



The Need for Systems Engineering in Technology Development Programs

Technical Leadership and the Role of the Systems Engineer for Program Success

Presentation Forum

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What is Systems Engineering?

Systems Engineering is:

- **An interdisciplinary approach and means to enable the realization of successful systems**
 - **Defining customer needs and required functionality early in the development cycle**
 - **Documenting requirements**
 - **Proceeding with design synthesis and system validation while considering the complete problem**

Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

(SE definition from INCOSE)

- ▶ **Part 1:** A Bold Assertion for Systems Engineering
- ▶ **Part 2:** Why Systems Engineering is Critical
- ▶ **Part 3:** Technical Leadership and the Role of the Systems Engineer for Program Success
 - Both Development *and* R&D Organizations
- ▶ **Part 4:** Ideas into Action: What Should Be Done

Part 1: A Bold Assertion for Systems Engineering

- ▶ **Systems Engineering is critical for success in today's R&D world**
(when purpose of R&D is to support a future system development activity)
 - A system includes multiple major components that go through their own development life cycles to maturity.
 - These components need to be engineered both individually and collectively after they pass the initial TRL levels.
 - Integrating proven components (TRL 7 to 9) from previous systems does not *necessarily* mean that the resulting system will achieve its mission.
 - ❖ There are examples of this truth later in this presentation
 - Or, in other words ...

$$\text{The New System} \neq \sum_{j=1}^n \text{Previous TRL 9 Components}_j + \text{New System Interfaces}$$

Part 2: Why Systems Engineering is Critical

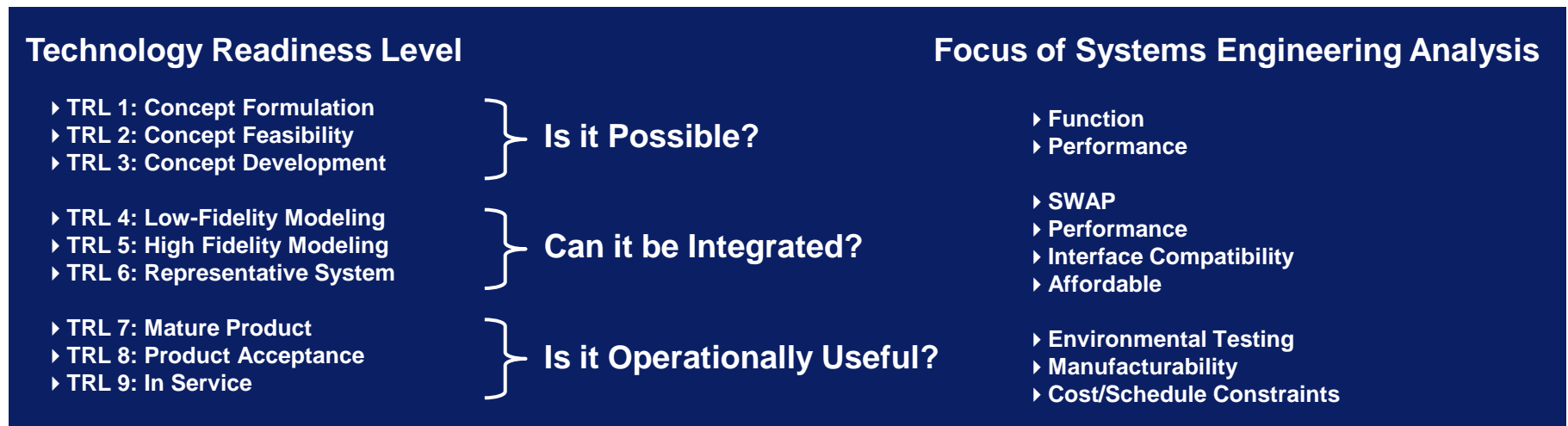
- ▶ The operational mission and conceptual design of a new system effects TRL milestone metrics.



