20-21 November 2003 solar and geomagnetic storm from CHAMP and GRACE accelerometer data”, Journal of Geophysical Research, Vol. 111, June 2006

Image: European Space Agency Debris Tracking

Mission Definition



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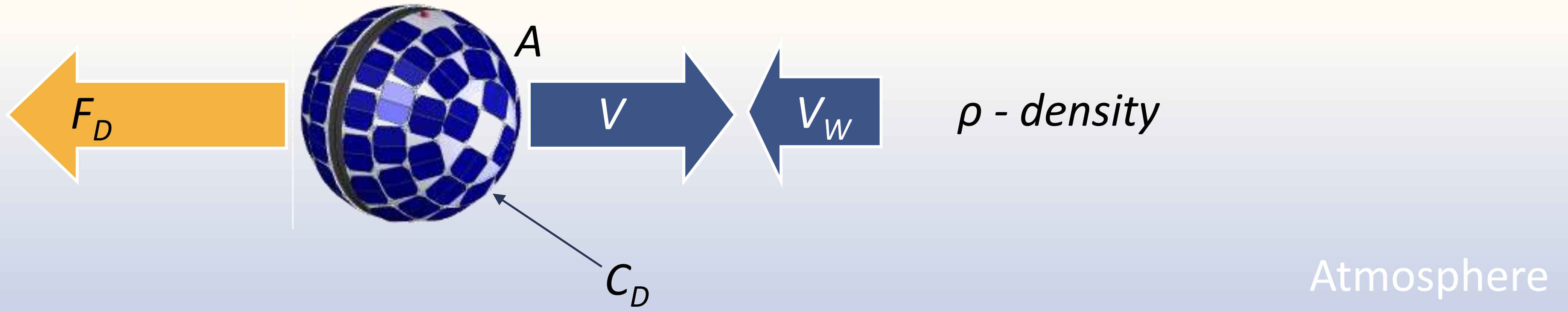
The Physics of DANDE



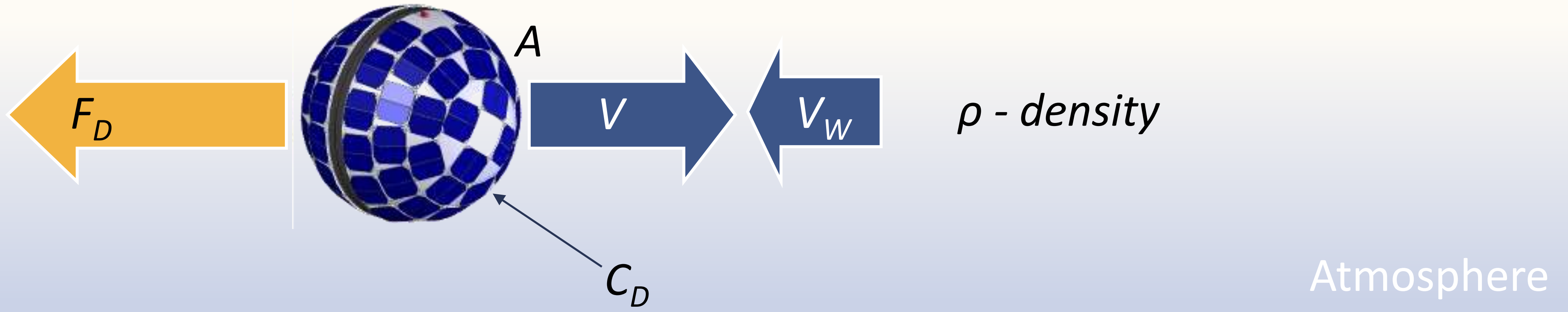
measured
a priori
solution

$$F_D = \frac{1}{2}\rho \cdot C_D \cdot A \cdot (V + V_W)^2 = M \cdot a$$

AFRL Image

- Well known physics used as basis for experiment
- Identifying all components of the constituents of the drag equation
- **CLEAR** identification of what can be measured, what is known, and what is being determined

The Physics of DANDE



Tracking

WTS sensor

Accelerometers

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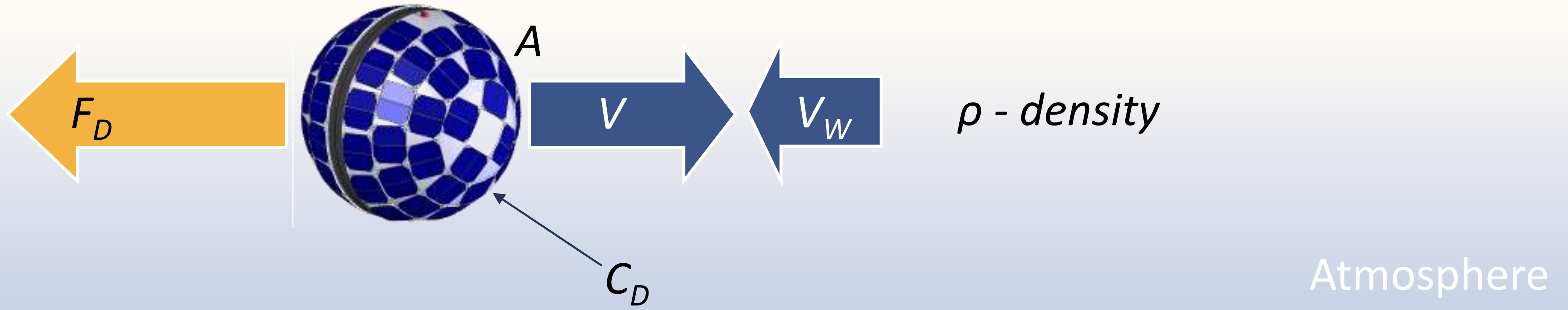

