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."

Systems Engineering Knowledge Base

Knowledge Base

- System Level Thinking and Basic Analytical Skills
  - Customer
  - Product
  - Technology
  - Organization

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

- System Engineering Roles
  - Meeting Focus
  - Questioning Skills
  - Conflict Resolution
  - Creativity
  - Closure

- Professional Effectiveness Skills
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

Requirements Flow Down from Level above

System Design Processes

Requirements Definition Processes
1. Stakeholders Expectations Definition
2. Technical Requirements Definition

Technical Solution Definition Processes
3. Logical Decomposition
4. Design Solution Definition

Cross-cutting

Technical Management Processes

Technical Planning Processes
10. Technical Planning

Technical Control Processes
11. Requirement Management
12. Interface Management
13. Technical Risk Management
14. Configuration Management
15. Technical Data Management

Technical Assessment Processes
16. Technical Assessment

Technical Decision Analysis Process
17. Decision Analysis

Cross-cutting

Realized Products to Level above

Product Realization Processes

Product Transition Processes
9. Product Transition

Evaluation Processes
8. Product Validation
7. Product Verification

Design Realization Processes
6. Product Integration
5. Product Implementation

Realized Products From Level below

Product Realization Processes applied to each product layer up through system structure

Requirements Flow Down To Level below

System Design Processes applied to each product layer down through system structure
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

**Systems Engineering**

**System Design Processes**
- Stakeholder Expectations Definition
- Technical Requirement’s Definition
- Logical Decomposition
- Design Solution Definition

**Product Realization Processes**
- Product Implementation
- Product Integration
- Product Verification
- Product Validation
- Product Transition

**Technical Management Processes**
- Technical Planning
- Requirements Management
- Interface Management
- Technical Risk Management
- Configuration Management
- Technical Data Management
- Technical Assessment
- Decision Analysis

**Common Areas**
- Stakeholders
- Risks
- Configuration Management
- Data Management
- Reviews
- Schedule

**PP&C**
- PP&C Integration
- Resource Management
- Scheduling
- Cost Estimation & Assessment
- Acquisition & Contract Management
- Risk Management
- CM/DM
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, Propellant-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?

<table>
<thead>
<tr>
<th>Phase</th>
<th>Purpose</th>
<th>Typical Output</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Formulation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-Phase A: Concept</td>
<td>To produce a broad spectrum of ideas and alternatives for missions from which new programs/</td>
<td>Feasible system concepts in the form of simulations, analysis, study reports, models, and mockups</td>
</tr>
<tr>
<td>Studies</td>
<td>projects can be selected. Determine feasibility of desired system, develop mission concepts,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>draft system-level requirements, identify potential technology needs.</td>
<td></td>
</tr>
<tr>
<td>Phase A: Concept and</td>
<td>To determine the feasibility and desirability of a suggested new major system and establish</td>
<td>System concept definition in the form of simulations, analysis, engineering models, and mockups</td>
</tr>
<tr>
<td>Technology Development</td>
<td>an initial baseline compatibility with NASA’s strategic plans. Develop final mission concept,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>system-level requirements, and needed system structure technology developments.</td>
<td></td>
</tr>
<tr>
<td>Phase B: Preliminary</td>
<td>To define the project in enough detail to establish an initial baseline capable of meeting</td>
<td>End products in the form of mockups, trade study results, specification and interface documents, and prototypes</td>
</tr>
<tr>
<td>Design and Technology</td>
<td>mission needs. Develop system structure and product (and enabling product) requirements and</td>
<td></td>
</tr>
<tr>
<td>Completion</td>
<td>generate a preliminary design for each system structure end product.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Implementation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase C: Final Design</td>
<td>To complete the detailed design of the system (and its associated subsystems, including its</td>
<td>End products detailed designs, end product component fabrication, and software development</td>
</tr>
<tr>
<td>and Fabrication</td>
<td>operations systems), fabricate hardware and code software. Generate final designs for each</td>
<td></td>
</tr>
<tr>
<td></td>
<td>system structure end product.</td>
<td></td>
</tr>
<tr>
<td>Phase D: System</td>
<td>To assemble and integrate the products to create the system, mean-while developing confidence</td>
<td>Operations-ready system end products with supporting related enabling products</td>
</tr>
<tr>
<td>Assembly, Integration</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>and Test, Launch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase E: Operations</td>
<td>To conduct the mission and meet the initially identified need and maintain support for that</td>
<td>Desired system</td>
</tr>
<tr>
<td>and Sustainment</td>
<td>need. Implement the mission operations plan.</td>
<td></td>
</tr>
<tr>
<td>Phase F: Closeout</td>
<td>To implement the systems decommissioning/disposal plan developed in Phase E and perform</td>
<td>Product closeout</td>
</tr>
<tr>
<td></td>
<td>analyses of the returned data and any returned samples.</td>
<td></td>
</tr>
</tbody>
</table>
## Project Life Cycle per NPR 7120.8A: NASA Research and Technology Program and Project Management Requirements