- ▶ Obstacles to success
 - Analytical assumptions (Known and Unknown)
 - Timing and performance surprises
 - Missed operational implications from new mission objectives
 - Cascading probabilities of failure hidden by old system design constraints (rule of unintended consequences)
 - R&D and Development Organization coordination and metric integration are of paramount importance

Part 2: Why Systems Engineering is Critical (cont'd)

- ▶ Success depends on management of risk (SE services flow data into that risk decision process)
 - Different levels of Systems Engineering services need to be applied for different technology readiness levels of components to manage risk
 - ❖ Systems Engineering analysis activities provide values to support TRL scoring as milestone gates are navigated and the components mature
 - ❖ Values of metrics associated with R&D of components must have traceability to total system objectives if incorporation into development programs is to occur
 - R&D organization and/or a Prime's Subcontractor must be fully transparent in their cost/risk activities against these metrics
 - Requires collaboration of SE leadership across organizations (PMO/PEO and R&D)



Part 2: Why Systems Engineering is Critical (cont'd)

▶ Typical Risk Assessment questions that require Systems Engineering activities

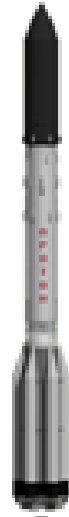
Possible?
Able to be Integrated?
Operationally Useful?

SCHEDULE RELATED			
1. Does the program have an updated schedule with realistic Milestone dates and sufficient detail to schedule a TRA?		X	X
2. Has a Work Breakdown Structure based preliminary evaluation of Critical Technology Elements been performed?		X	X
3. Is the schedule reflective of available resources?		X	X
4. Does the program schedule have an identified critical path?		X	X
5. Is the critical path consistent with overall technical risk, and are the critical path tasks based upon the preferred system concept and specification?		X	X
6. What is the status versus Critical Path?		X	X
RISK RELATED			
7. Have risk items in the system requirements been defined and analyzed?		X	X
8. Is the risk assessment process tightly coupled with the technical effort and reflective of the technical risks inherent in the system requirements?		X	X
9. Has the risk assessment addressed future risks to development?		X	X
10. Have cost and schedule impacts been defined for mitigation options?		X	X
11. Have supportability and logistics risk items been defined, analyzed, and included in the Program Risk Assessment?		X	X
12. Have cost and schedule impacts for supportability and logistics risk mitigation been documented and identified in the risk assessment?		X	X
PRACTICALITY RELATED			
13. Is the technology new or novel (i.e. disruptive in nature)?	X	X	
14. Is the technology a modification of an existing technology?	X	X	
15. Has the technology been repackaged such that a new relevant environment is realized?	X	X	
16. Is the technology expected to operate in an environment beyond its original design?	X	X	
17. Is the technology expected to achieve performance expectation beyond its original capability?	X	X	
PROGRAM RELATED			
18. Does the WBS structure show terminations where there are no critical technologies?		X	X
19. Have the WBS segments which contain critical technologies been identified?		X	X
20. Is the Concept of Operations (CONOPS) described?	X	X	
21. Is the technology roadmap schedule included with significant milestones, critical path items, and status progress indicated?		X	X
22. Are the operational performance requirements and KPPs described?	X	X	X
23. Is the program technology maturation roadmap shown?		X	X
24. Is a technical description of the subsystem/technology included with the critical technologies highlighted?		X	X
25. Is the significance of the critical technologies and system/technology discussed relative to each other and relative to the overall design?		X	X
26. Is the critical technology and its relevance to operational requirements and KPPs described?		X	X
27. Is a current risk matrix for the subsystem element included?		X	X
28. Are facts and accomplishments that directly reflect the system/technology maturity described?		X	X
29. Is tangible evidence (e.g. hardware, pictures, displays) of subsystem/technology maturation accomplishments presented?		X	X
30. Is relevant subsystem/technology maturation which was leveraged from other programs presented?		X	X
31. Have the critical technologies received the TRL scores necessary to meet milestone decision criteria?		X	X

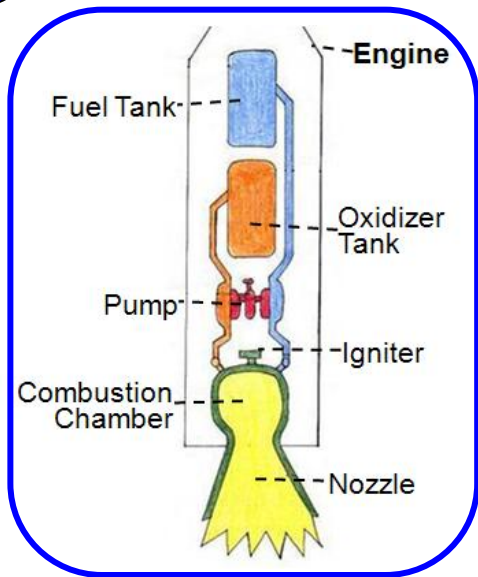
Part 2: Why Systems Engineering is Critical – Context