measured
a priori
solution

Tracking
WTS sensor
Accelerometers

$$F_D = \frac{1}{2}\rho \cdot C_D \cdot A \cdot (V + V_W)^2 = M \cdot a$$

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a priori knowledge comparison
a priori knowledge
a priori knowledge

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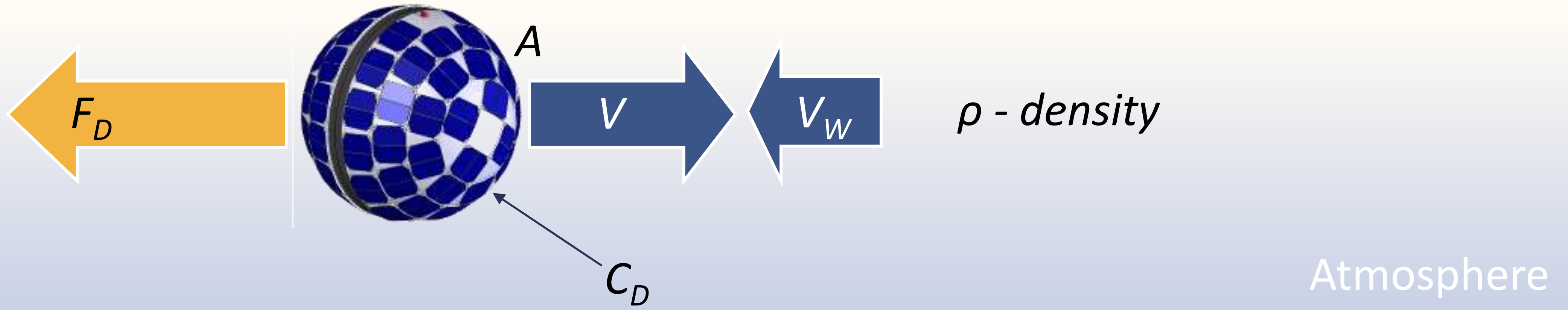
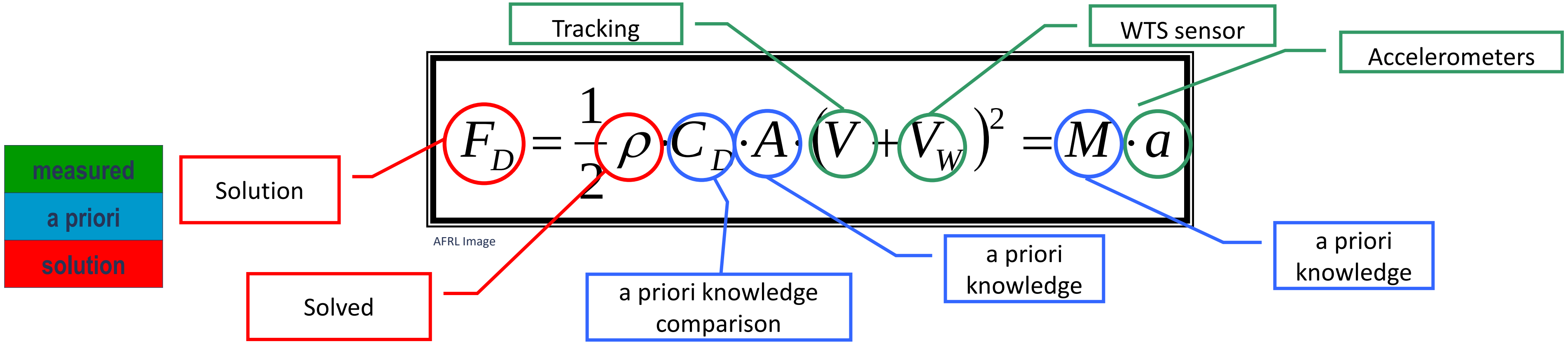
The Physics of DANDE





