Exploitation of a Validation Hierarchy for Modeling and Simulation

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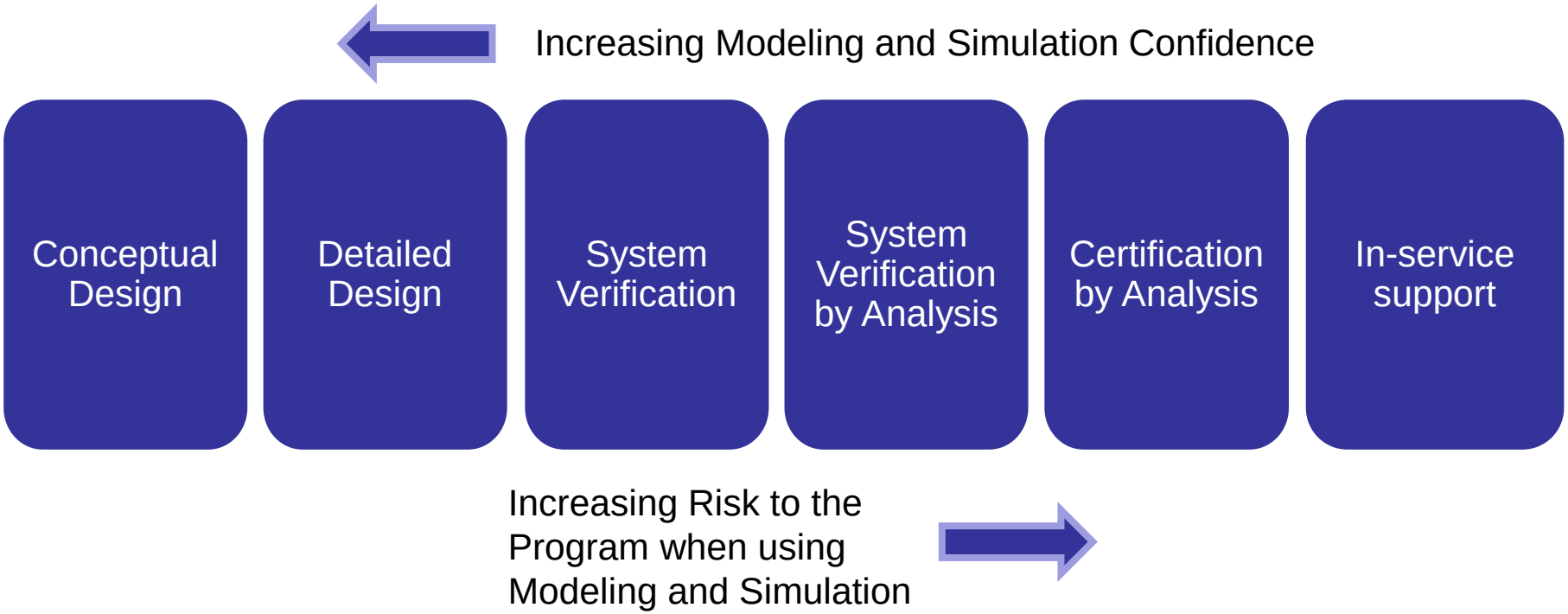
The Challenge : The Vision

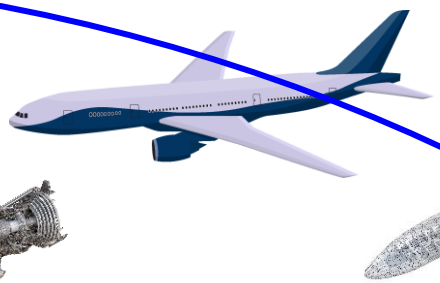
Design complexity continues to increase	❖	Exploit Digital Transformation initiatives to reduce development time and cost
Budgets continue to be challenged	❖	Build on the successful use of Modeling and Simulation (M&S) to reduce design time and testing costs
Expectation of time to deployment continues to shorten	❖	Critically assess simulation credibility to increase confidence in certification by analysis

