National Aeronautics and Space Administration

Fundamentals of Systems Engineering

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Access to Space for All
Systems Engineering Webinar Series

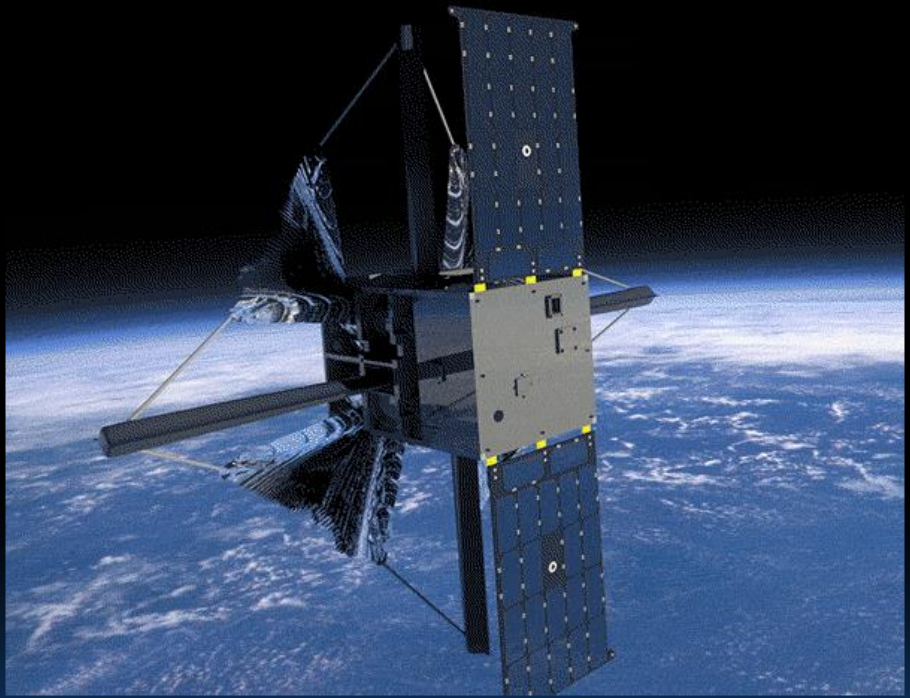
Craig D. Burkhard, Ph.D.

Deputy Director, NASA Small Spacecraft Systems Virtual Institute

Webinar Overview

This webinar offers an overview of the fundamentals of systems engineering and project management as they relate to small spacecraft projects. This overview includes a discussion of the following:

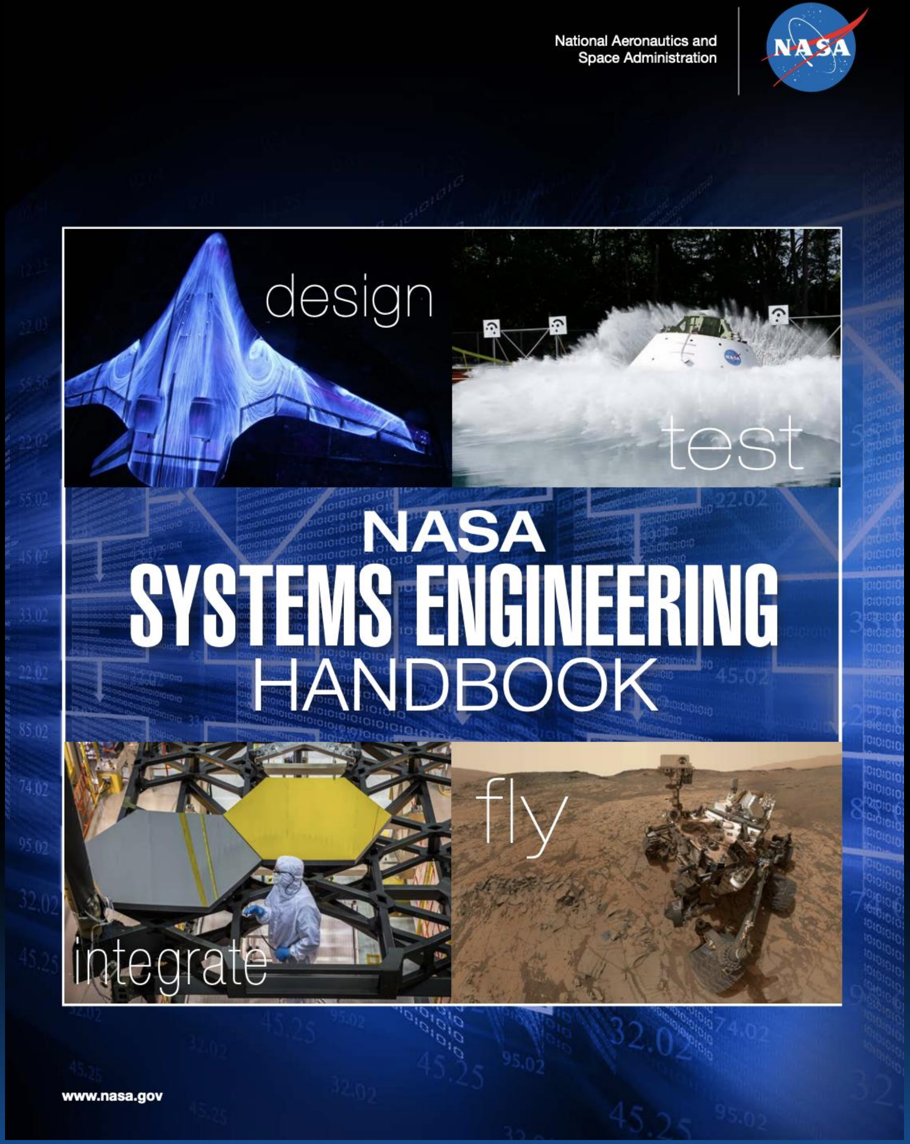
- What is Systems Engineering?
- What does a Systems Engineer do?
- What are the Elements of Managing a Small Spacecraft Project?
- What are the Elements of a Project’s Life Cycle Phases?
- What are the Roles and Responsibilities of a Systems Engineer?
- Why does NASA use Systems Engineering?



What is Systems Engineering?

Systems Engineering, is a “*robust approach to the design, creation, and operation of systems. In simple terms, the approach consists of identification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment of how well the system meets (or met) the goals*."

