

Connecting System Design to Modeling and Simulation Capabilities

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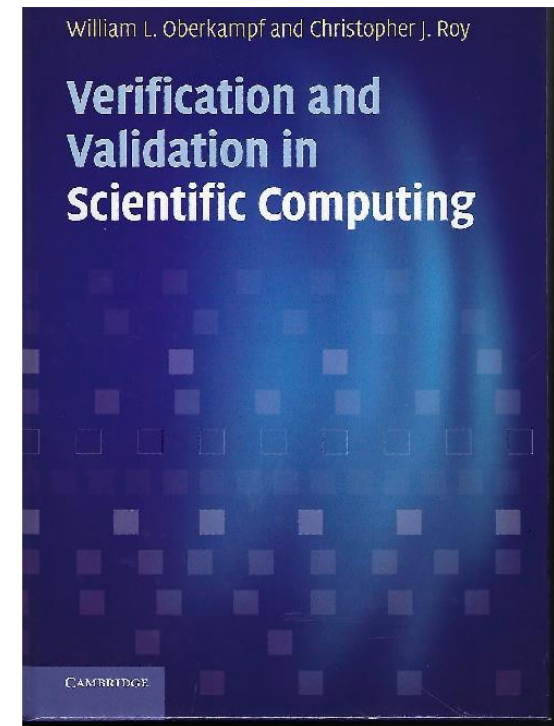
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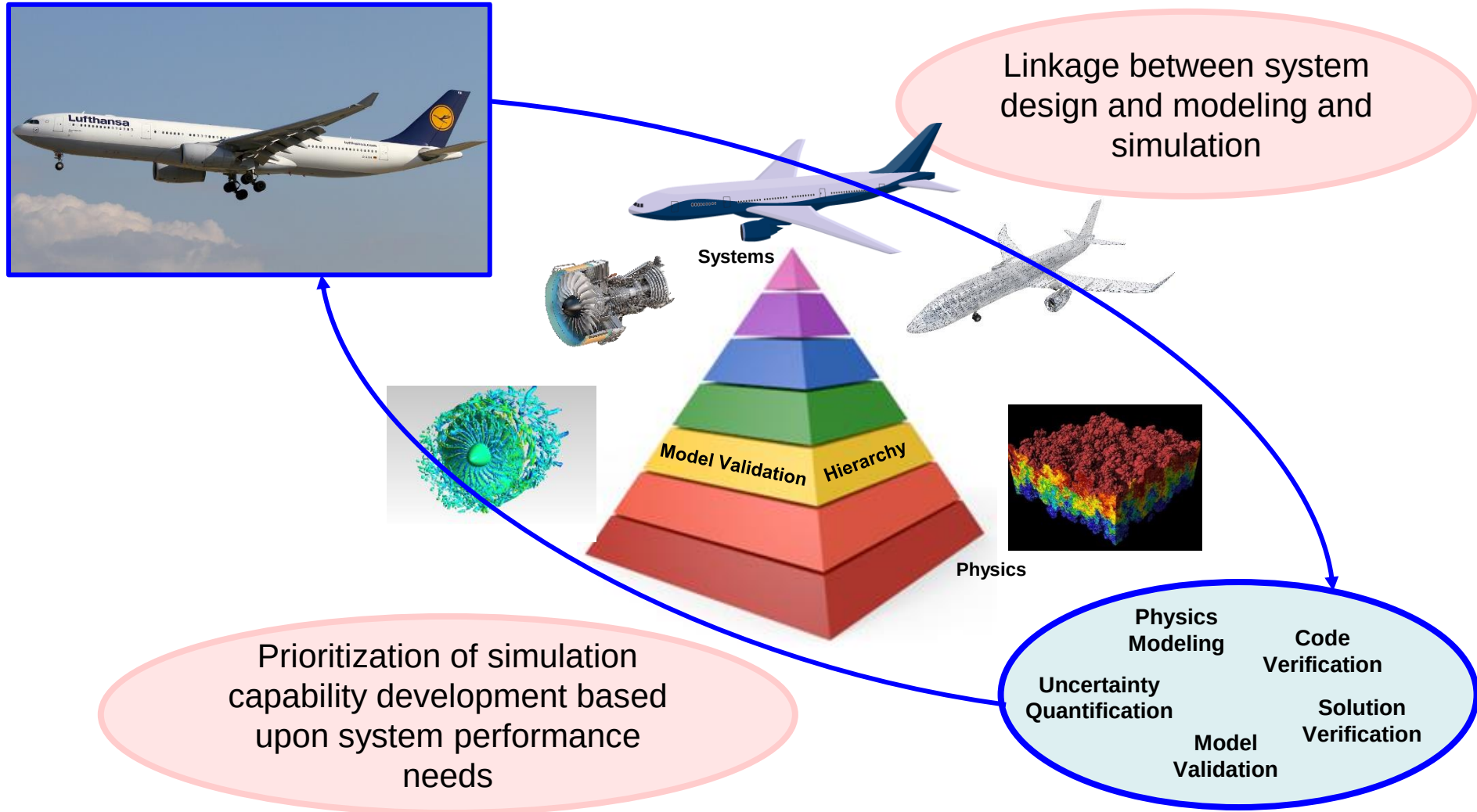
Focus for Present Research

- **How can modeling and simulation (M&S) better contribute to aircraft system design?**
- **A Model Validation Hierarchy technique has been developed**
 - Creation of the Model Validation Hierarchy
 - Prioritization within the Model Validation Hierarchy
 - General principles and a practical application are included
- **Our approach extends the concepts discussed in Oberkampff & Roy***
 - Model validation hierarchies
 - Phenomena Identification and Ranking Table (PIRT)
 - Gap analysis