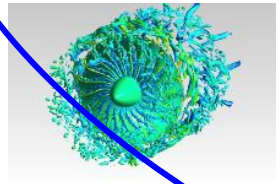
Potential uses of Modeling and Simulation (M&S) in the System Development Lifecycle

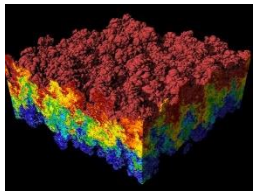


To enable the use of M&S capability later in the system design cycle, we need a rigorous process to establish confidence in the M&S capability for the *overall* system.

Bridge from Systems Engineering to Modeling and Simulation



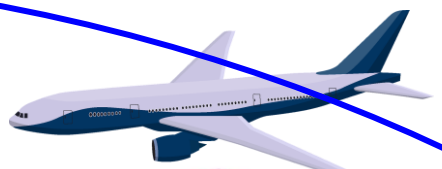


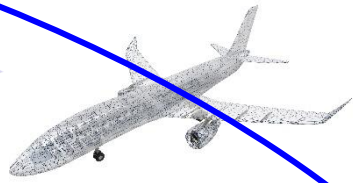


How can we establish a linkage between system engineering and modeling and simulation?

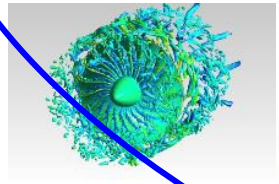
- Physics Modeling
- Code Verification
- Uncertainty Quantification
- Solution Verification
- Model Validation

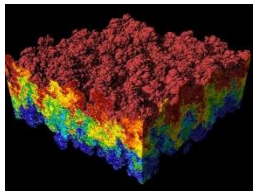
Bridge from Systems Engineering to Modeling and Simulation