NASA Systems Engineering Handbook, 1995



Systems Engineering Knowledge Base

Knowledge Base

System Level Thinking and Basic Analytical Skills

Domain Specific Knowledge

- Customer
- Product
- Technology
- Organization

System Engineering Roles

- Process
- Tools
- Role
- Product Line Functions
  - Manufacturing
  - Quality
  - Test
  - H/W & S/W Development

Professional Effectiveness Skills

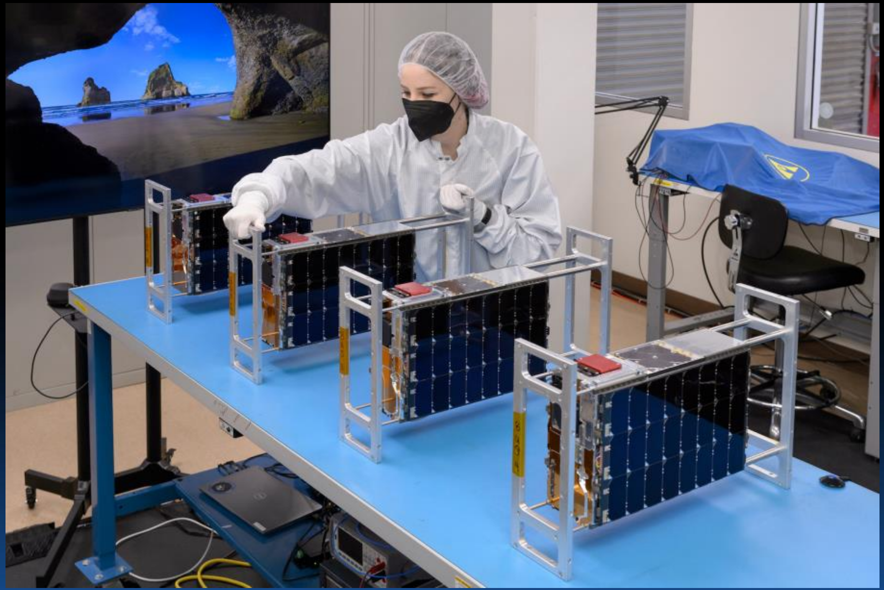
- Meeting Focus
- Questioning Skills
- Conflict Resolution
- Creativity
- Closure

What Does a Systems Engineer Do?

- Lead requirements analysis efforts:
  - Top level requirements
  - Derived requirements
  - Detailed design requirements
  - Allocate requirements to segment/ subsystem level
  - Validate requirements with customers, users, authorities
- Develop specification inputs
- Establish functional baseline
- Ensure technical integrity
- Integrate specialty inputs
- Develop interface definitions
- Lead architecture identification
- Develop system concept
- Synthesize potential system solutions
- Partition the system into elements
- Lead feasibility studies
- Identify/lead/perform trade studies and analyses
- Support design solutions
- Approve test plans
- Coordinate verification activities
- Coordinate failure analyses

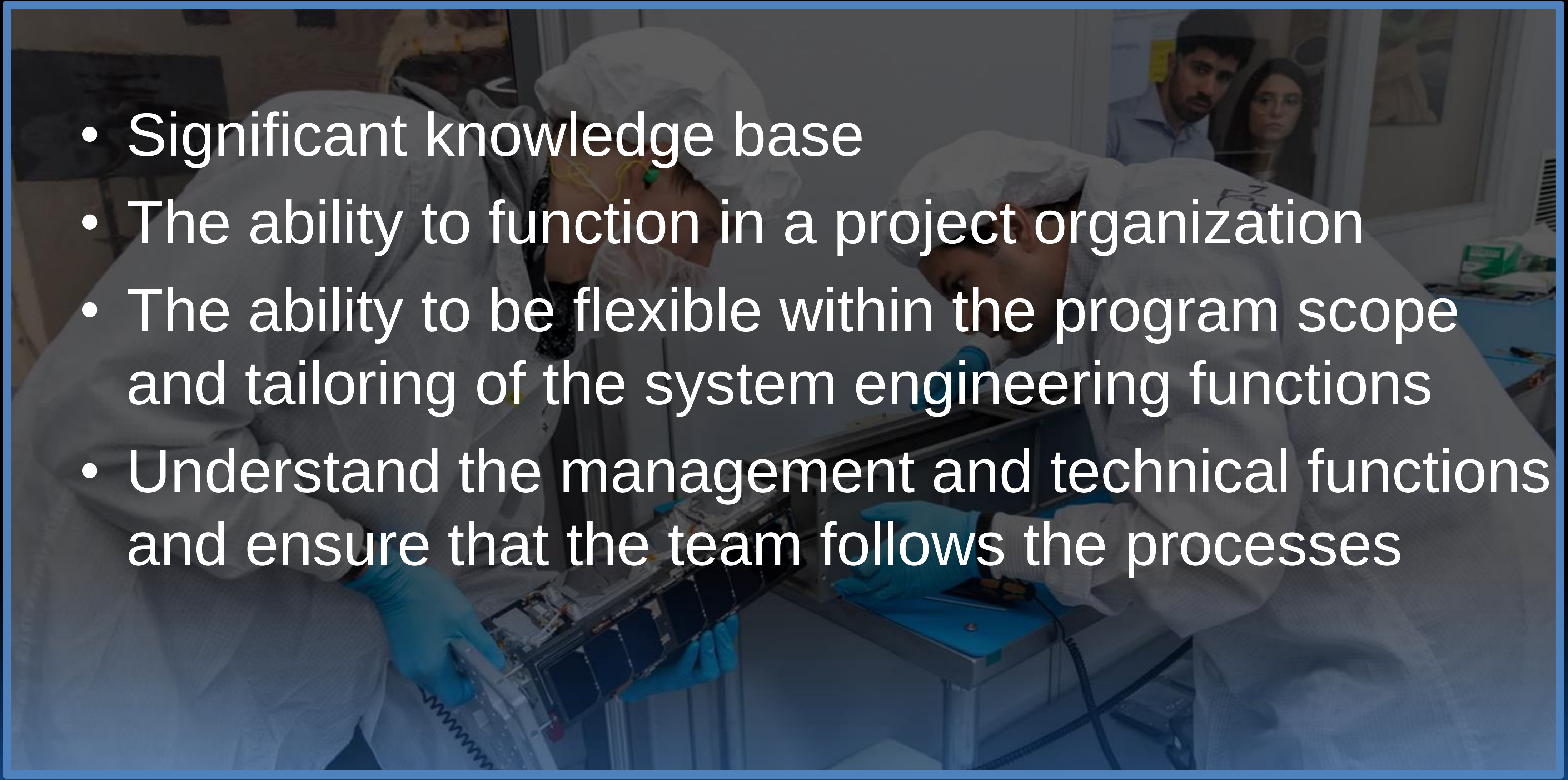
Attributes of a Good Systems Engineer

- Possesses Intellectual Curiosity
- Sees the Big Picture
- Understands Connections
- Comfortable with Change
- Comfortable with Uncertainty



