Engineering Space Nuclear Power Systems Using a System of Systems Perspective

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Topics

• Research approach
• Current/Historical Approach to Space Nuclear Power Systems (NPS) Development
• NPS as a “system of systems” (SoS)
  • SoS terminology and characteristics
  • Selected practices that may benefit systems engineering approach for NPS
• Next Steps
  • Steps already underway – can we monitor effectiveness and adopt SoS mindset for implementation?
  • Areas for further study, not currently being implemented
Research Approach

- Examined historical literature for factors related to NPS flight use
- Found common (but not universal) themes
  - Mission definition, realism and level of involvement
  - Level of technical challenges relative to expected
- Looked at historical challenges and best practices, focused on how they related to these “themes”
- Reviewed literature on “system of systems” approach and practices, to evaluate how current practices could be expanded or enhanced
Challenges to Space NPS Development

- Flight use of NPS is challenged by a few interdependent factors, many of which are common to large-scale projects in general:
  - Cost
  - Technical Complexity
  - Project Duration
  - Lack of a Clearly Defined Mission
  - Sustainment of Investments

- Historical mitigations have been attempted, sometimes successfully, but effectiveness is not formally measured or analyzed
Mitigation Approaches

• Concurrent Engineering
  – Can address duration and cost
  – Shorter duration can help with “lack of mission”
  – Has sometimes been successful
  – Can exacerbate technical complexity issues
  – Does not significantly affect sustainment of investments

• Skipped or Streamlined testing
  – Similar risk/benefit profile as concurrent engineering
  – May affect investment sustainment, if test streamlining extends beyond initial development
Mitigation Approaches (continued)

- Multi-Purpose Design of components or systems
  - Assumes high investment of time/money and works toward greatest “bang for the buck”
  - Could dramatically improve investment sustainability
  - Counterintuitively, could exacerbate “lack of mission”
    - Design for multiple missions can cause requirements creep, extension of duration and cost of projects
    - Multi-purpose design can diffuse requirements authority, while trying to be “all things to all people” may prevent the NPS from being any mission’s first choice.
  - Likely to exacerbate technical complexity
“Typical” SE Approach
Key Practices in Current SE Approach

• Mission success probability (to include reliability) is an important criterion in system selection and design.
• Analysis and testing are used together at multiple levels.
• Rigorous quality assurance practices evolved from both the nuclear and aerospace sectors are applied.
• Users of the systems remain engaged throughout the system development life cycle.
• Formal, independent reviews are conducted at critical steps of the development cycle.
• Hardware testing complements the review cycle.

These should be retained/expanded on in any changed approach
What is a System?

- “the combination of elements that function together to produce the capability required to meet a need” [NASA, NPR 7123.1B, NASA Systems Engineering Processes and Requirements, 2013]

What is a System of Systems?

- “a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities” [US Department of Defense, "Systems Engineering Guide for Systems of Systems," v1.0, 2008, emphasis added]
Hypothetically, interactions among “multi-purpose” components or systems can become extremely complex.

Many SoS exist, but we will define as the mission architecture for this discussion:
How do SoS Differ from Systems?

• Management and Oversight Considerations
  – Managerial Independence
  – Stakeholder Involvement
  – Governance
  – Geographic dispersion

• Operational Objectives Definition

• Acquisition Approach

• Test & Evaluation – capturing emergent properties

• Engineering & Design Considerations
  – Boundaries and Interfaces
  – Performance & Behavior
Emerging Practices

• The field of “SoS Engineering” is broad, captured under a variety of titles, and relatively new compared to “traditional” SE

• The subset of most use here will address:
  – Even younger field of research viewing SoS from the system level, where SoS is vaguely defined, unstructured or absent/lagging
  – Acquisition approach
  – SE approach to requirements definition, change control and multi-mission optimization
Selected SoS Practices to Explore

• Formal definition of the SoS context for a system or technology development effort
  • Clarity on the type of SoS is critical
• Understanding of non-technical factors affecting SE trades and decisions
• Adoption of a SE process acting at the SoS level
• Prioritization of design attributes supporting multi-mission use
• SoS perspective incorporated into system acquisition life cycle
• Use of advanced SE tools to manage nuclear systems complexity
Future NPS Development Considerations

• Surrogate mission approach
  – Design for robustness
  – Minimize requirements creep

• Continue to provide and sustain a suite of NPS capabilities
  – Enables more science opportunities

• Use of model-based systems engineering methodology in SE approach
  • Better understanding of sensitivities within NPS and interfaces at the SoS level
Actively used in many large companies in Aerospace, Defense, and Automotive industries:
– In recent survey, 45 companies participated:

No longer small pilot studies!

Project Duration
1 mo – 1 year: 20%
1 year – 3 years: 35%
> 3 years: 45%

Project Size
< 10 people: 28%
10 -100: 40%
100 – 1000: 22%
> 1000 people: 10%

Space Systems: 23%
Aircraft: 20%
Defense: 20%
Automotive: 7%
Other: 30%

Source: Chris Paredis, Georgia Tech, Why Model-Based Systems Engineering? Benefits and Payoffs
Collaboration and NPS Development

• Interagency approach to future NPS development:
  - Continuous engagement, communication, and integration (technical and programmatic)
  - Joint strategic short-term and long-term planning
    - Motivation to achieve buy-in
  - Cohesive messaging to stakeholders

Effectively managing organizational complexities will strengthen the ability to resolve technical complexity and issues as they arise.