Systems



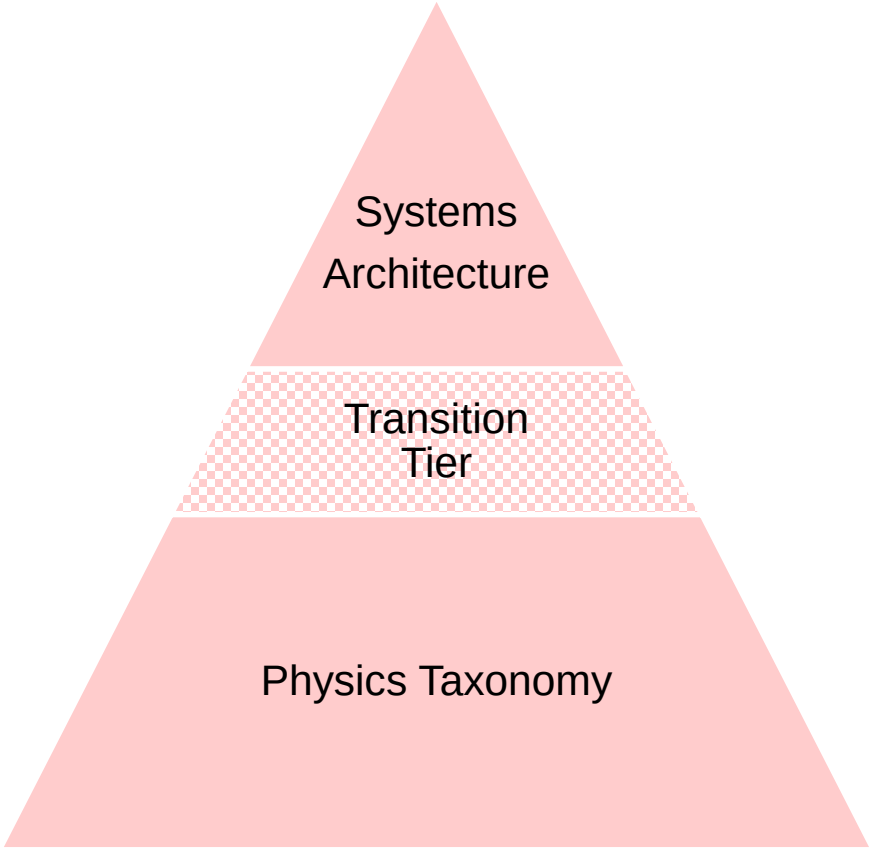


Physics

Using a Validation hierarchy which provides a systematic and pragmatic approach

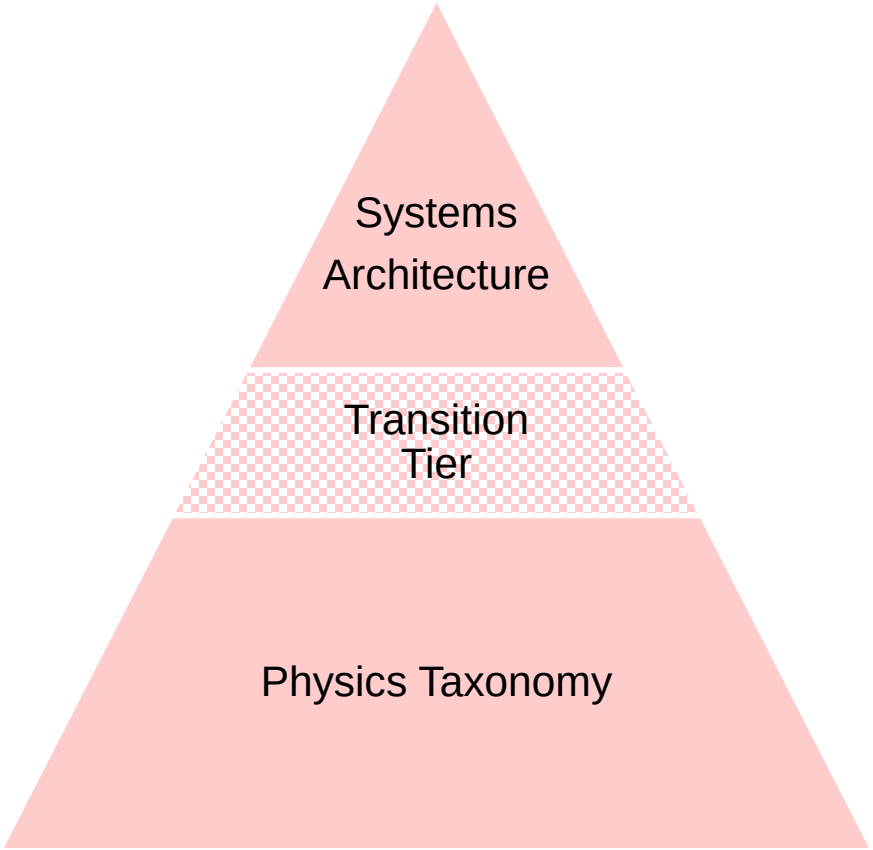
Physics Modeling
Code Verification
Uncertainty Quantification
Solution Verification
Model Validation

Model Validation Hierarchy



- **Systems architecture perspective**
  - Systems/subsystems/etc.
  - System design requirements are specified
- **Transition tier**
  - Transforms hierarchy from a systems architecture to a physics taxonomy view
  - Mathematical modelling introduced
- **Physics taxonomy perspective**
  - Modeling and simulation features specified
  - Physics/phenomenological decomposition from complex simulations to unit problems