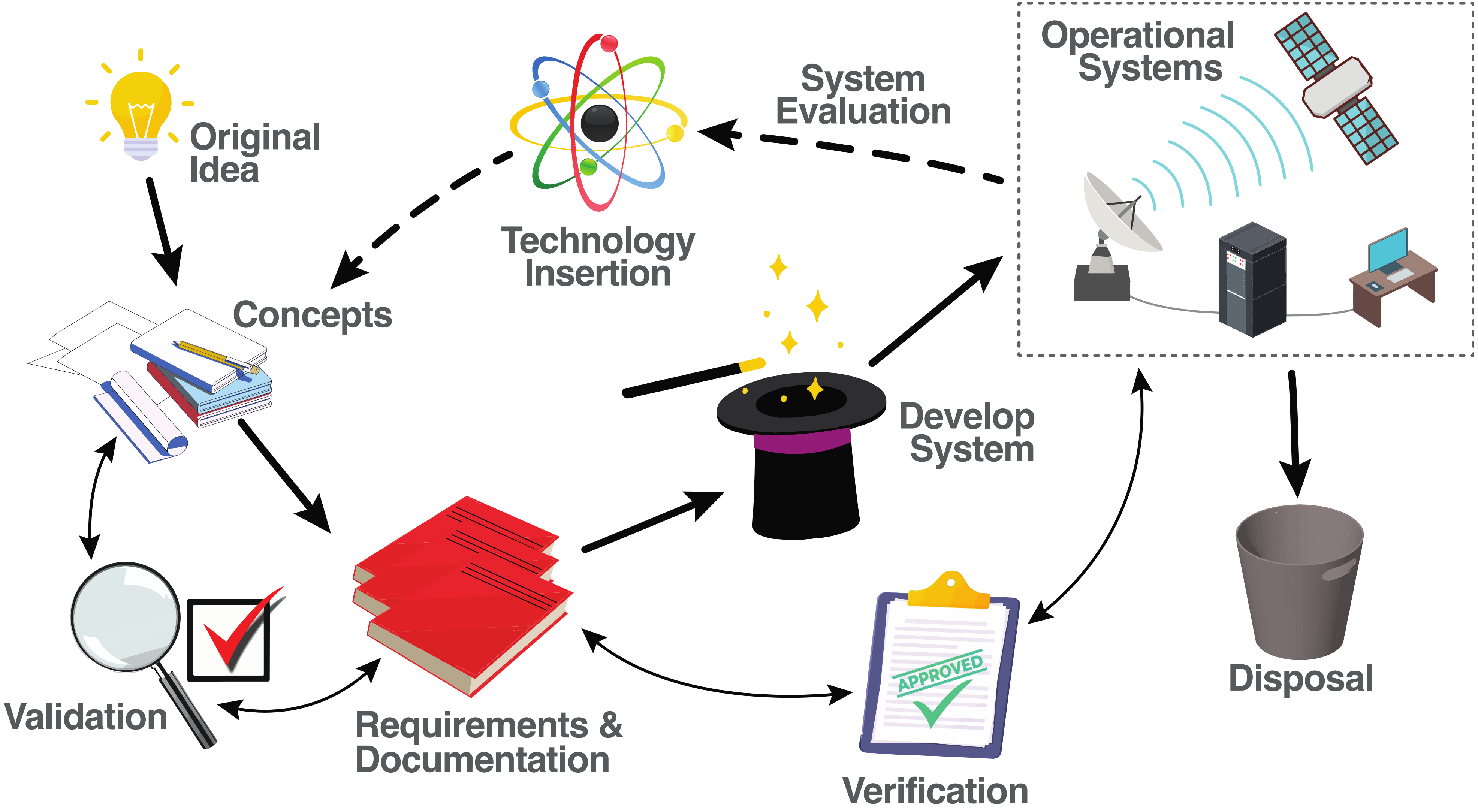
- Processes “Proper Paranoia”
- Manages Resources and Margins
- Good Communication Skills
- Self-Confident and Energy
- Has an Appreciation for Process

What Does It Take to be a Systems Engineer?