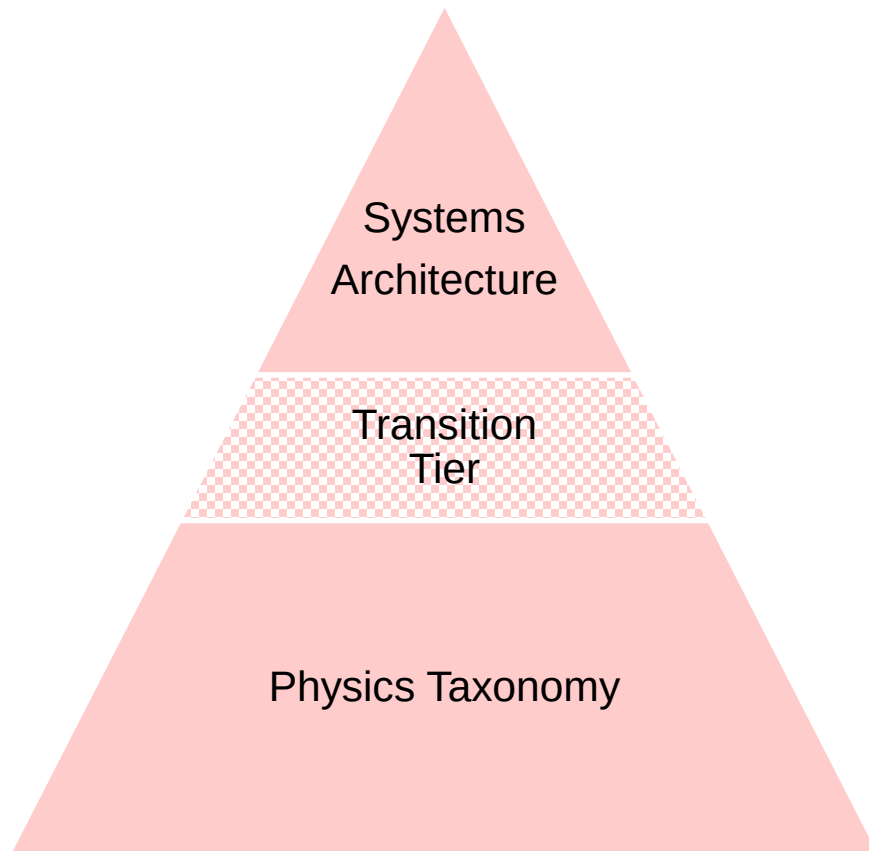


* Oberkampff WL, and Roy CJ, "Verification and Validation in Scientific Computing," CUP, 2010.

Bridge from Systems Engineering to M&S Development



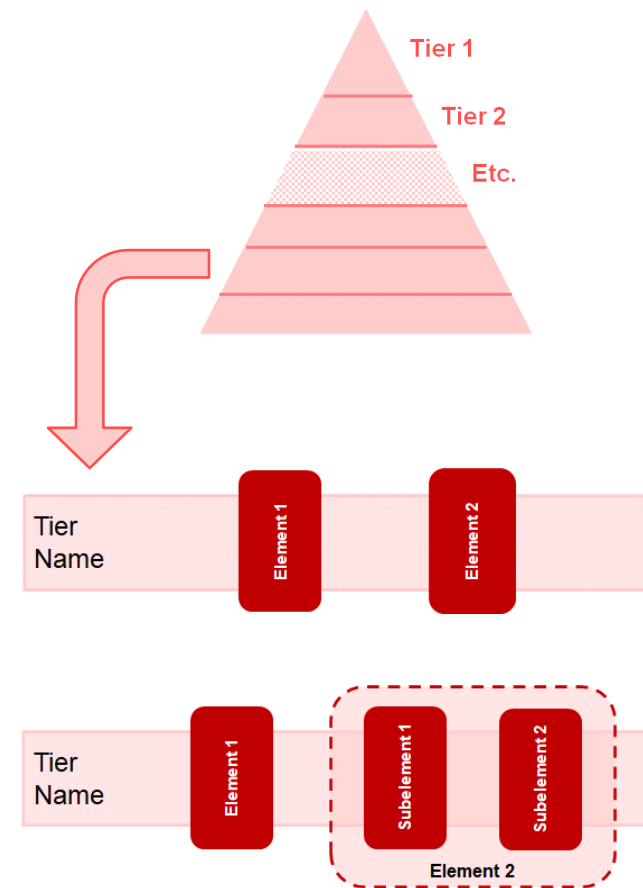
Structure of the Model Validation Hierarchy



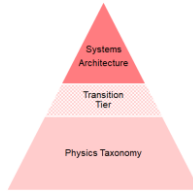
- **Systems architecture perspective**
 - Systems/subsystems/etc.
 - System design requirements are specified
- **A transition tier has been created**
 - Transforms hierarchy from a systems architecture to a physics taxonomy view
 - Mathematical modelling introduced
- **Physics taxonomy perspective**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

Model Validation Hierarchy Attributes

- **Hierarchy developed to address system design requirements**
 - Systems architecture and M&S linkages established
 - System design requirements focus hierarchy content
- **Moving down the hierarchy corresponds to a deconstruction of element complexity**
 - Sections of the hierarchy can have multiple tiers
 - Number of tiers is arbitrary
 - Each tier can have multiple elements and subelements
- **Hierarchy is modular**
 - Reusable and adaptable to support new requirements
 - Can become a strategic asset for a system and its future modifications



Systems Architecture: Notional Structure



Highest Systems
Architecture Tier

System 1

System 2

System 3

Intermediate Systems
Architecture Tier(s)