- **New Mission Objective** - Future deployment + 15 years (eliminates use of existing launch systems)
- **Bottom Line** - The future platform needs greater throw weight
- **Decision** - A new launch platform is planned and R&D investment is required for long lead subsystems/components

Engine R&D paces the success of next system, and there are two approaches to organizing R&D



1 Coupled, Total Subsystem Technology R&D Projects



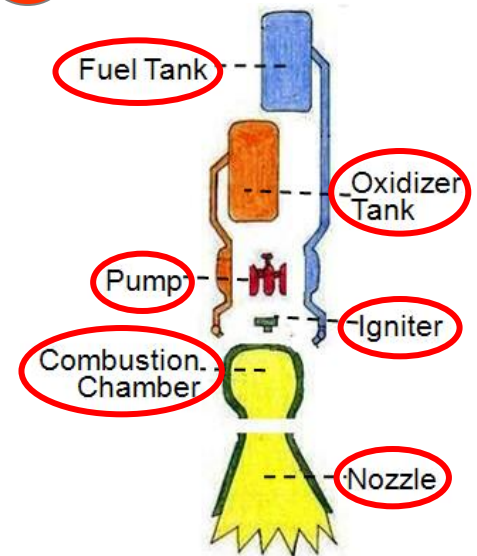
**The Key Question is:
Which Approach?**

Approach 1: Component and Subsystem R&D that optimizes results in the context of the total platform and total platform constraints

- OR -

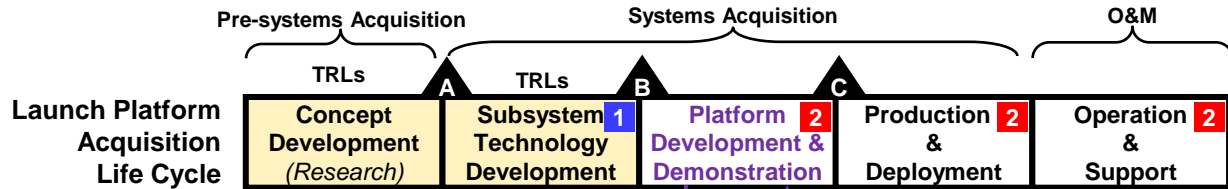
Approach 2: Component R&D that optimizes results in the context of each component as a stand-alone item

2 Decoupled, Component Technology R&D Projects



Part 2: Why Systems Engineering is Critical – R&D as Part of the Acquisition Management Framework

Defense Acquisition Management Framework (DoD 2003)



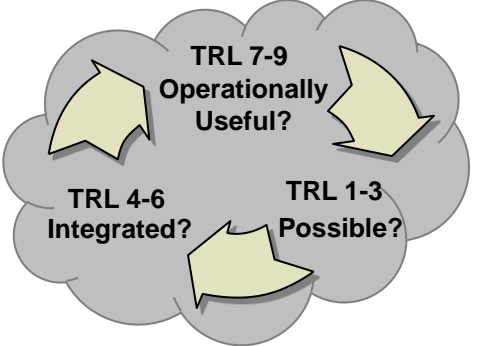
1 is where problems usually are discovered if Approach 1 is used. (\$)
2 is where problems usually are discovered if Approach 2 is used. (\$\$\$)

Platform Development & Demonstration (Multiple Contracts)