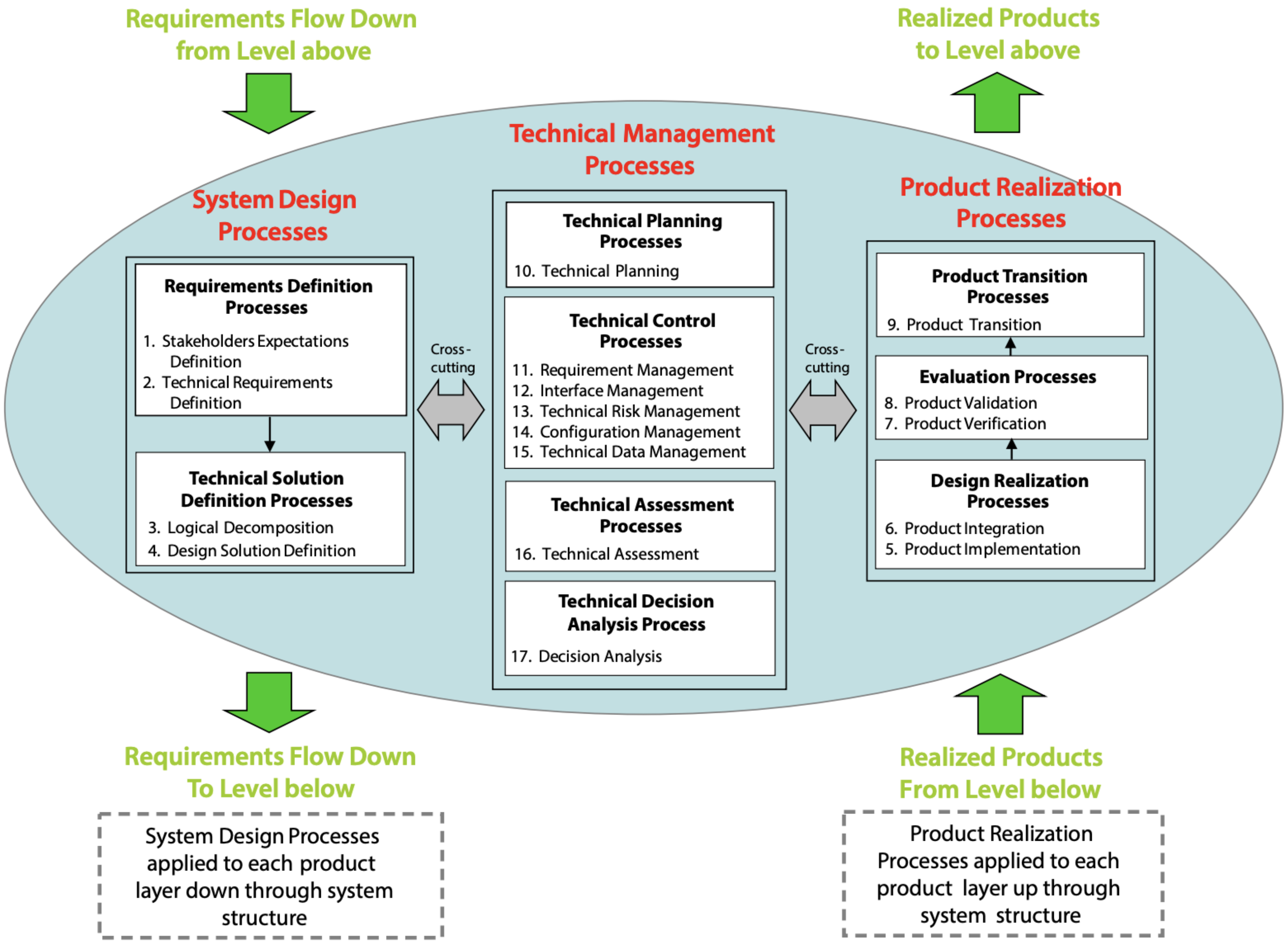


- Significant knowledge base
- The ability to function in a project organization
- The ability to be flexible within the program scope and tailoring of the system engineering functions
- Understand the management and technical functions and ensure that the team follows the processes

Idea to Operational System



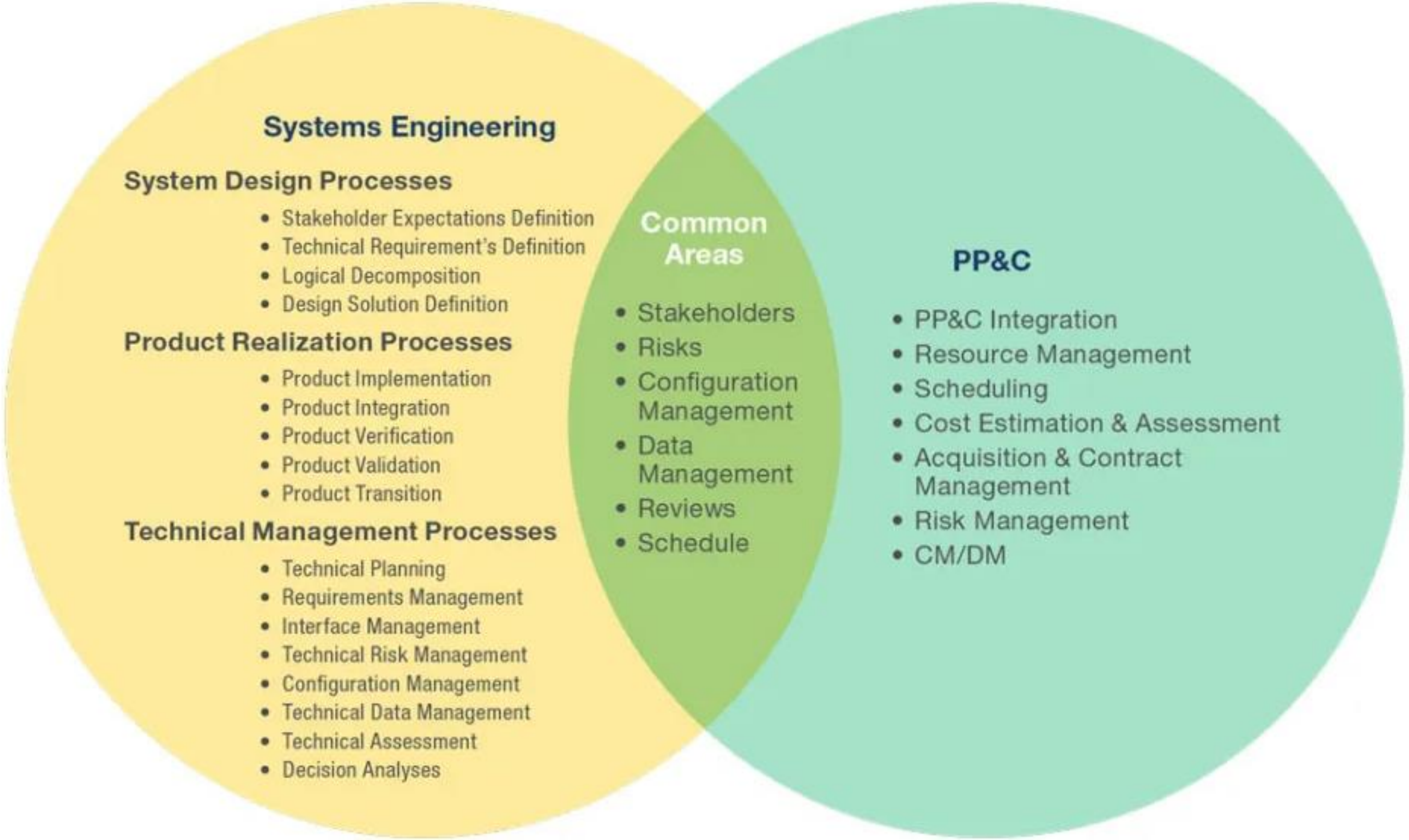
The Systems Engineer Engine



Systems Engineering in Context of Overall Project Management

PROJECT MANAGEMENT ACTIVITIES

- Setting up Project Team
- Programmatic Stakeholders (non-technical, non-business)
- Programmatic Planning (non-technical, non-business)
- Identifying Programmatic (non-technical) requirements
- Identifying Programmatic Risks
- Technology Transfer and Commercialization
- Integration of technical and non-technical activities
- Overall Approver/Decider



What are the Elements of Managing a Small Spacecraft Project?