Model Validation Hierarchy



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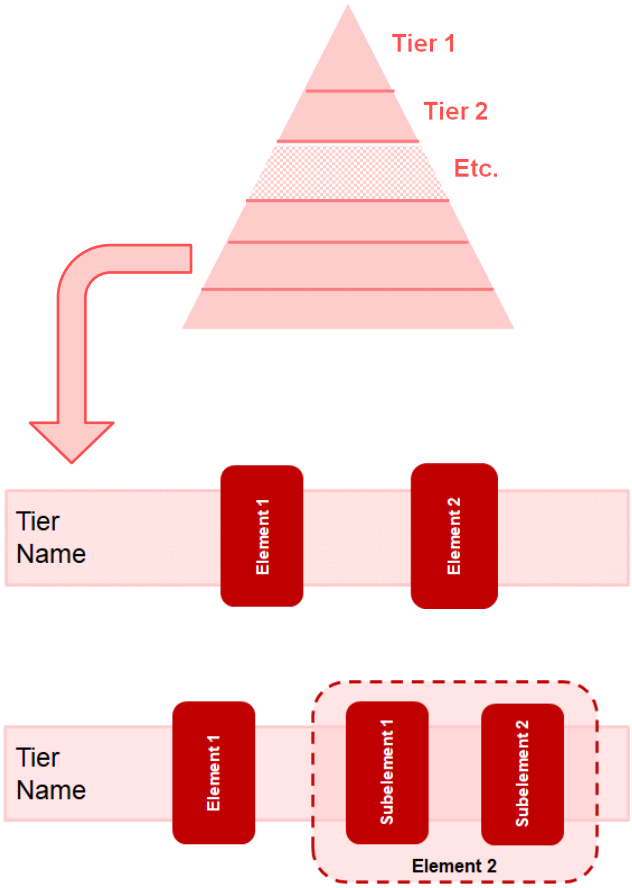
How can we exploit this technology to prioritize Validation Experiments?