Subsystem 1

Subsystem 2

Subsystem 3

Subsystem 4

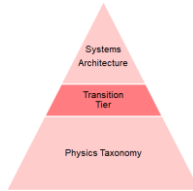
**Systems
Architecture**

Lowest Systems
Architecture Tier

Element 1

Element 2

Transition Tier: Notional Structure



Lowest Systems
Architecture Tier

Element 1

Element 2

Element 1 Modeling

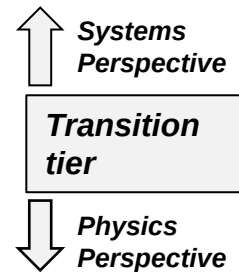
Modeling
Discipline 1

Modeling
Discipline 2

Modeling
Discipline 3

Element 2
Modeling

*Transition
Tier*



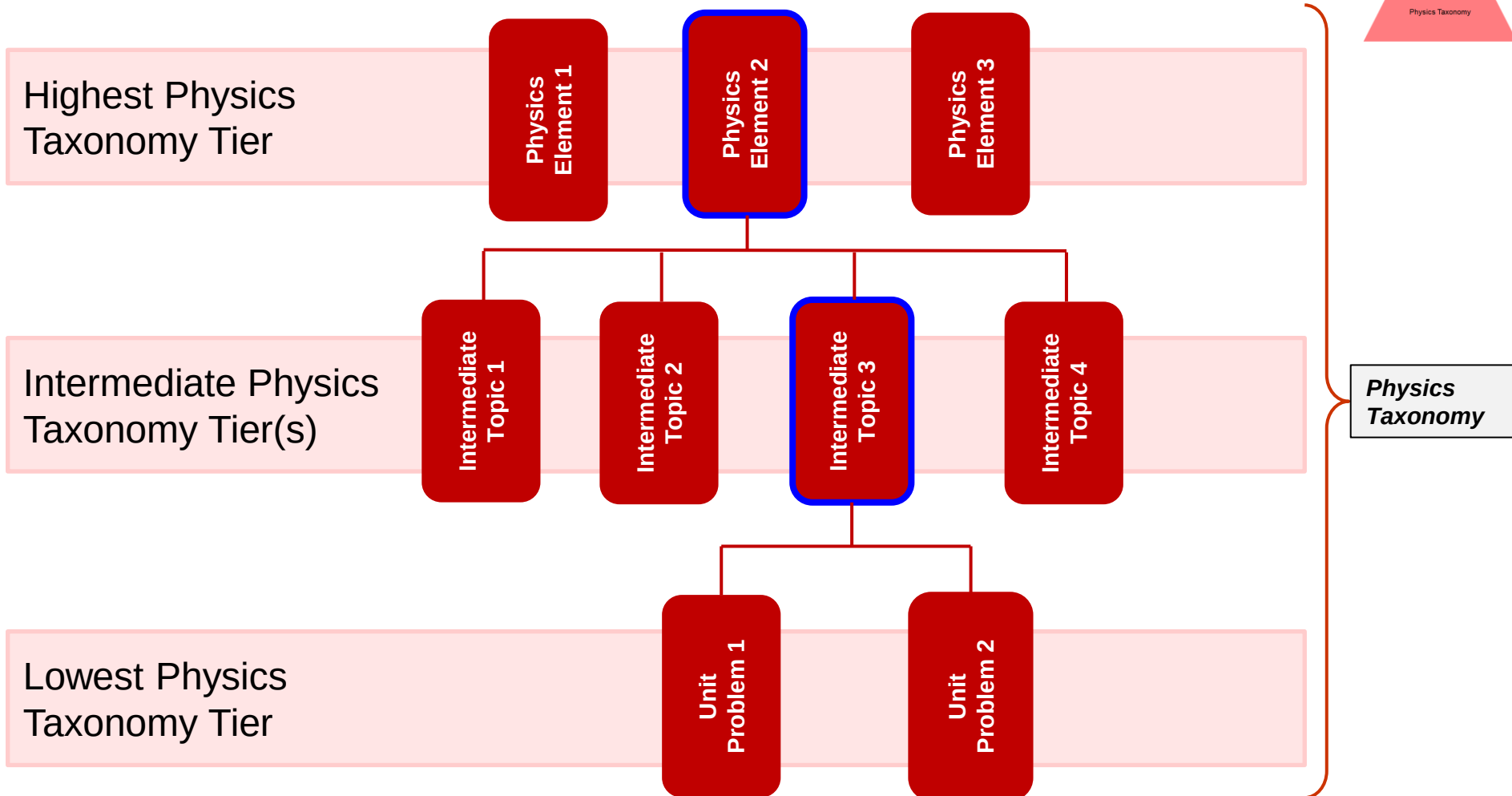
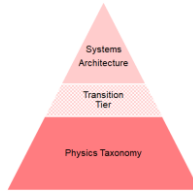
Highest Physics
Taxonomy Tier