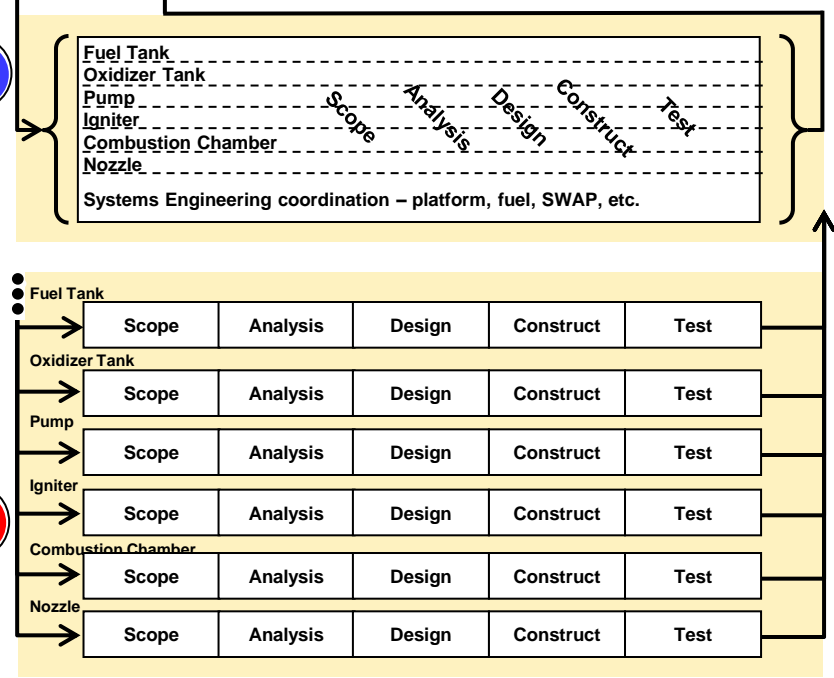


Likelihood of success in platform development and demonstration program integration is enhanced by proper systems engineering during the technology development phase

Coupled, Total Subsystem Technology R&D Projects **1**



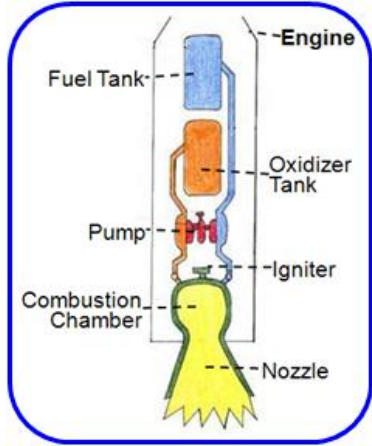
Decoupled, Component Technology R&D Projects **2**



Part 2: Why Systems Engineering is Critical – Illustration

Mission requires new launch system: **Technology Development - A More Powerful Engine**

1 Coupled, Total Platform Technology R&D Projects

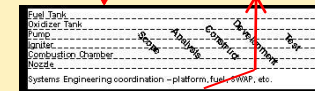


Implement System “End Game” Constraints:

Metrics values based on subsystem improvements plus Allocated Platform Requirements

- Technology Development - Engine Subsystem R&D:

- Individual Engine Components
- PLUS (among others)
 - SWAP
 - Consumables
 - Payload I/Fs
 - Operations
 - Environmental
 - Human Factors / Safety

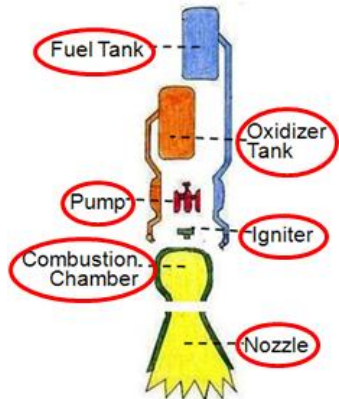


Problems detected

Platform problems detected early

- Platform Development & Demonstration
- Platform Production & Deployment
- Platform Operation & Support

2 Decoupled, Component Technology R&D Projects

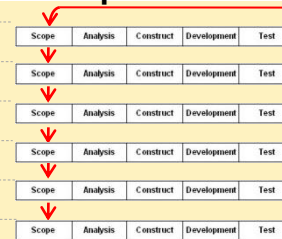


Enhance Engine Components (“stovepiped” R&D):

Metrics values based on component improvements

- Technology Development – Individual Component R&D:

- Fuel Tank R&D
- Oxidizer Tank R&D
- Pump R&D
- Igniter R&D
- Combustion Chamber R&D
- Nozzle R&D



Problems detected

Platform problems detected late

- Platform Development & Demonstration
- Platform Production & Deployment
- Platform Operation & Support

Systems Engineers must consider all possibilities and eventualities, taking a broad view of the appropriate nature and use of even high TRL components.