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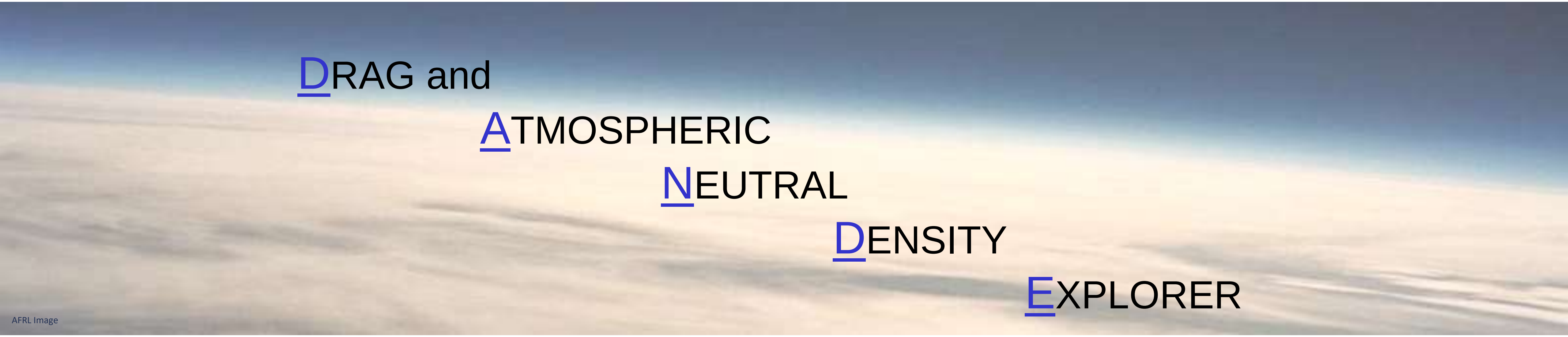
DANDE Mission Statement



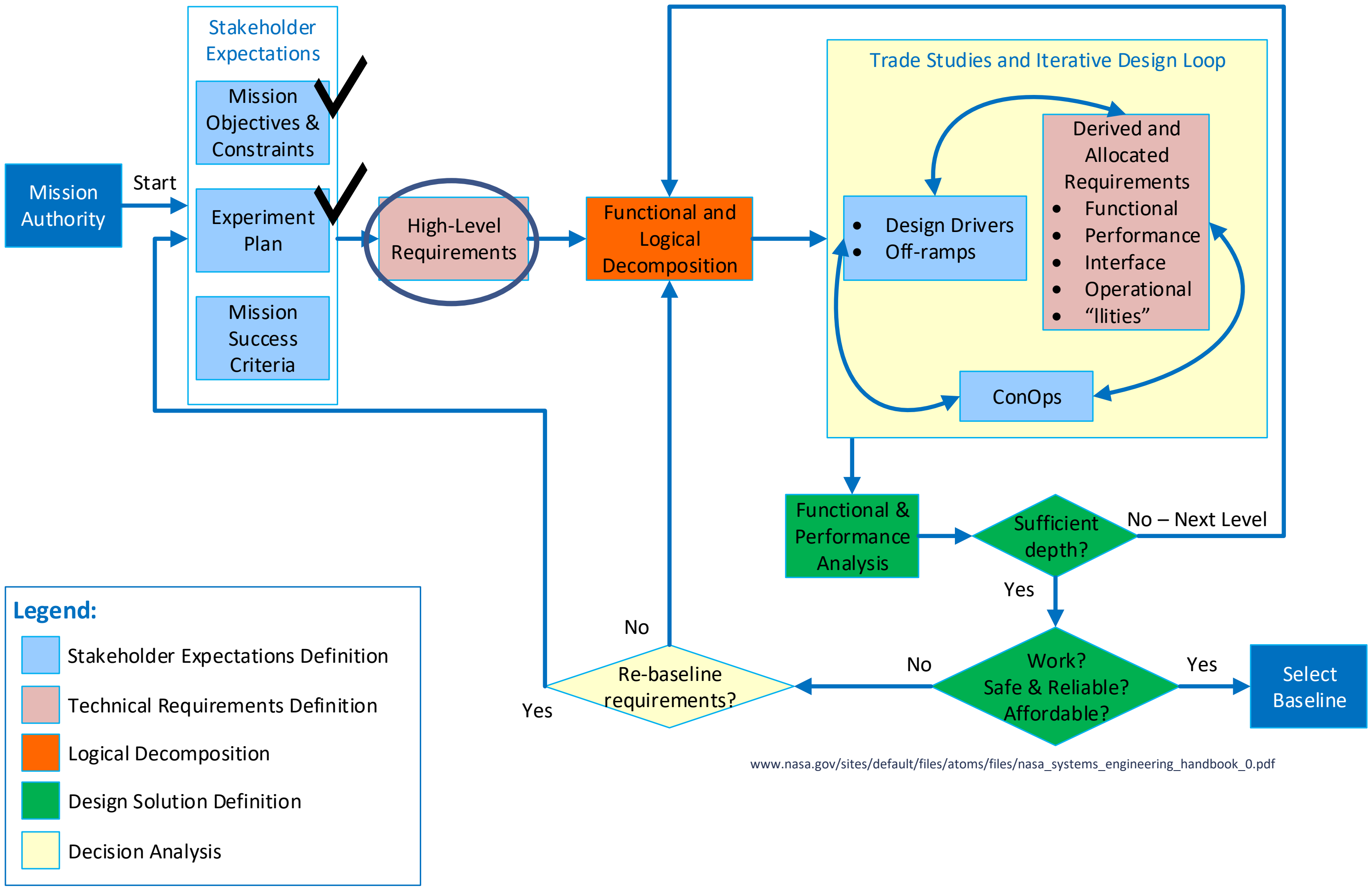
Mission Statement

Explore the spatial and temporal variability of the neutral thermosphere at altitudes of 350 - 200 km and investigate how wind and density variability translate to drag forces on satellites.

