Connecting System Design to Modeling and Simulation Capabilities

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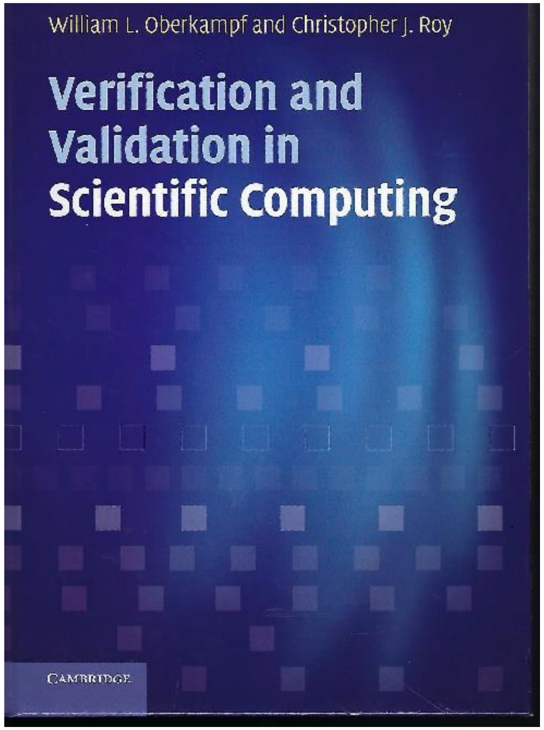
Focus for Present Research

- **How can modeling and simulation (M&S) better contribute to aircraft system design?**

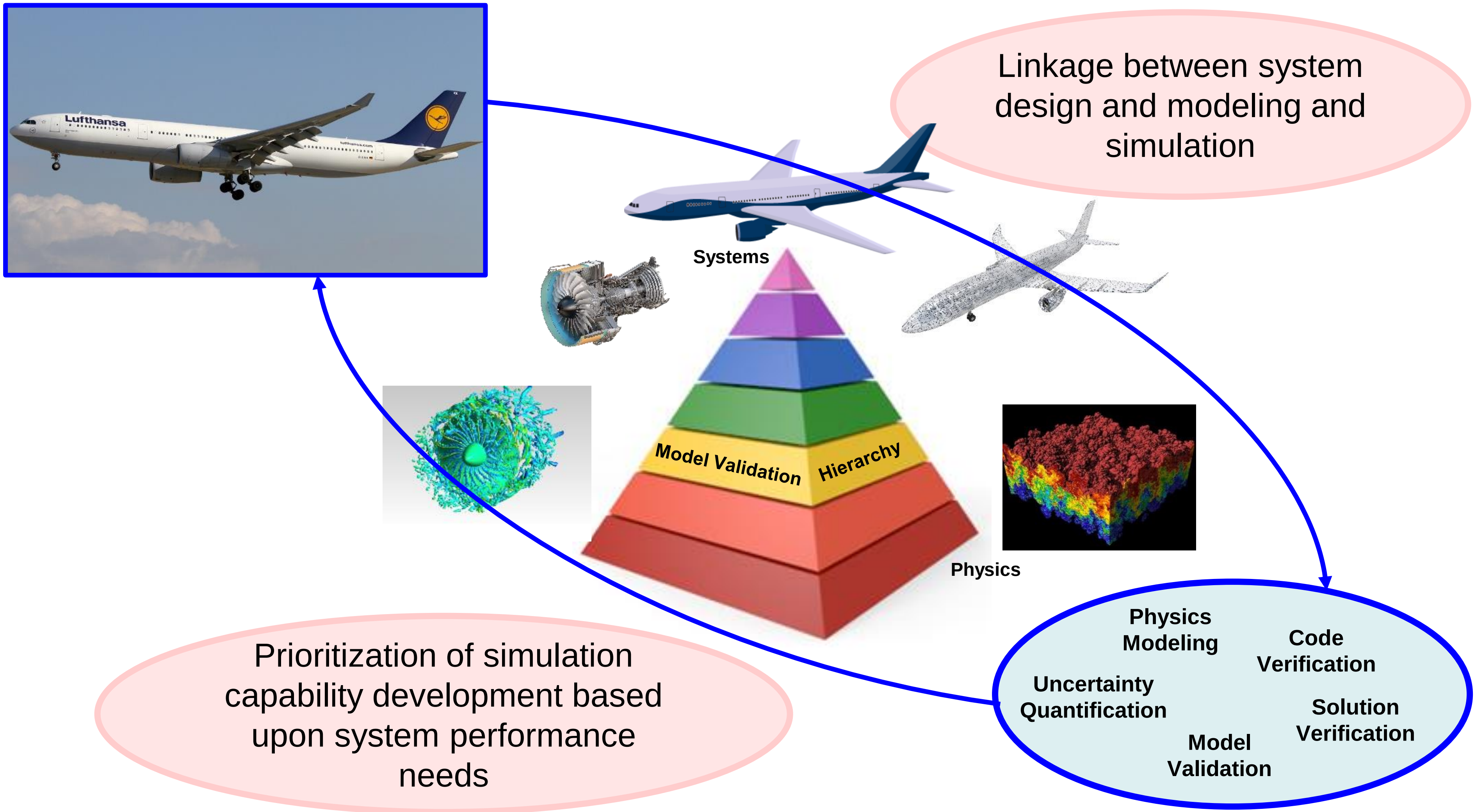
- **A Model Validation Hierarchy technique has been developed**
  - ➢ Creation of the Model Validation Hierarchy
  - ➢ Prioritization within the Model Validation Hierarchy
  - ➢ General principles and a practical application are included