Managing a project consists of three main objectives:

- Managing the technical aspects of the project
- Managing the project team
- Managing the cost and schedule.

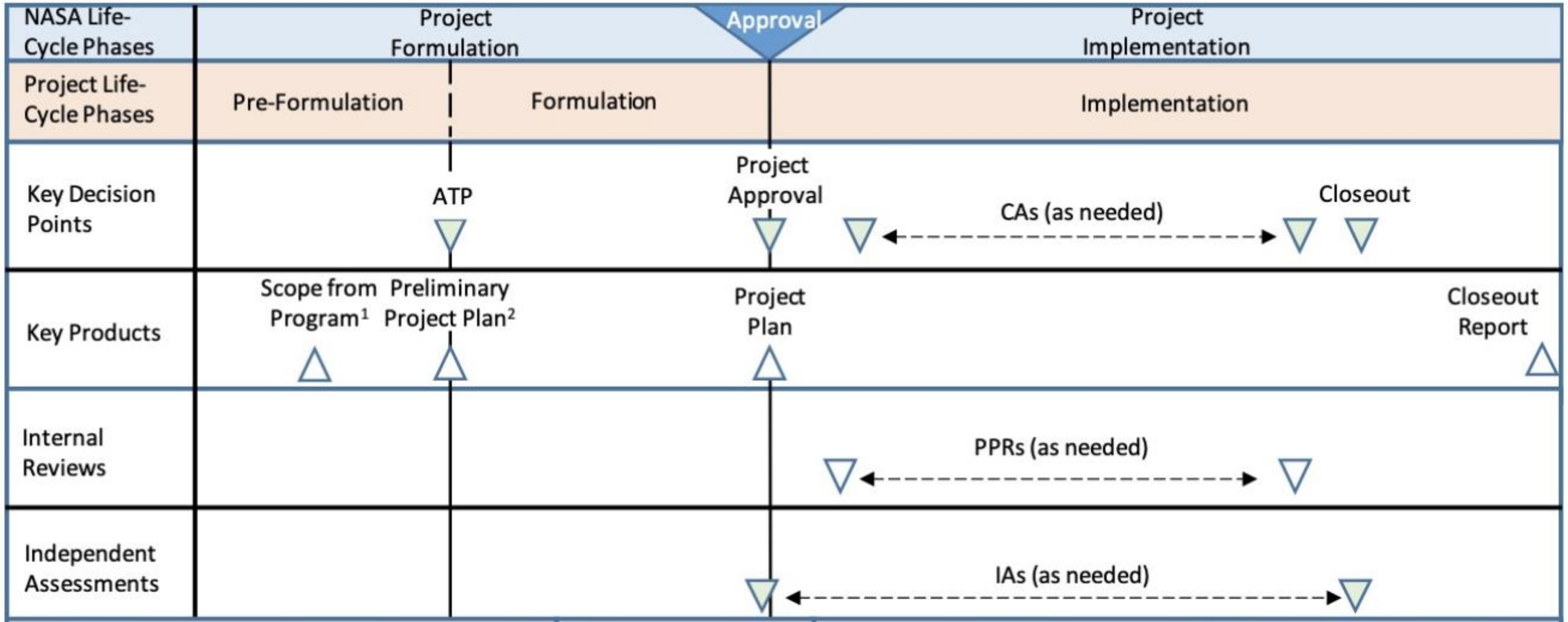
Spacecraft Subsystems

Propulsion	Chemical, Electric, Propellent-Less
Structures	CubeSat Structures, Radiation Effects and Mitigation Strategies
Power	Solar Panels and Arrays, Solar Cells, Power Storage
Thermal	Radiators, Heat Pipes, Cryocoolers, Sun Shields
Platforms	Hosted Payloads, Dedicated Spacecraft Bus
GNC	Reaction Wheels. Magnetic Torquers, Thrusters, Sun & Star Trackers
Avionics	Onboard Computing, Bus Electrical Interfaces. Flight Software
Payloads	

What are the Elements of a Project's Life Cycle Phases?

Phase		Purpose	Typical Output
Formulation	Pre-Phase A: Concept Studies	To produce a broad spectrum of ideas and alternatives for missions from which new programs/ projects can be selected. Determine feasibility of desired system, develop mission concepts, draft system-level requirements, identify potential technology needs.	Feasible system concepts in the form of simulations, analysis, study reports, models, and mockups
	Phase A: Concept and Technology Development	To determine the feasibility and desirability of a suggested new major system and establish an initial baseline compatibility with NASA's strategic plans. Develop final mission concept, system-level requirements , and needed system structure technology developments.	System concept definition in the form of simulations, analysis, engineering models, and mockups and trade study definition
	Phase B: Preliminary Design and Technology Completion	To define the project in enough detail to establish an initial baseline capable of meeting mission needs. Develop system structure and product (and enabling product) requirements and generate a preliminary design for each system structure end product.	End products in the form of mockups, trade study results, specification and interface documents, and prototypes
Implementation	Phase C: Final Design and Fabrication	To complete the detailed design of the system (and its associated subsystems, including its operations systems), fabricate hardware and code software. Generate final designs for each system structure end product.	End products detailed designs, end product component fabrication, and software development
	Phase D: System Assembly, Integration and Test, Launch	To assemble and integrate the products to create the system, mean-while developing confidence that it will be able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use.	Operations-ready system end products with supporting related enabling products
	Phase E: Operations and Sustainment	To conduct the mission and meet the initially identified need and maintain support for that need. Implement the mission operations plan.	Desired system
	Phase F: Closeout	To implement the systems decommissioning/disposal plan developed in Phase E and perform analyses of the returned data and any returned samples.	Product closeout

Project Life Cycle per NPR 7120.8A:
NASA Research and Technology Program and Project Management Requirements



Acronyms

ATP – Authority to Proceed into Formulation
CA – Continuation Assessment
IA – Independent Assessment
PPR – Periodic Project Review

Notes:

[1]For projects without a Pre-Formulation Phase, the scope of their work is provided during the Formulation Phase

[2]For projects without a Pre-Formulation Phase, the preliminary project plan may be skipped and the final project plan provided during the Formulation Phase

Legend

△ Product
▽ External Review
▽ Internal Review

Key Products

Scope – Documentation from program stating purpose and scope of project in a form appropriate for the type, size, and complexity of the project