Physics
Element 1

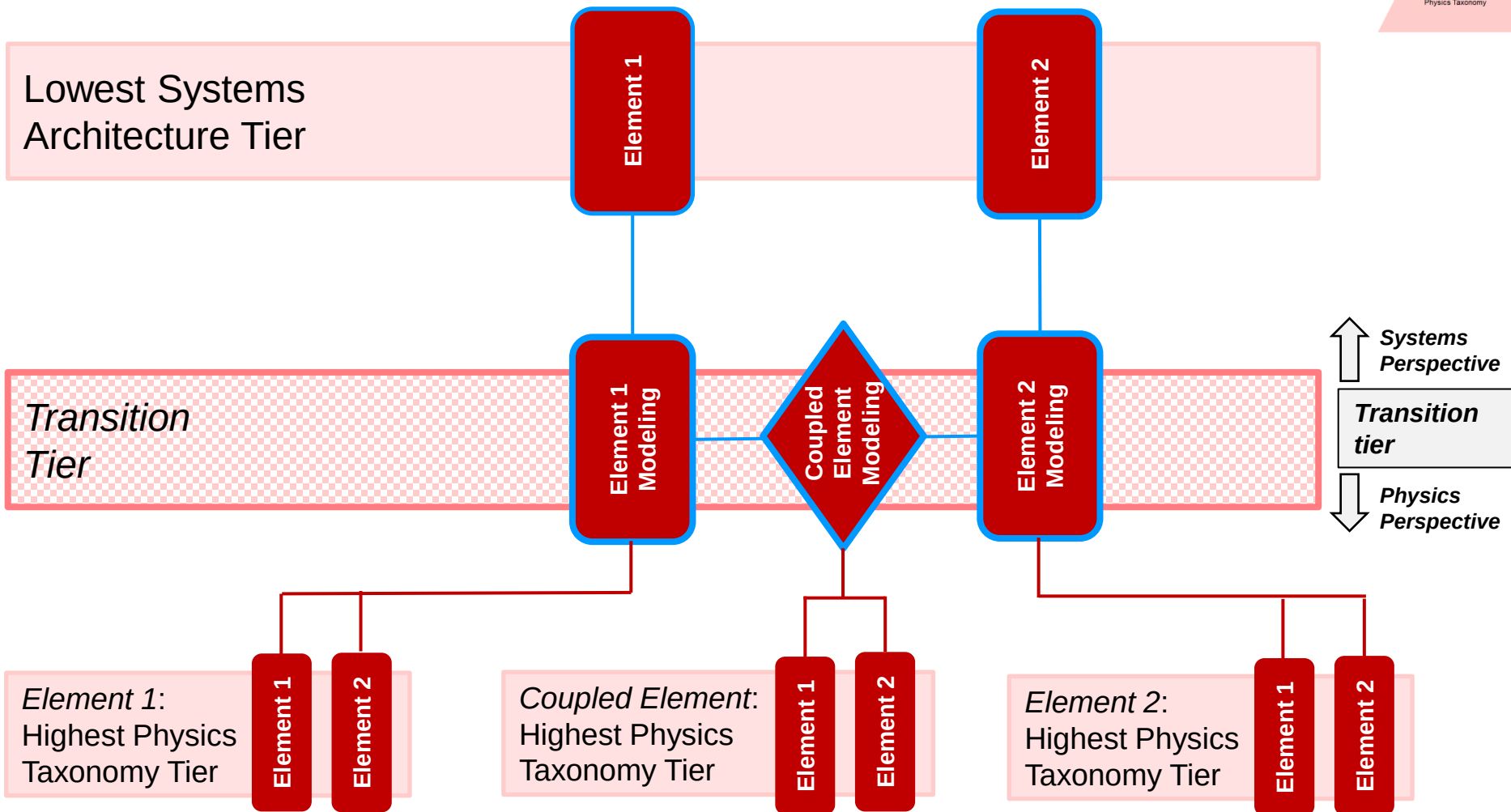
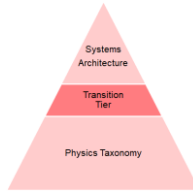
Physics
Element 2

Physics
Element 3

Physics Taxonomy: Notional Structure

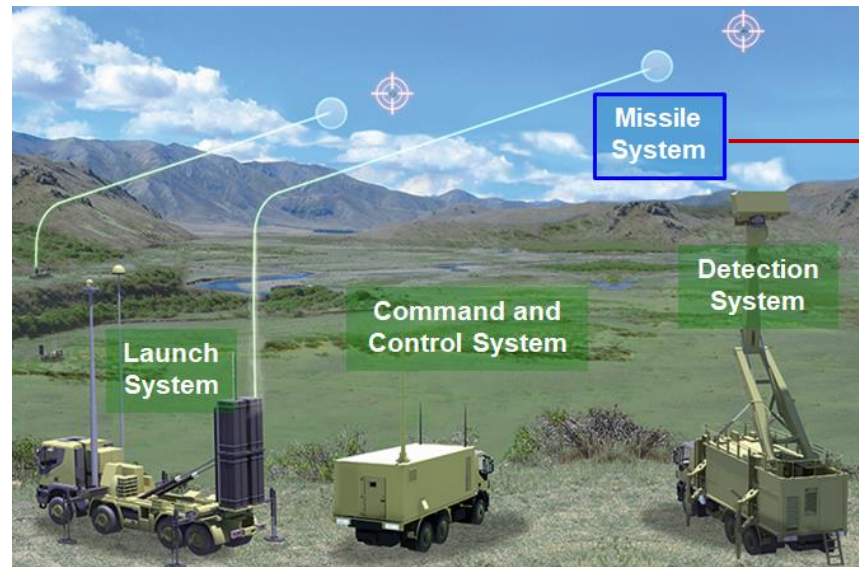
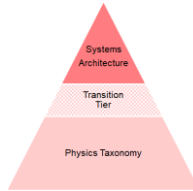