DANDE Objectives

Mission Statement and Mission Objectives				
Ref	Description	Parent Ref.	Applicable Documents	Related Science Questions
G1	Explore the spatial and temporal variability of the neutral thermosphere at altitudes of 350 -100 km and investigate how wind and density variability translate to drag forces on satellites.	AFSPC-A9A, NOAA, CU-ASEN	SYS101.0 DANDE Proposal	
PO1	Establish and understand the relationship between total mass density, composition, and winds as functions of latitude, level of magnetic activity, and horizontal scale.	G1	DoD Multidisciplinary University Research Initiative (MURI) BAA, FY07 MURI topic #14 - Atmospheric Neutral Density Prediction	Q1. What are the global relationships between density, composition and winds? Q2. How do density, composition and winds vary with respect to each other locally? Q3. How well do current empirical and first principles models emulate variations in density, composition and winds?
PO2	Establish the relative contributions of density and winds to satellite drag as a function of latitude, level of magnetic activity, and horizontal scale.	G1	MURI BAA	Q5. Under what conditions do winds have a non-negligible effect on satellite drag? Q6. What is the relationship between spatial variability of density and winds, and the integrated drag on a satellite?
PO3	Demonstrate key technologies for performing in-situ measurements of the orbital drag environment at low cost.	G1	MURI BAA	Q7. Can the in-situ density-measurement concept be employed effectively for aeronomic research within the framework of the University Nanosatellite Program?
PO4	Improve understanding of the variation in coefficient of drag in the 200-300 km altitude region.	G1	MURI BAA	Q8. How does the coefficient of drag vary when with altitude?

Mission Definition



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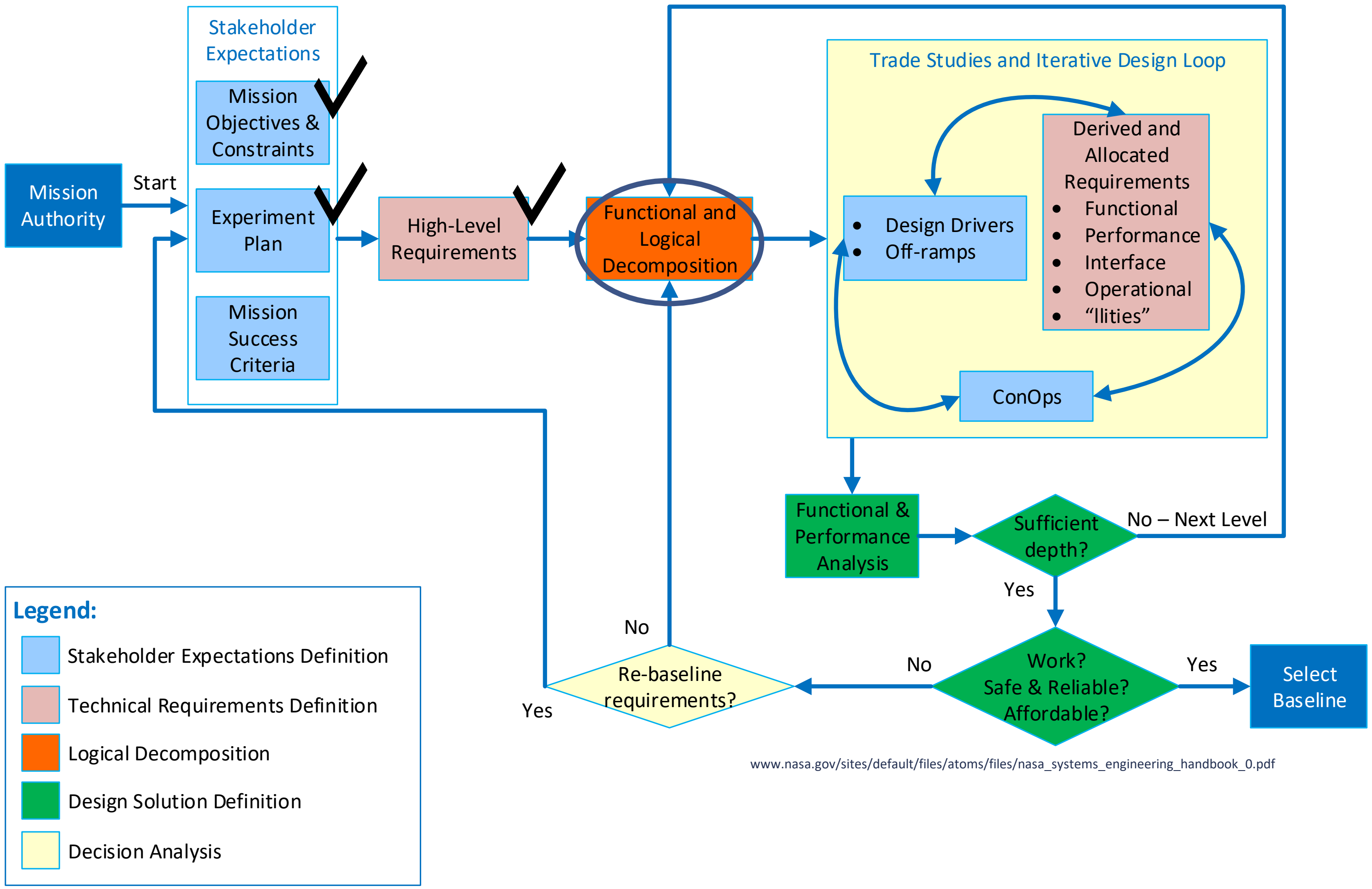