<table>
<thead>
<tr>
<th>NASA Life-Cycle Phases</th>
<th>Project Formulation</th>
<th>Approval</th>
<th>Project Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Formulation</td>
<td>Formulation</td>
<td>Project Approval</td>
<td>Implementation</td>
</tr>
<tr>
<td>Formulation</td>
<td></td>
<td>CAAs (as needed)</td>
<td>Closeout</td>
</tr>
<tr>
<td>Implementation</td>
<td></td>
<td>Closeout Report</td>
<td></td>
</tr>
</tbody>
</table>

### Key Decision Points
- ATP
- Project Approval
- Closeout

### Key Products
- Scope from Program
- Preliminary Project Plan
- Project Plan
- Closeout Report
- PPRs (as needed)
- IAs (as needed)

### Internal Reviews

### Independent Assessments

### 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

### 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

### Legend
- Product
- External Review
- Internal Review
What are the key Program Life Cycle Reviews?

<table>
<thead>
<tr>
<th>Key Reviews</th>
<th>Definition/Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Requirements Review (SRR)</td>
<td>What are we building?</td>
</tr>
<tr>
<td>Preliminary Design Review (PDR)</td>
<td>Does the design close analytically?</td>
</tr>
<tr>
<td>Critical Design Review (CDR)</td>
<td>Are you ready to build/test?</td>
</tr>
<tr>
<td>Flight Readiness Review (FRR)</td>
<td>Are you ready to launch/operate?</td>
</tr>
</tbody>
</table>
Project Life Cycle per NPR 7120.5F: NASA Space Flight Program and Project Management Requirements

### NASA Life-Cycle Phases

<table>
<thead>
<tr>
<th>Project Life-Cycle Phases</th>
<th>Approval for Formulation</th>
<th>Approval for Implementation</th>
<th>IMPLEMENTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Phase A: Concept Studies</td>
<td>KDP A, FAD</td>
<td>KDP B</td>
<td>KDP C</td>
</tr>
<tr>
<td>Phase A: Concept &amp; Technology Development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase B: Preliminary Design &amp; Technology Development</td>
<td>Preliminary Project Plan</td>
<td>Baseline Project Plan</td>
<td></td>
</tr>
<tr>
<td>Phase C: Final Design &amp; Fabrication</td>
<td>DR, DRR</td>
<td>PDR</td>
<td>CDR, PRR*</td>
</tr>
<tr>
<td>Phase D: System Assembly, Integration &amp; Test, Launch &amp; Checkout</td>
<td></td>
<td></td>
<td>CERR</td>
</tr>
<tr>
<td>Phase E: Operations &amp; Sustainment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Archival of Data</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Agency Reviews

- Human Space Flight Project Life-Cycle Reviews 1,2
- Re-flights
- Robotic Mission Project Life-Cycle Reviews 1,2
- Other Reviews
- Supporting Reviews

### 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 3-5.
3. PRR is needed only when there are multiple copies of systems. It does not require an SRR. Tinning is optional.
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 MDA or AA, as compliant with NPR 10005, and may take place at any time during Phase A.
8. Placement of arrows is optional. See Section 2.2.4.3 for more guidance on re-flights.

### 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
- MCR: Mission Concept Review
- MDR: Mission Definition Review
- MRR: Mission Readiness Review
- ODR: Operational Readiness Review
- PDR: Preliminary Design Review
- PLAR: Post-Launch Assessment Review
- PRR: Production Readiness Review
- SAR: System Acceptance Review
- SDR: System Definition Review
- SIB: System Integration Review
- SMAR: Safety and Mission Assurance Review
- SRR: System Requirements Review

Red triangles represent life-cycle reviews that require SRRs. The Decision Authority, Administrator, MDA, or Center Director may request the SRR 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.
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 is 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

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