Coupling Element Concept

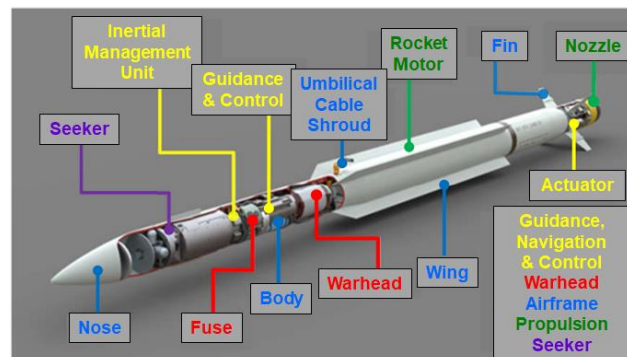
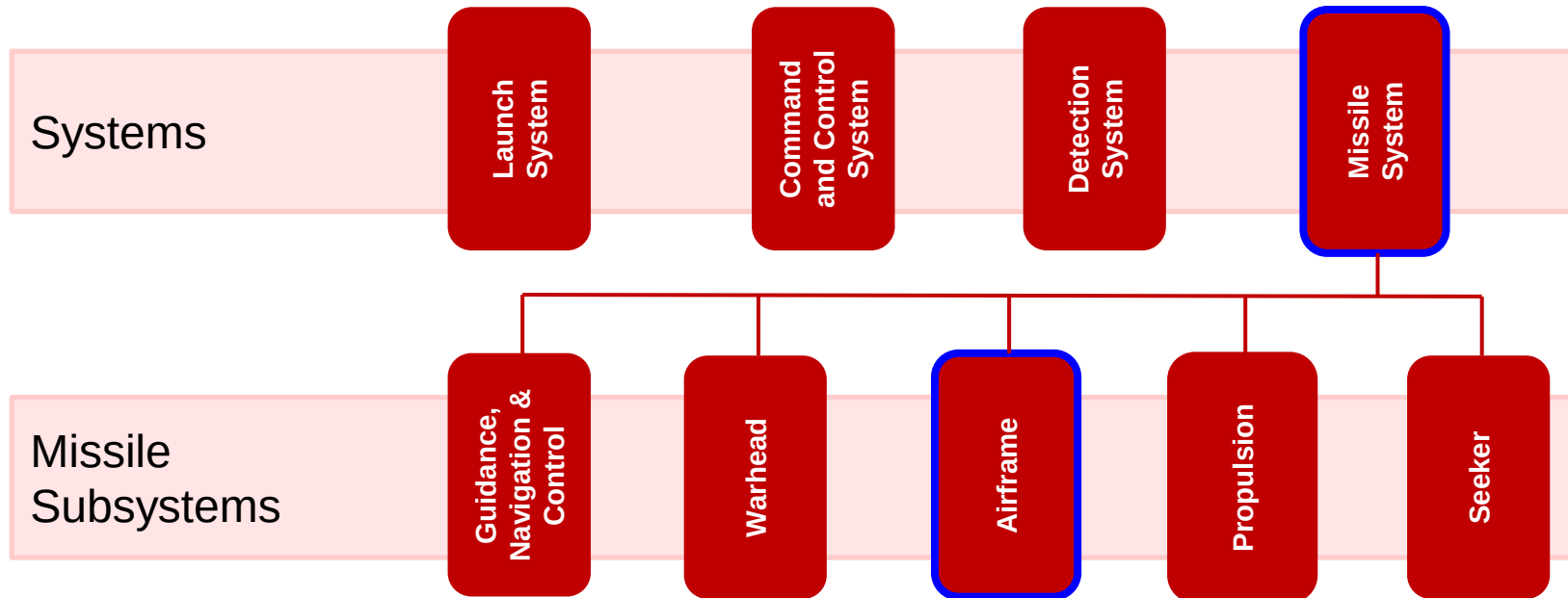
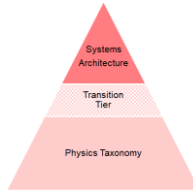


Model Validation Hierarchy Example

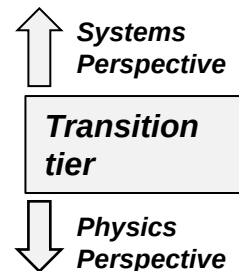
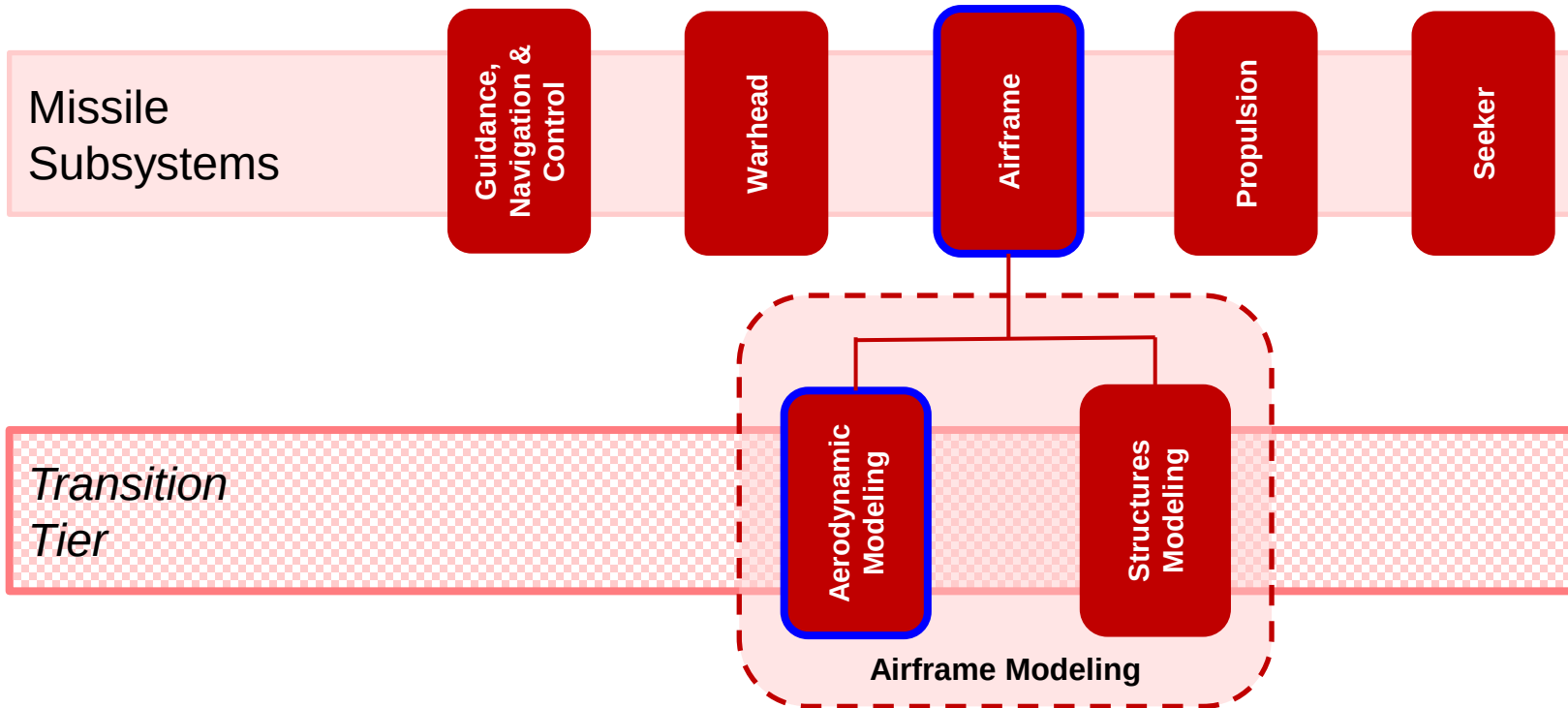
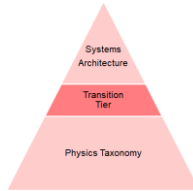
Ground-Based Air Defense System (GBADS)