Part 2: Why Systems Engineering is Critical

Systems Engineering is Empowered Through a Enterprise Governance



**SE Enterprise Governance Process
Required to tie Organizations Together**

1

Fuel Tank	Scope	Analysis	Design	Construct	Test
Oxidizer Tank					
Pump					
Igniter					
Combustion Chamber					
Nozzle					
SE coordination – platform, fuel, SWAP, etc.					

2

Scope	Analysis	Design	Construct	Test
Scope	Analysis	Design	Construct	Test
Scope	Analysis	Design	Construct	Test

**Platform Development & Demonstration
(Multiple Contracts)**

Finalize Requirements	Design	Development	Integration & Test
Finalize Requirements	Design	Development	Integration & Test
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Finalize Requirements	Design	Development	Integration & Test

**Systems Engineering across both
-- R&D and System Development Organizations --
results in clearer metrics for TRL gates and better insertion of new technology into platforms.**

Part 2: Why Systems Engineering is Critical – Proof by Example



Mars Observer

Mars Observer, an unmanned spacecraft designed to study the geosciences and climate of Mars, was launched in September, 1992. Three days before it was scheduled to enter Mars orbit, contact with the spacecraft was lost. Attempts to re-establish communication were unsuccessful.

► Was it Possible ?

- **Yes.** System and Subsystem performance metrics met all requirements. Extensive design reuse from the LEO platforms.

► Could it be integrated?

- **Yes.** System models, interfaces, ICDs were put in place. All hardware met specifications. Interfaces and interdependencies were documented.

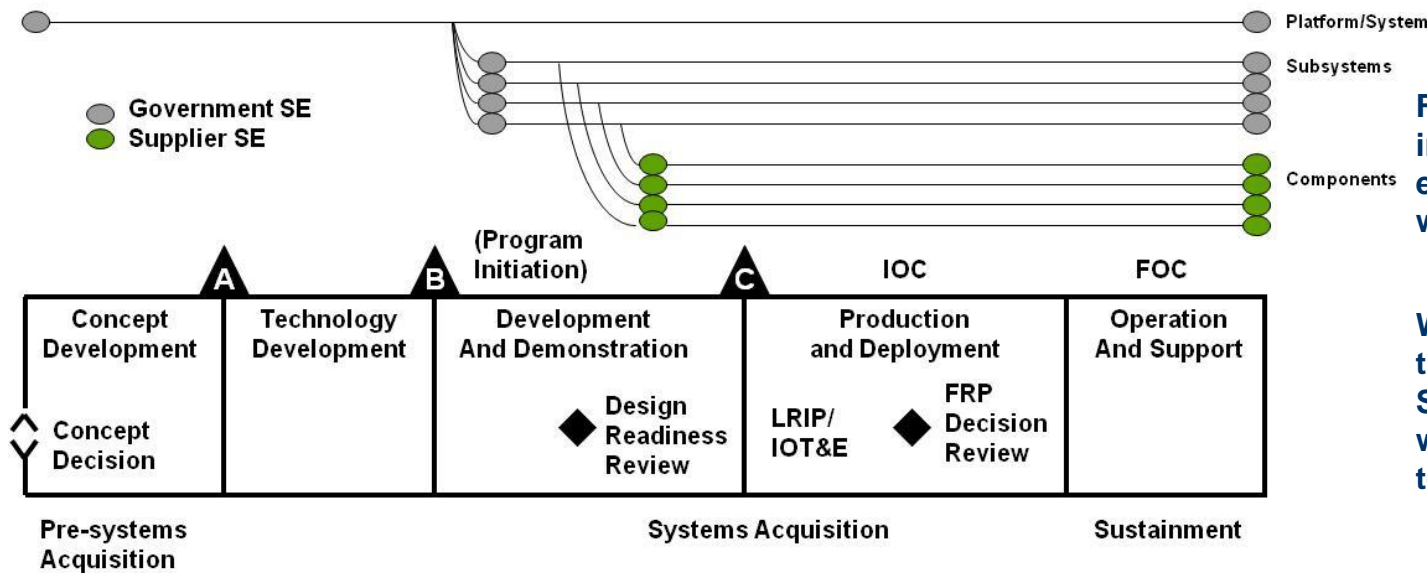
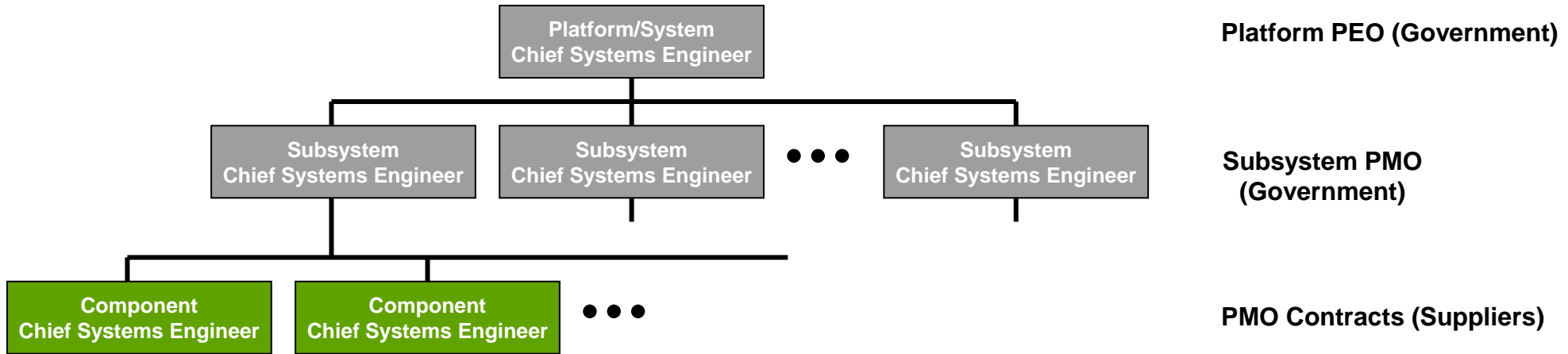
► Was it Operationally Useful?