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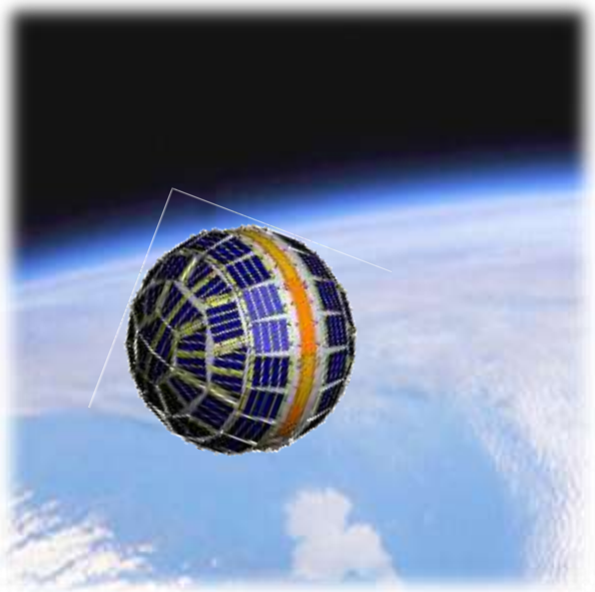
Functional & Logical Breakdown



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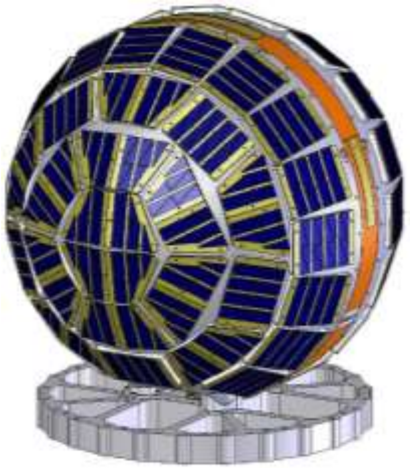

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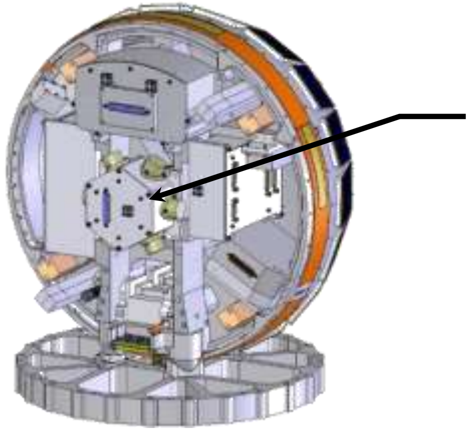