- **Our approach extends the concepts discussed in Oberkampf & Roy***
  - ➢ Model validation hierarchies
  - ➢ Phenomena Identification and Ranking Table (PIRT)
  - ➢ Gap analysis

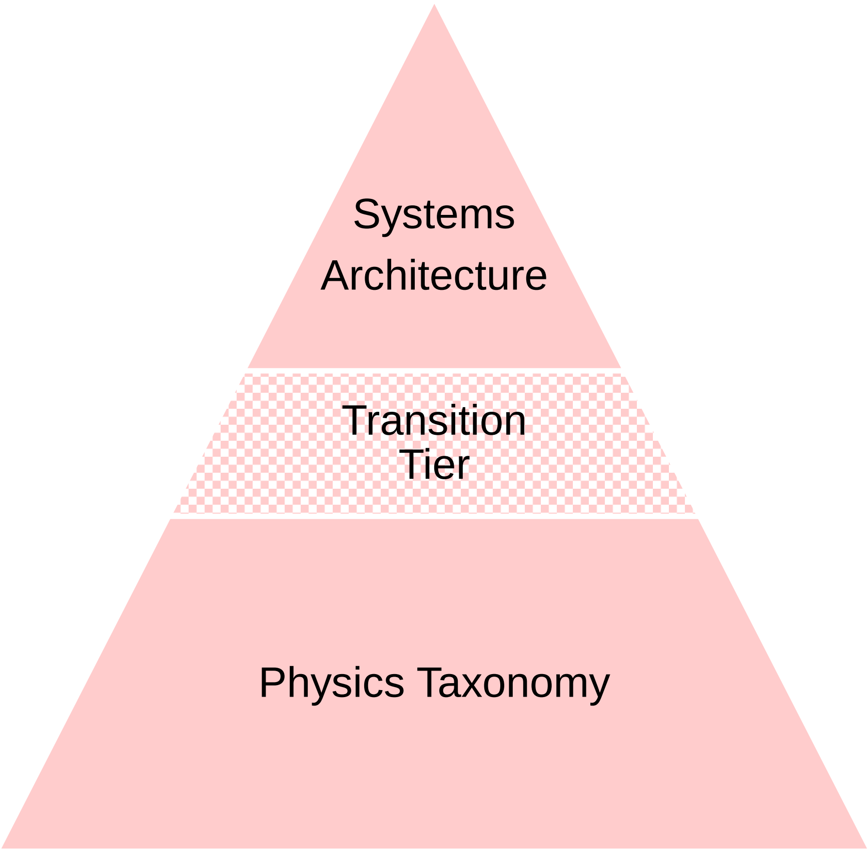


* Oberkampf WL, and Roy CJ, "*Verification and Validation in Scientific Computing*," CUP, 2010.

Bridge from Systems Engineering to M&S Development



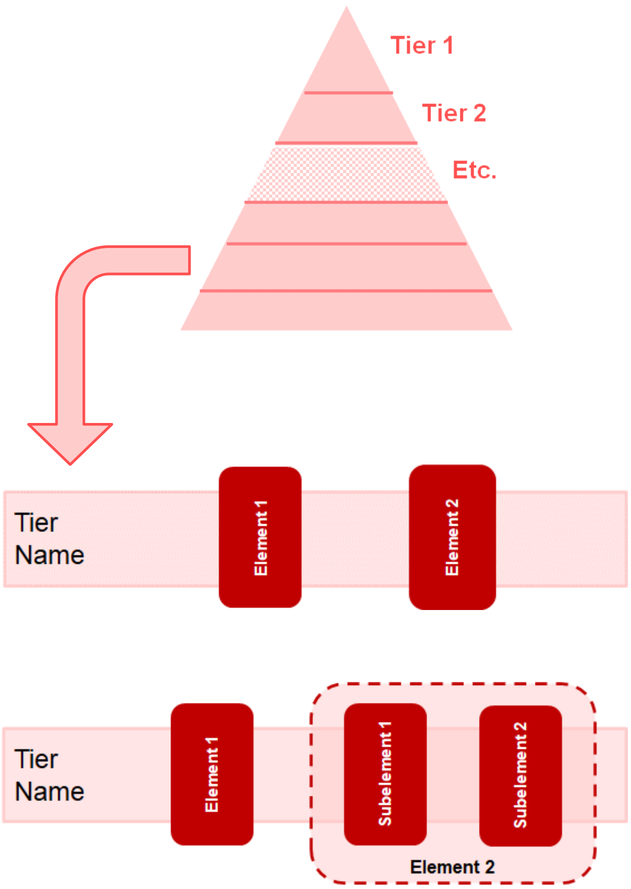
Structure of the Model Validation Hierarchy