Preliminary Project plan – Documentation from the project to the program with agreement on resources, cost, reviews, and planned schedule for activities in the formulation phase in a form appropriate for the type, size, and complexity of the project

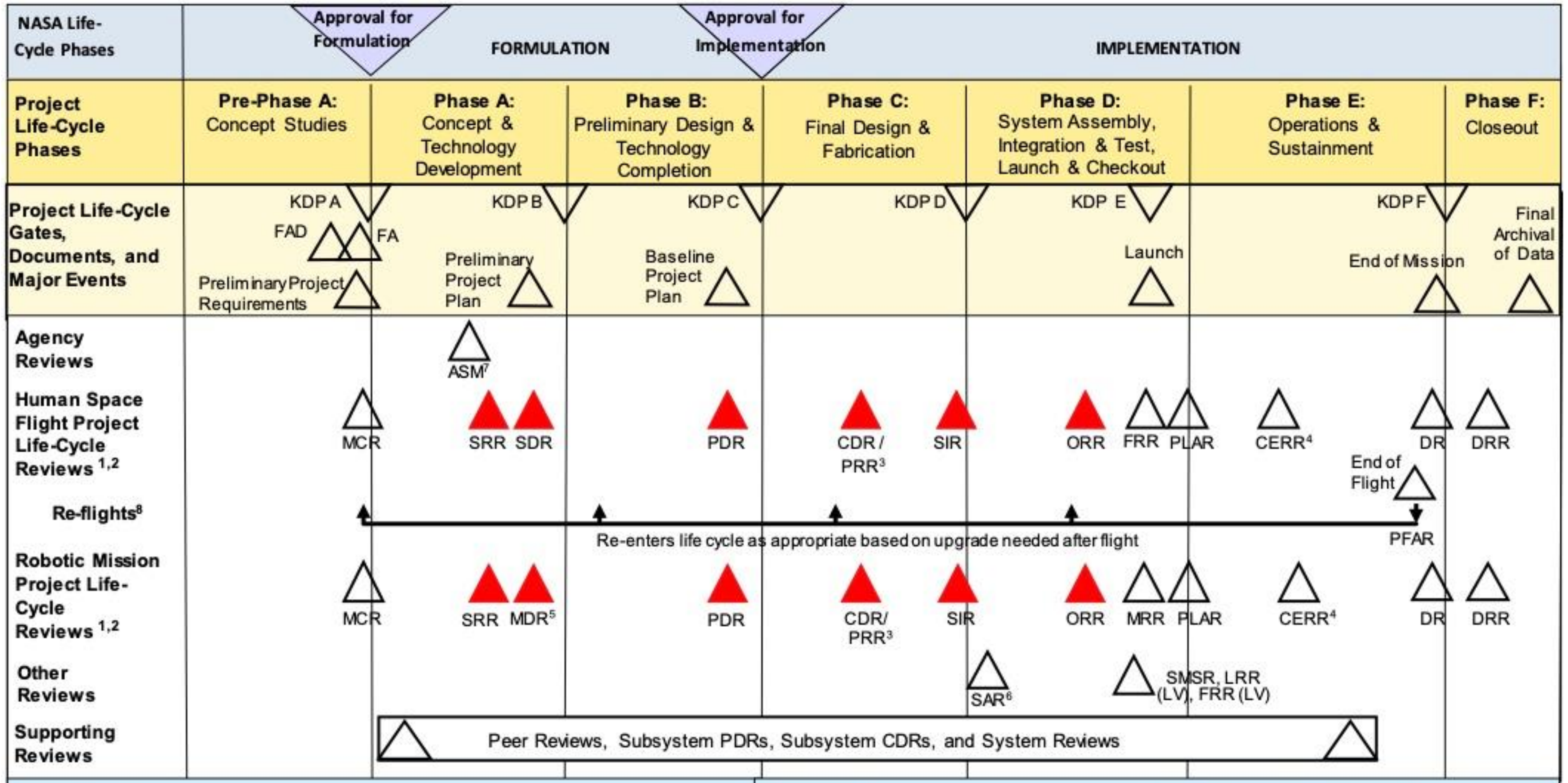
Project Plan – Documentation from project to program with agreement on resources, cost, reviews, schedule, implementation approach, and other plans

Closeout Report – Project documentation to program and external stakeholders on the results of the project, recommendations, and where the project information has been archived

What are the key Program Life Cycle Reviews?

Key Reviews	Definition/Context
System Requirements Review (SRR)	What are we building?
Preliminary Design Review (PDR)	Does the design close analytically?
Critical Design Review (CDR)	Are you ready to build/test?
Flight Readiness Review (FRR)	Are you ready to launch/operate?

Project Life Cycle per NPR 7120.5F:
NASA Space Flight Program and Project Management Requirements



FOOTNOTES

1. Flexibility is allowed as to the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan.
2. Life-cycle review objectives and expected maturity states for these reviews and the attendant KDPs are contained in Table 2-5.
3. PRR is needed only when there are multiple copies of systems. It does not require an SRB. Timing is notional.
4. CERRs are established at the discretion of Program Offices.
5. For robotic missions, the SRR and the MDR may be combined.
6. SAR generally applies to human space flight.
7. Timing of the ASM is determined by the MDAA or AA, as compliant with NPD 1000.5 and may take place at any time during Phase A.
8. Placement of arrows is notional. See Section 2.2.4.3 for more guidance on reflights.

ACRONYMS

ASM - Acquisition Strategy Meeting
CDR - Critical Design Review
CERR - Critical Events Readiness Review
DR - Decommissioning Review
DRR - Disposal Readiness Review
FA - Formulation Agreement
FAD - Formulation Authorization Document
FRR - Flight Readiness Review
KDP - Key Decision Point
LRR - Launch Readiness Review
LV - Launch Vehicle
MCR – Mission Concept Review
MDR - Mission Definition Review
MRR - Mission Readiness Review
ORR - Operational Readiness Review
PDR - Preliminary Design Review
PFAR - Post-Flight Assessment Review
PLAR - Post-Launch Assessment Review
PRR - Production Readiness Review
SAR - System Acceptance Review
SDR - System Definition Review
SIR - System Integration Review
SMSR - Safety and Mission Success Review
SRB - Standing Review Board
SRR - System Requirements Review