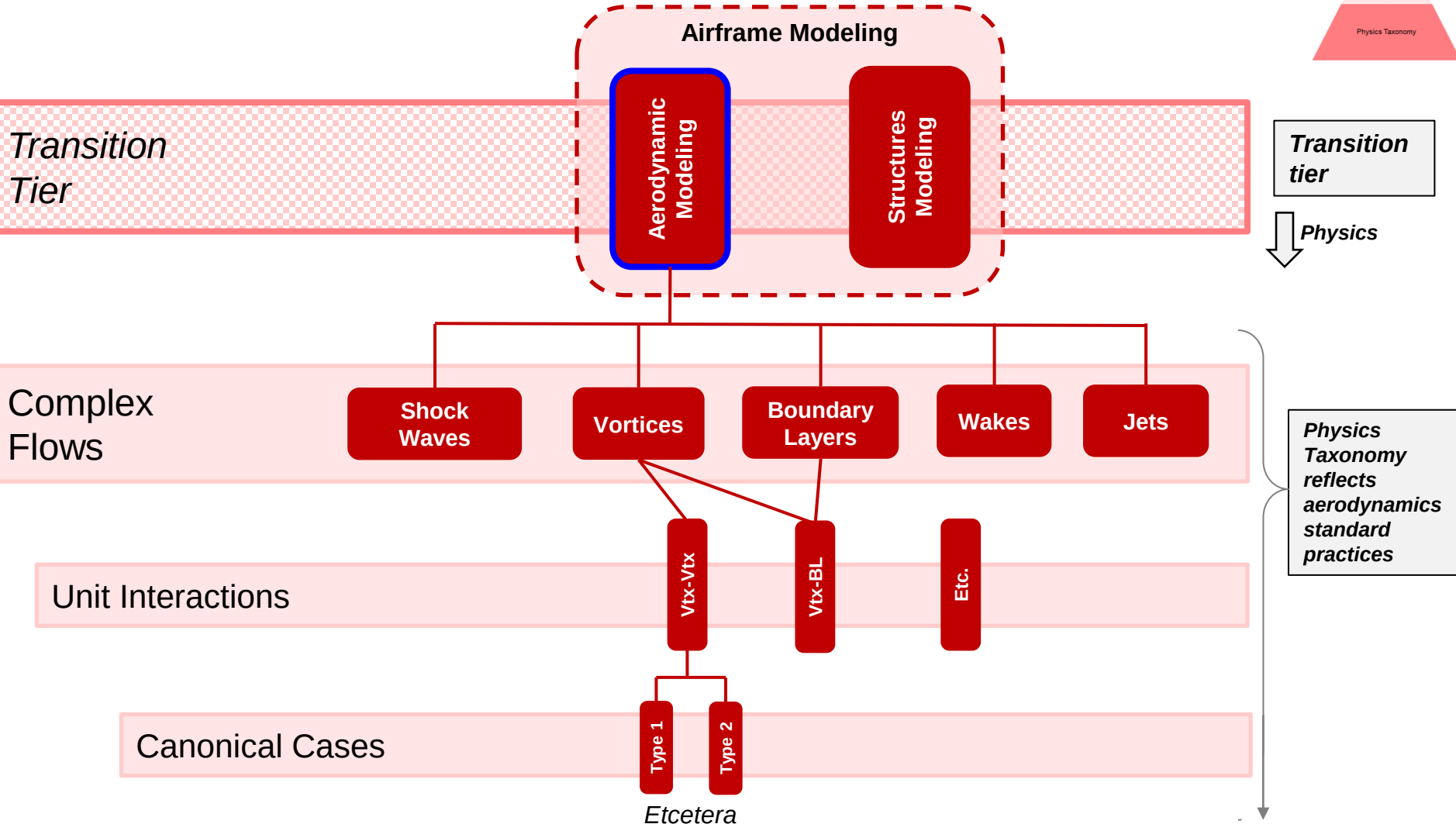
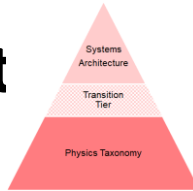
Expansion of the Missile System Element