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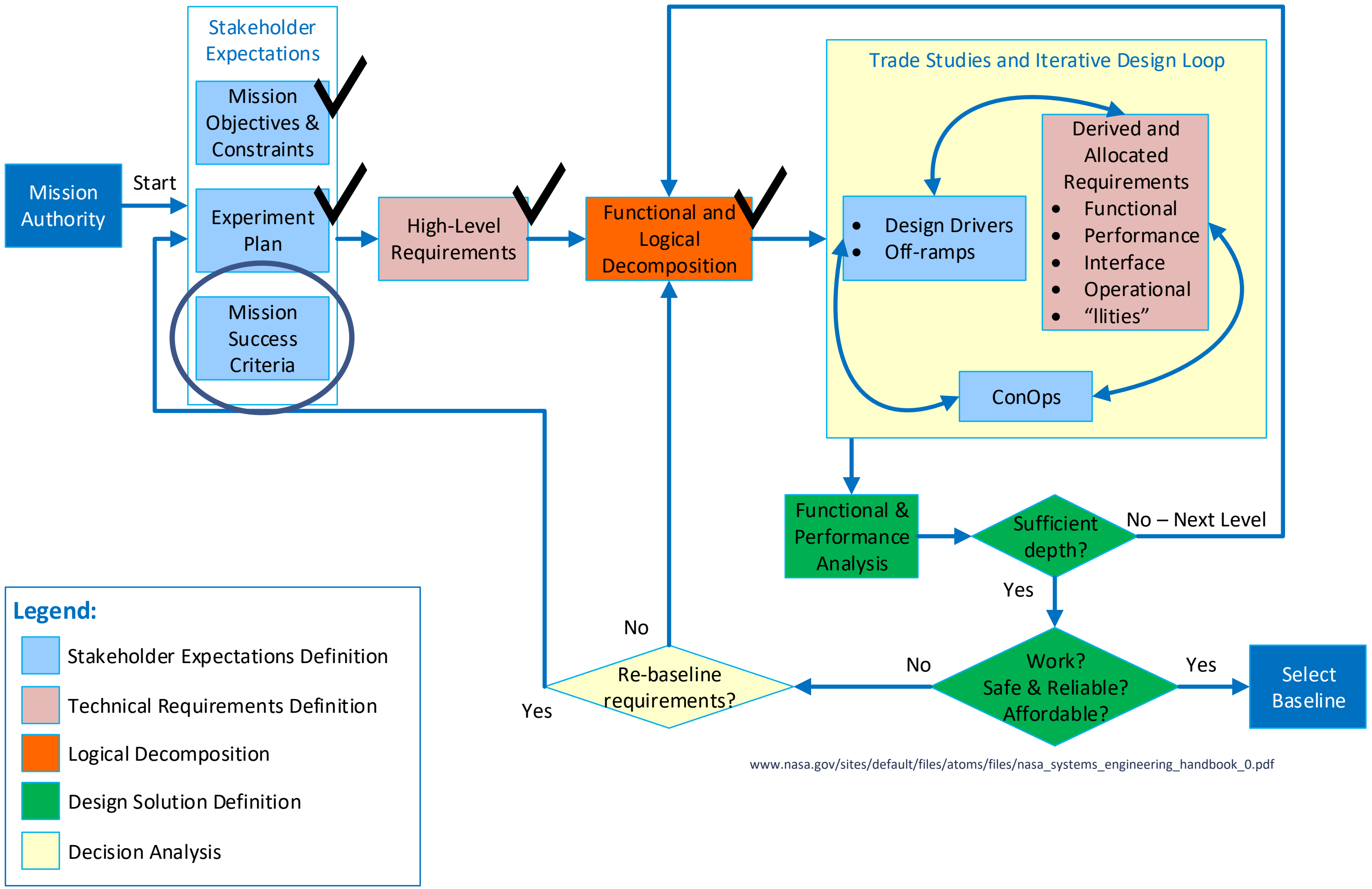
- Spherical section necessary for constant Cd
  - Can be passively utilized for ground measurements!
- Commonly utilized attachment for launch (Lightband)

Accelerometers (x6)
Placed at CG/rotation center

Mission Definition



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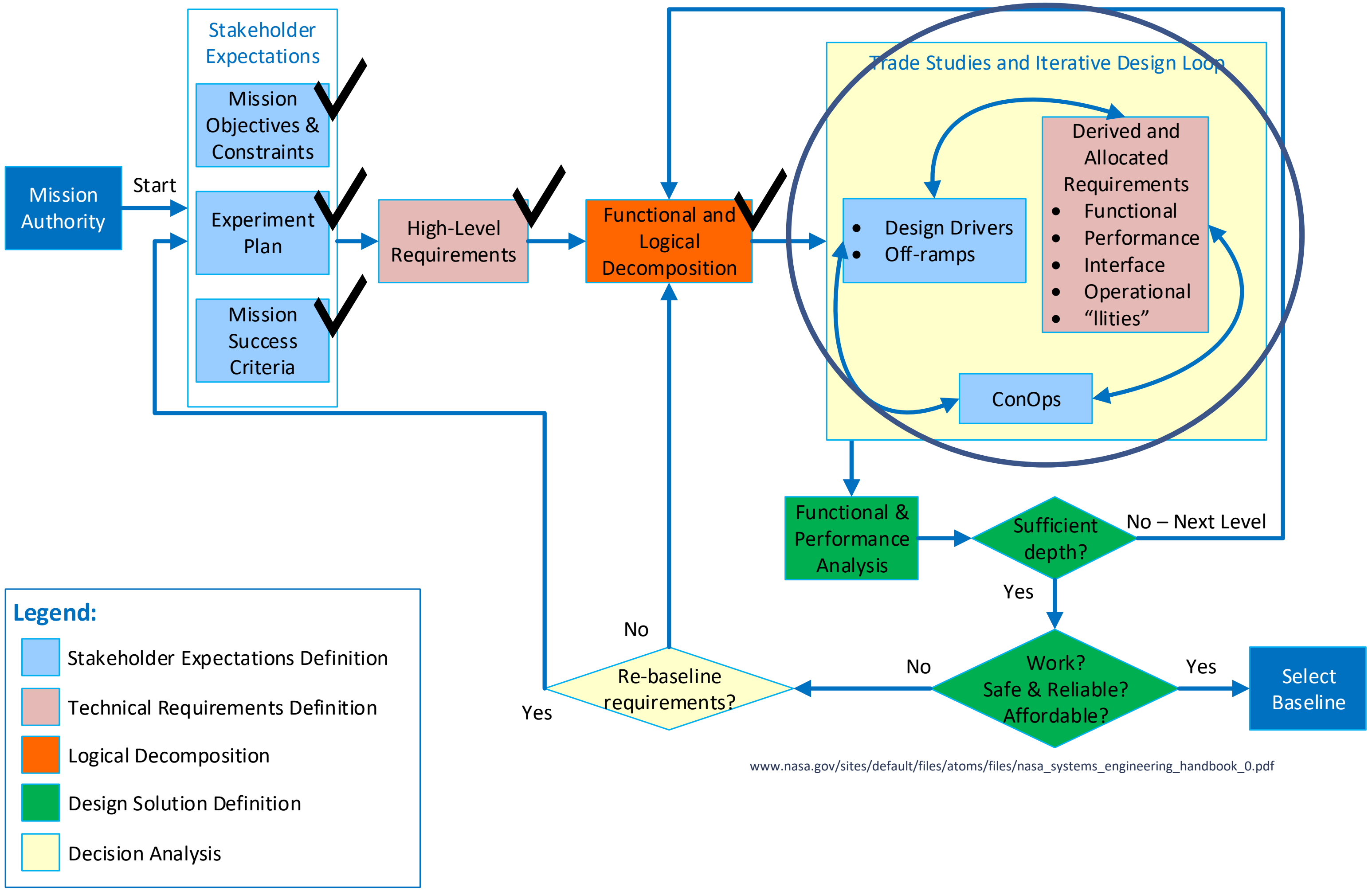
Mission Success Criteria