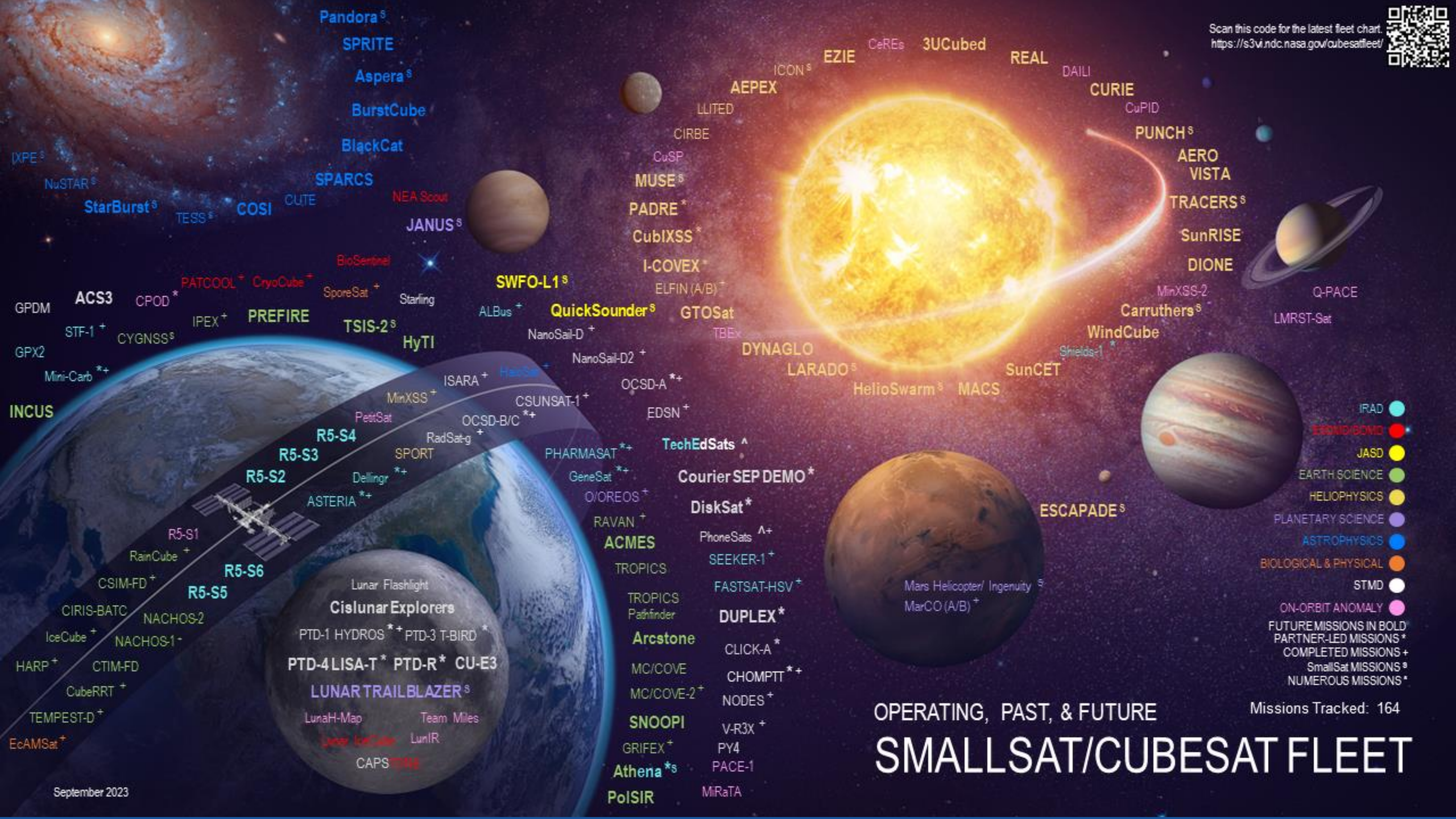
Red triangles represent life-cycle reviews that require SRBs. The Decision Authority, Administrator, MDAA, or Center Director may request the SRB to conduct other reviews.

What are the Roles and Responsibilities of a Systems Engineer?

- The exact role and responsibility of the systems engineer may change from project to project depending on the size and complexity of the project and from phase to phase of the life cycle.
- For large projects, there may be one or more systems engineers.
- For small projects, the project manager may sometimes perform these practices. But whoever assumes those responsibilities, the systems engineering functions should be performed.
- The actual assignment of the roles and responsibilities of the named systems engineer may also therefore vary.
- The lead systems engineer ensures that the system technically fulfills the defined needs and requirements and that a proper systems engineering approach is being followed.
- The systems engineer oversees the project’s systems engineering activities as performed by the technical team and directs, communicates, monitors, and coordinates tasks.
- The systems engineer reviews and evaluates the technical aspects of the project to ensure that the systems/subsystems engineering processes are functioning properly and evolves the system from concept to product.
- The entire technical team is involved in the systems engineering process.

Why Does NASA Use Systems Engineering?

The engineering of NASA systems requires a systematic and disciplined set of processes that are applied recursively and iteratively for the design, development, operation, maintenance, and closeout of systems throughout the life cycle of the programs and projects. The systems engineering discipline serves this purpose.