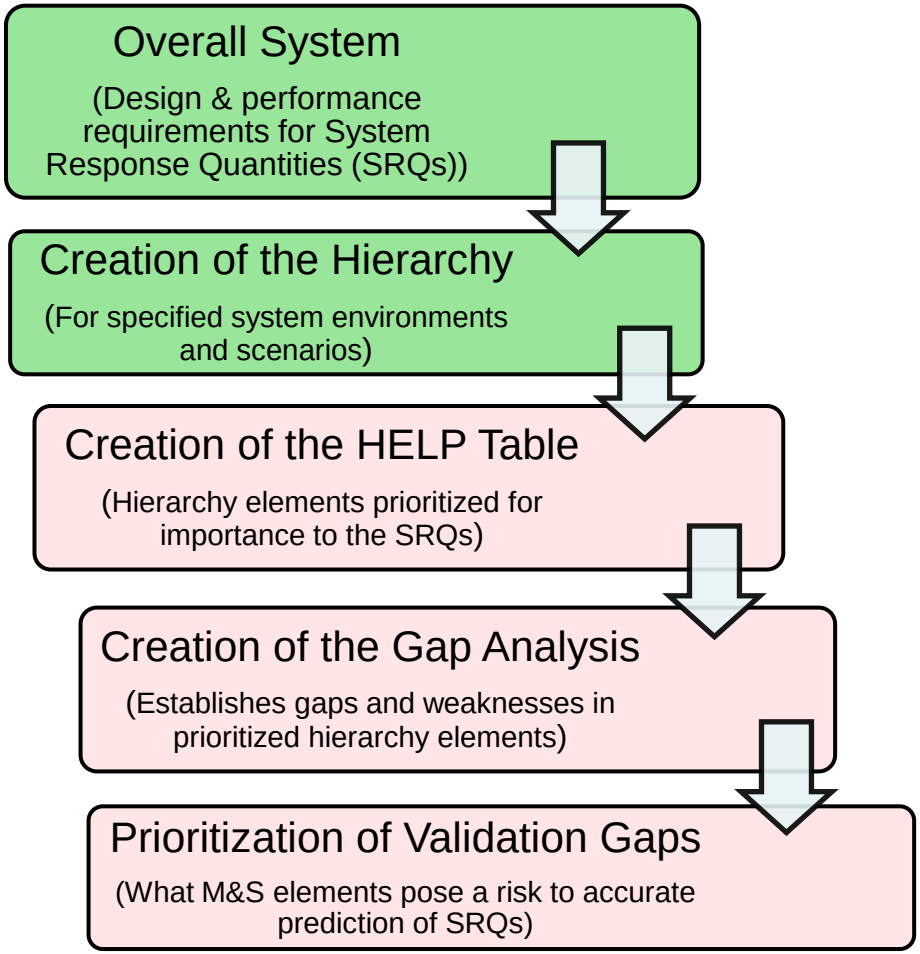
Model Validation Hierarchy Attributes

- **Hierarchy addresses system engineering (SE) requirements**
  - Presents SE and M&S concerns in a single view
  - Establishes a clear, logical connection between physical phenomenon and system behavior/performance
  - Is a rigorous and systematic approach that draws attention to missing elements
- **Moving down the hierarchy corresponds to a deconstruction of element complexity**
  - Sections of the hierarchy can have multiple tiers
  - Each tier can have multiple elements and subelements
- **The hierarchy is modular**
  - Reusable and adaptable to support new requirements
  - A strategic asset for a system and its future modifications
  - Elements may be reused for other systems



Prioritization of Validation Experiments

- **The prioritization process has four main tasks**
  - Creation of the Validation Hierarchy
    - Based on system design requirements
  - Creation of the Hierarchy ELement Prioritization (HELP) table
    - Prioritization based upon importance of validation hierarchy elements for an SRQ
  - Creation of the Gap Analysis
    - Establish validation status of prioritized elements
    - Many gaps can result
  - Prioritization of the Validation Gaps
    - Which gaps are most important to address



Hierarchy ELement Prioritization Table Analysis

- **A single HELP Table is produced for each environment and scenario**
- **The importance of each element for each SRQ of interest is assessed**
  - We can exploit the nature of a hierarchy to avoid assessing children of elements that are considered of low importance
  - Importance is assessed using a small number of ranks (typically 3)
- **Results in a ranking of the importance of hierarchy elements for each SRQ**
- **We use this ranking as an initial prioritization.**
  - Only high importance elements are considered in the next stage

Environment A, Scenario 1

Hierarchy Elements	SRQ 1	SRQ 2	SRQ 3
A			
B			
C			
D			
E			
F			

Importance
High
Moderate
Low

Gap Analysis

- **A single Gap Analysis is performed for each environment, scenario and SRQ**
- **The adequacy of each Element is assessed for the adequacy of the**
  - Physical Modeling
  - Code Verification
  - Solution Verification
  - Model Validation
  - Uncertainty Quantification and Sensitivity Analysis
- **Results in the identification of gaps in the M&S capability**
- **Identifies M&S capability weaknesses**

Environment A, Scenario 1 – SRQ 3

Heirarchy Elements	Modeling	Verification		Model Validation	Uncertainty Quantification
		Code Verification	Solution Verification		
B					
C					
F					

Capability
Inadequate
Unknown
Adequate

Sensitivity Analysis

- **Gap analysis often identifies many gaps, and consequently further prioritization may be required**

- **We propose sensitivity analyses to assess the impact of closing gaps**
  - Establish a baseline using an initial Sensitivity Analysis
  - For each gap estimate the impact on the SRQ of closing the gap

- **Results in a ranking of the gaps according to the expected improvement in uncertainty for the SRQ**

Concluding Remarks

- **We have presented a *rigorous* approach for identifying and prioritizing validation experiments**
  - Exploits the properties of a Validation hierarchy
  - A three step Prioritization process based on:
    - HELP Table prioritizes hierarchy elements that are of *importance*
    - Gap Analysis identifies *weaknesses of the M&S capability*
    - Sensitivity Analysis measures the *impact of closing gaps*
  - Hierarchical approach is *modular* and creates artifacts/assets that can be *reused*:
    - to meet changing requirements of a single system
    - effort for one system can be recapitalized for other systems

- **By identifying and prioritizing gaps in validation coverage, the approach provides a basis for critically assessing simulation credibility**