1. Minimum Success
   - Eject Lightband + adapter to achieve spherical shape: can be used as ground calibration target without any further data
   - *<We learned minimum need was to at least make DANDE a calibration object e.g. a sphere.>*
2. Full Success
   - Achieve L0 Requirements

Mission Definition



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Trade Studies & Iterative Design Loop

MANY Iterations

- System:
  - Started as 3 deployable orbs + mother ship doing tracking
    - Why it changed: CONOPS challenges, sensor availability, team's capability to create 4 spacecraft limited
  - Altitude reduction deployable (drag-sail)
    - Why it changed: deemed too challenging of mechanism. Requirement relief from stakeholders + UNP PMO

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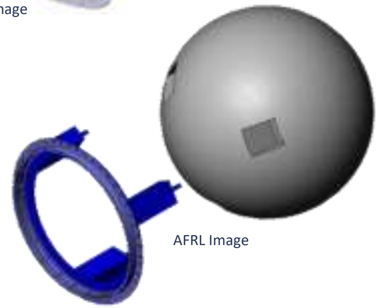

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- Subsystem (post Mission Definition)
  - Structural design: changed to single piece
    - Why it changed: did not pass protoqual vibe levels; increased stiffness but more machining time
  - COMM: added whip + patch antennas
    - Why it changed: initial data rates not achievable and radio hardware not available
  - Ballast + Nutation damping: several iterations
    - Why it changed: avoiding fluid filled containers, changes as ADCS evolved

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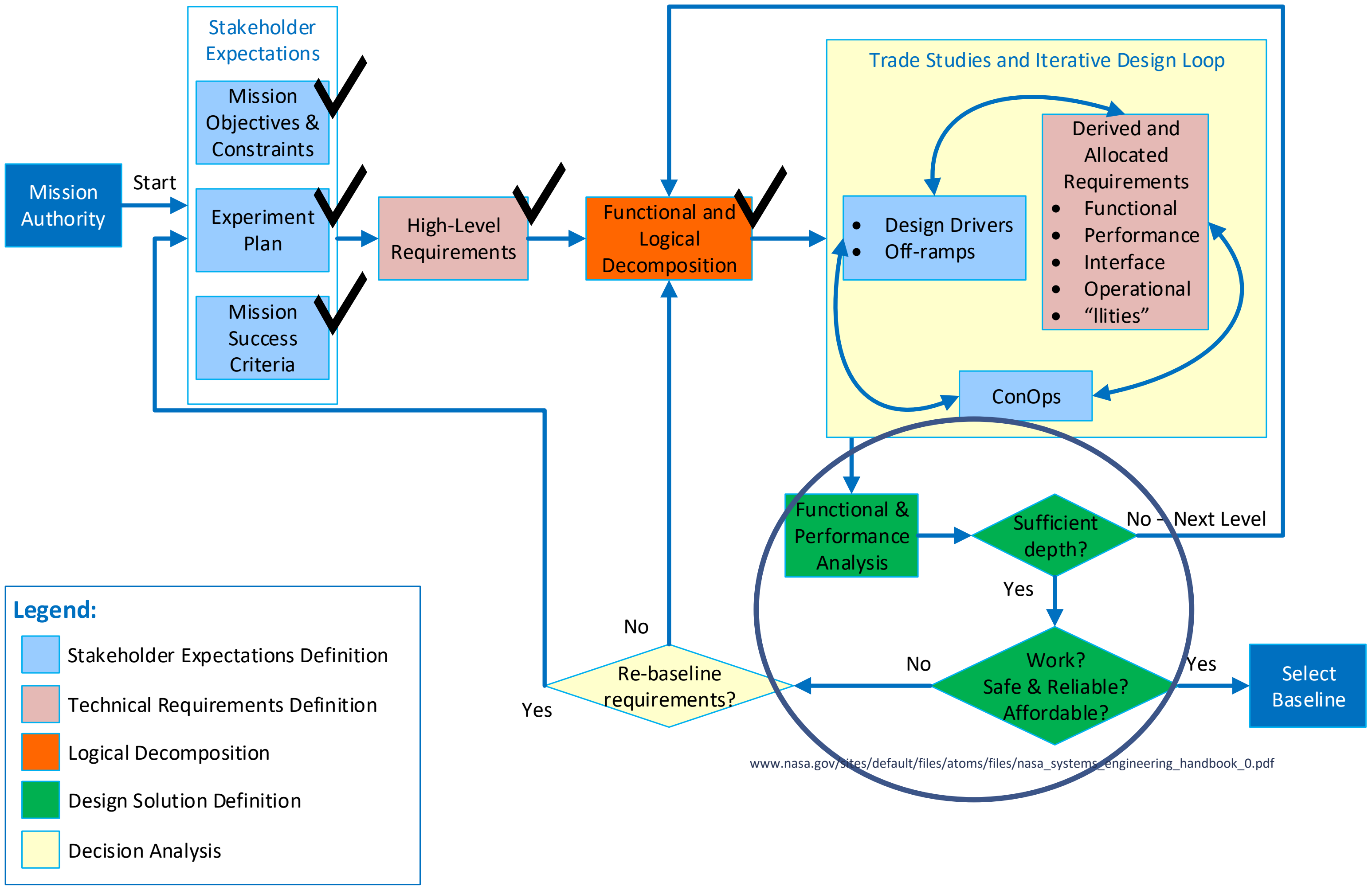
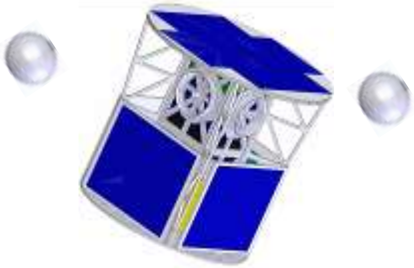