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IXPE s
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StarBurst s
TESS s
COSI
CUTE
NEA Scout
JANUS s
BioSentinel
PATCOOL +
CryoCube +
SporeSat +
Starling
GPDM
ACS3
CPOD *
IPEX +
PREFIRE
TSIS-2 s
HyTI
STF-1 +
CYGNSS s
GPX2
Mini-Carb *+
INCUS
SWFO-L1 s
ALBus +
QuickSounder s
NanoSail-D +
NanoSail-D2 +
ISARA +
MinXSS +
CSUNSAT-1 +
OCSD-A *+
PetitSat
OCSD-B/C *+
RadSat-g +
SPORT
EDSN +
R5-S4
R5-S3
R5-S2
Dellingr *+
ASTERIA *+
PHARMASAT *+
GeneSat *+
O/OREOS +
RAVAN +
TechEdSats ^
Courier SEP DEMO *
DiskSat *
R5-S1
RainCube +
CSIM-FD +
R5-S6
R5-S5
CIRIS-BATC
NACHOS-2
IceCube +
NACHOS-1 +
HARP +
CTIM-FD
CubeRRT +
TEMPEST-D +
EcAMSat +
September 2023
Lunar Flashlight
Cislunar Explorers
PTD-1 HYDROS *+
PTD-3 T-BIRD *
PTD-4 LISA-T *
PTD-R *
CU-E3
LUNAR TRAILBLAZER s
LunaH-Map
Team Miles
LunIR
CAPSTONE
ACMES
TROPICS
TROPICS Pathfinder
Arcstone
MC/COVE
MC/COVE-2 +
SNOOPI
GRIFEX +
Athena *s
PolSIR
PhoneSats ^+
SEEKER-1 +
FASTSAT-HSV +
DUPLEX *
CLICK-A *
CHOMPTT *+
NODES +
V-R3X +
PY4
PACE-1
MiRaTA
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EZIE
CeREs
3UCubed
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MUSE s
PADRE *
CubIXSS *
I-COVEX *
ELFIN (A/B) +
GTOSat
TBEx
DYNAGLO
LARADO s
HelioSwarm s
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SunCET
CURIE
CuPID
PUNCH s
AERO VISTA
TRACERS s
SunRISE
DIONE
MinXSS-2
Carruthers s
WindCube
Shields-1 *
Q-PACE
LMRST-Sat
ESCAPADE s
Mars Helicopter/ Ingenuity s
MarCO (A/B) +
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HELIOPHYSICS
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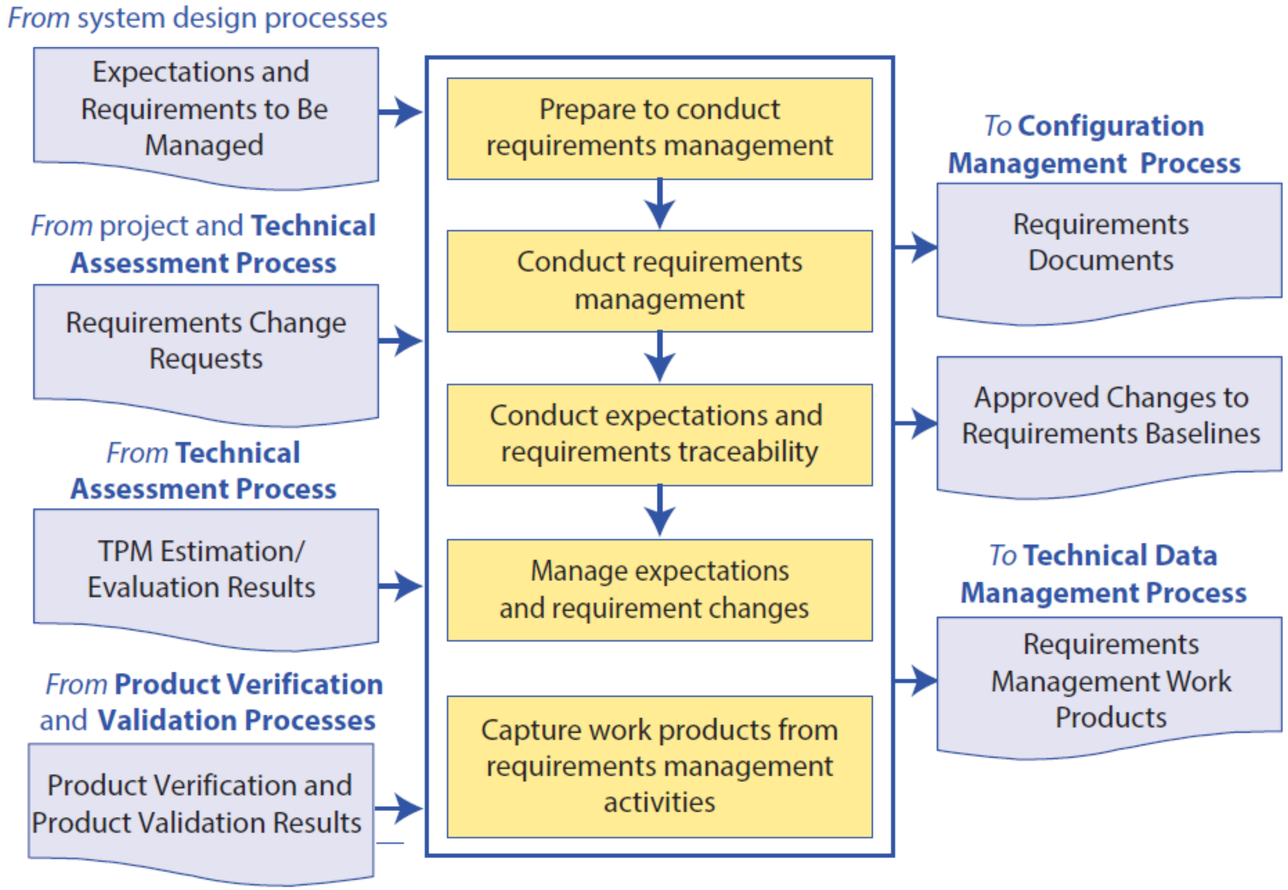
STMD
ON-ORBIT ANOMALY
FUTURE MISSIONS IN BOLD
PARTNER-LED MISSIONS *
COMPLETED MISSIONS +
SmallSat MISSIONS s
NUMEROUS MISSIONS ^
OPERATING, PAST, & FUTURE
Missions Tracked: 164
SMALLSAT/CUBESAT FLEET

Upcoming Webinar: Requirements and System Design

This webinar will cover discussions on the requirement and systems design aspects.

- How do you define requirements for small spacecraft mission?
- Why are requirements important to NASA missions?
- How trade studies are used to determine parts selection and why i it important?
- What is a concept of operations (ConOps) and why is it vital to a NASA mission?



Upcoming Webinar: Topic Preview

Steps to Requirements Development for Systems and Subsystems

1. Customer and User Identification
2. Prioritize Customer Objectives and Needs
3. Define Constraints
4. Customer Needs to Functional Attributes
5. Develop Functional Requirements
6. Establish Functional Flow
7. Functional Attributes to Technical Characteristics
8. Establish Quantifiable Requirements
9. Note Interfaces & Hardware/Software Relationships
10. Decompose Functional Requirements
11. Iterate to Reconcile Requirements & Implementation

References

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

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

Questions?

www.nasa.gov/smallsat-institute/

Definitions

- NASA Procedural Requirements (NPR) 7120.5: NASA Spaceflight Program and Project Management Requirements
  - Establishes the requirements that NASA formulates and implements space flight programs and projects
- NASA Procedural Requirements (NPR) 7120.8: NASA Research and Technology Program and Project Management Requirements
  - Research and Technology typically using ground systems or sub-orbital vehicles, aircraft, sounding rockets, and balloons)
  - More recently CubeSats, SmallSats, ISS payloads have been included