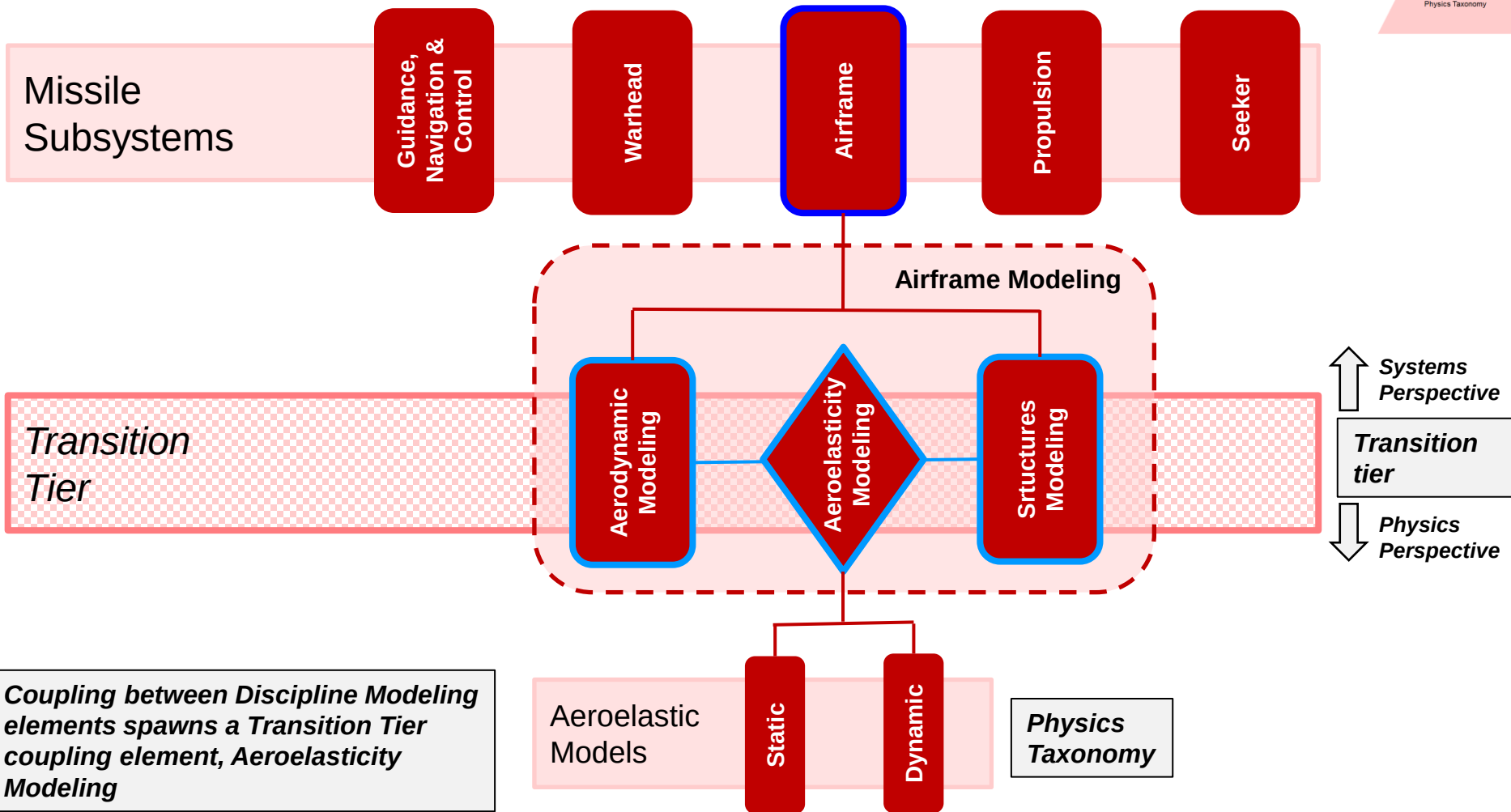
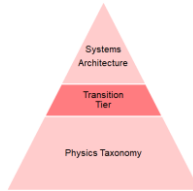
Expansion of the Airframe Subsystem Element