- **No.** After a 725 million kilometer voyage lasting eleven months, just two days prior to planned entry into Mars orbit, the spacecraft suddenly fell silent.

► What happened? What did we learn?

- The results of a five-month investigation were inconclusive, but one likely cause of the catastrophic failure may have been a fuel line, throwing the vehicle into a spin or creating an explosion.
- The propulsion system was designed for Low Earth Orbiting vehicles, not interplanetary missions. Subsequent testing showed that the hydrazine in the LEO propulsion system decomposed over the long trip to Mars, creating an unstable mixture. When the normally closed pyro-valve fired to wet the lines to the thrusters, the line, and perhaps the spacecraft, exploded.
- ***As Systems Engineers, we must consider all possibilities and eventualities, taking a broad view of the appropriate nature and use of even High TRL components.***

Part 3: Technical Leadership and the Role of the Systems Engineer for Program Success (cont'd)



Frequently, Supplier SEs do not have insight into the entire platform—or even an entire subsystem—into which their components fit.

When responsibility is distributed in this way, it is the Platform- and Subsystem-level Systems Engineers who must provide total life cycle technical leadership

Part 4: Ideas into Action: What Should Be Done?

- ▶ **Institute strong, pervasive risk management for technology evolution & integration**
 - Demand SE discipline; Empower SE leadership within Orgs and across Orgs (Dev and R&D)
 - ❖ *SE active leadership during entire life cycle across all activities*
 - ❖ *Demand collaboration of SE at all levels (PMO/PEO, Joint Processes, R&D)*
 - Risk identification and mitigation strategies (early identification of CTEs & KPPs)
 - ❖ *Define metrics and activation thresholds for mitigation action*
 - ❖ *Engineer just enough to provide only critical constraining metrics into TRL levels.*
 - Contingency activity planning (for technology evolution, more important than preventive activity planning)
 - “Continuous” TRL re-assessment through Joint Development and R&D SE teams
 - Define Requirements with Integrity (include total mission aspects)
 - ❖ *Obey “Rule of Unintended Consequences”*
 - ❖ *Employ M&S early and often; validate with real data from the R&D organizations*

- ▶ **Install processes to ensure that appropriate metrics flow back and forth and that technical leadership reviews and owns the outcomes of each TRL and System milestone gate**
 - Catalog and Track Technical Interdependencies (and some programmatic ones)
 - ❖ *Parameters and constraints*
 - ❖ *Integrated with risk management plans*
 - Integrated IMS & WBS (include TRA events)
 - Independent design validation activities (peer review)