Feasibility



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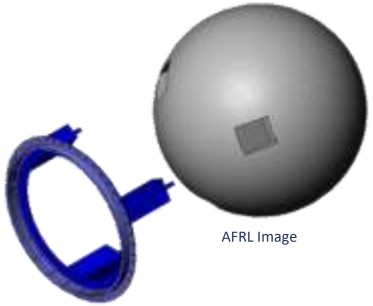
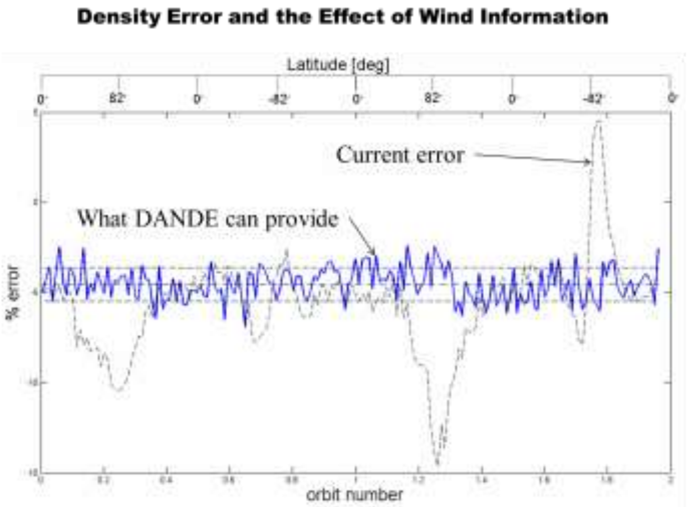


AFRL Image

AFRL Image

Evolution of Architecture: “90% of mission for half cost/risk”

Analyses of instrument needs/capabilities vs. current models



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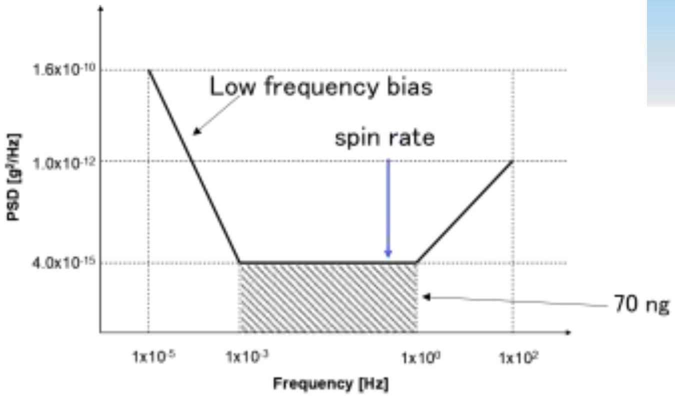

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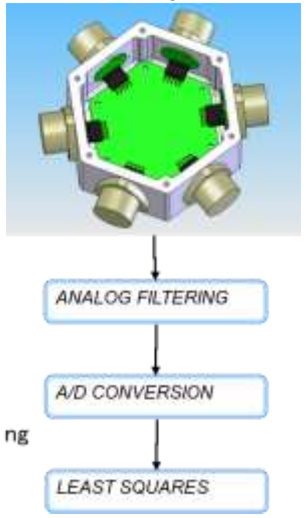

Questions?