Expansion of the Aerodynamic Modeling Subelement

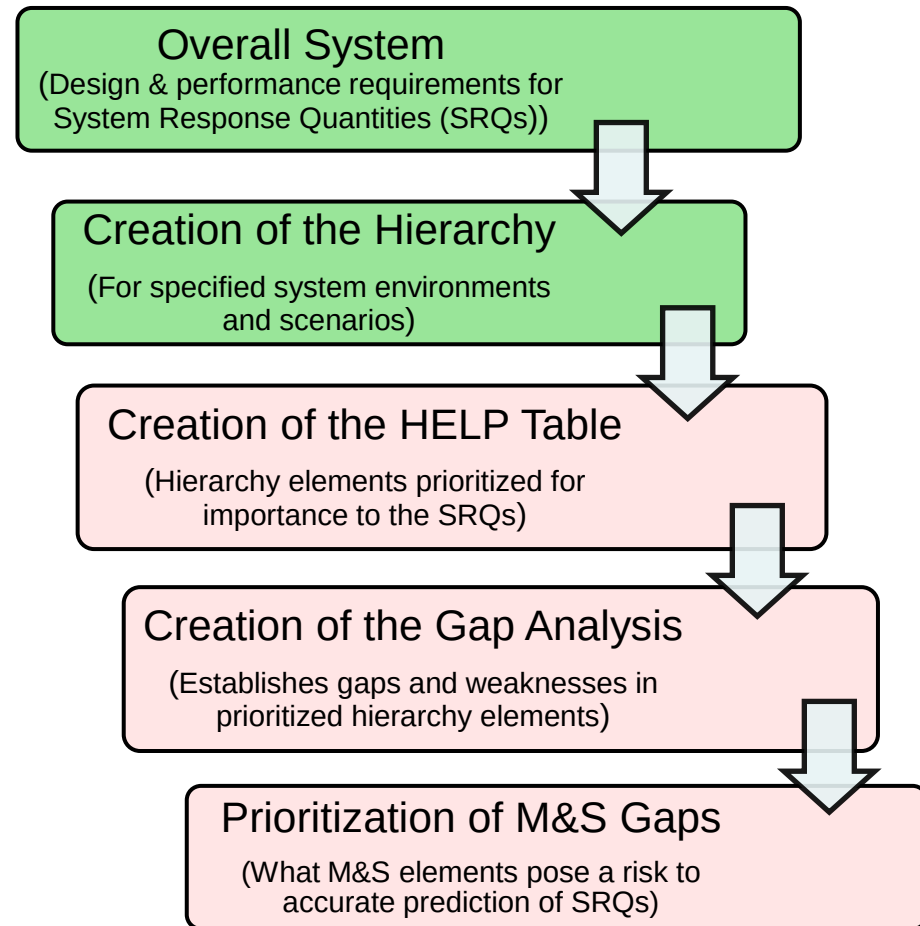


Example of Coupling between Airframe Modeling Subelements



Prioritization of M&S Development

- **Our Prioritization process relies on four key elements**
 - Creation of the Model 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 M&S Gaps
 - Which gaps are most important to address



HELP Table Analysis

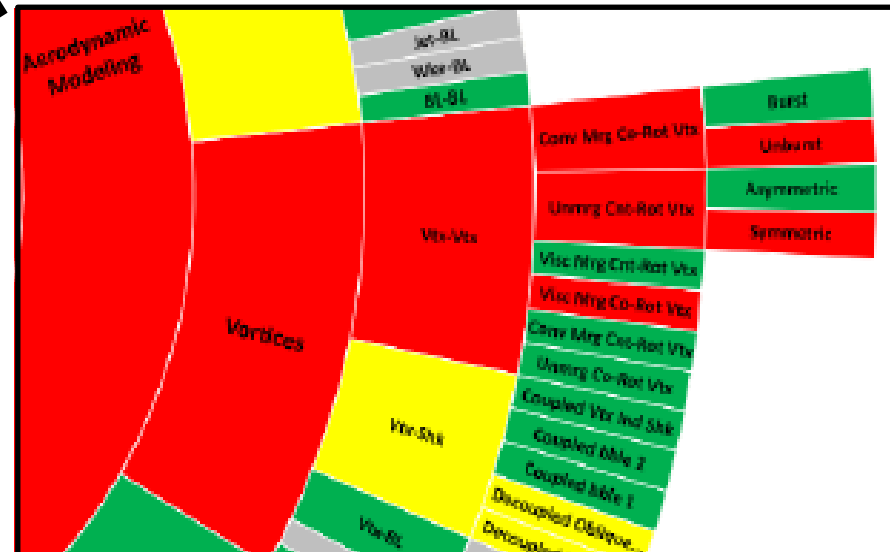
- **Shares common philosophy with a prior process**
 - Phenomena Identification and Ranking Table (PIRT)
- **Four key features of HELP table**
 - Environment and scenario under analysis
 - List of hierarchy elements for assessment
 - System Response Quantities of interest
 - Outcome from importance assessment
- **Results in ranking of importance of hierarchy elements**

Environment A, Scenario 1

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

Importance
High
Moderate
Low

- **Chart shows Model Validation Hierarchy from GBADS example**
 - Missile system
 - Elements colored from HELP analysis
 - Many elements ruled out
 - Some high-importance unit problems found



Gap Analysis Table

Environment A, Scenario 1 – SRQ 3

- **Shares common philosophy with a prior process**
 - Gap analysis associated with PIRT process
- **Five key features of Gap table**
 - Each environment and scenario under analysis
 - Each SRQ assessed independently
 - **Subset of Model Validation Hierarchy elements from HELP Table**
 - Column for each M&S technology
 - Importance indicator
- **Identifies M&S capability weaknesses**

Subset of Hierarchy Elements	Modeling	Capability Verification		Capability Validation	UQ Capability
		Code Verification	Solution Verification		
A					
B					
C					
F					

Importance
Inadequate
Unknown
Adequate

Closing the Gaps

- **Gap findings**
 - Gap analysis identifies high-priority M&S elements
 - M&S elements connect to system design requirements
- **Gap closure work**
 - Conduct model validation experiments and improve numerical simulation
- **Gap closure impacts**
 - Gap closure provides enhanced M&S confidence at the level of the hierarchy element
 - Model Validation Hierarchy could broaden impact of gap closure
 - Physics Taxonomy enables impact assessments of closely related phenomena
 - Systems Architecture enables impact assessments of closely related design options
 - Enhanced understanding can result from both

Concluding Remarks, 1/2

- **A significant extension to the Model Validation Hierarchy has been developed**
 - Built on the general concept of deconstruction of a complex system
 - Allows system design requirements to be systematically connected with physics-based model validation features
 - Connects system architecture and physics taxonomy through a transition tier
 - Accommodates coupling effects
 - Accommodates discipline-specific conventions and practices
 - Is robust (air, land, or sea systems; diverse physics)
- **Approach is modular**
 - Allows reuse of hierarchy to meet new system design requirements
 - Model validation hierarchy can become a strategic asset

Concluding Remarks, 2/2

- **Validation hierarchies can be exploited using HELP and Gap analyses**
 - HELP table provides a structured means to rank the importance of Model Validation Hierarchy elements based on system design requirements
 - Gap analysis provides a structured means for prioritizing HELP table elements for targeted M&S improvements
- **Integrated Model Validation Hierarchy, HELP and Gap processes**
 - Generally applicable to any type of engineering system
 - Establish rigorous and traceable analysis driven by system design requirements
 - Lays firm foundation for improved M&S-based decision making on systems

Acknowledgments

- **Diverse sponsorship has enriched this research product**
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