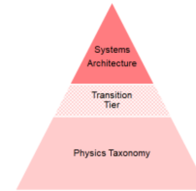
- **Systems architecture perspective**
  - Systems/subsystems/etc.
  - System design requirements are specified
- **A transition tier has been created**
  - Transforms hierarchy from a systems architecture to a physics taxonomy view
  - Mathematical modelling introduced
- **Physics taxonomy perspective**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

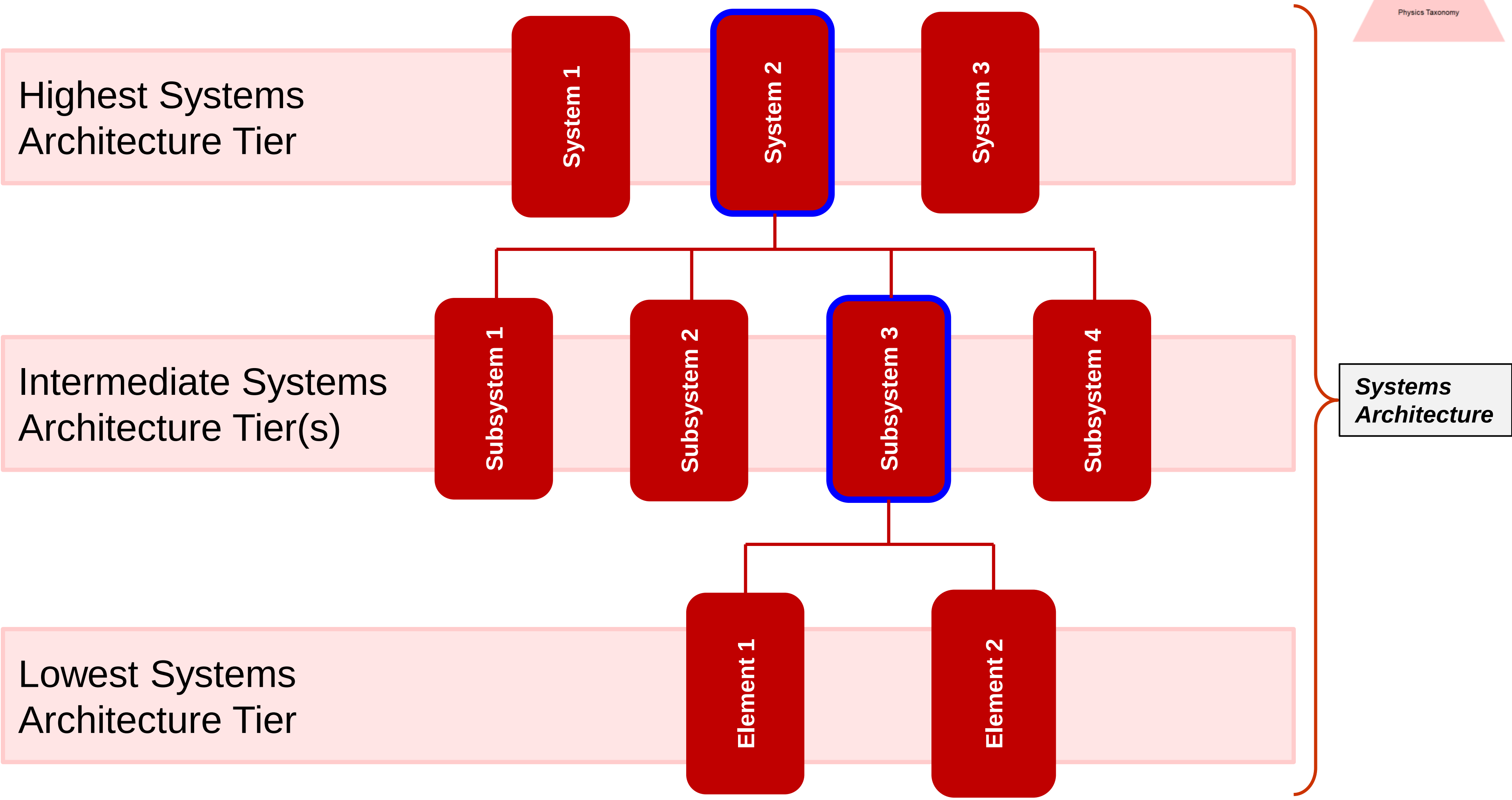
Model Validation Hierarchy Attributes

- **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

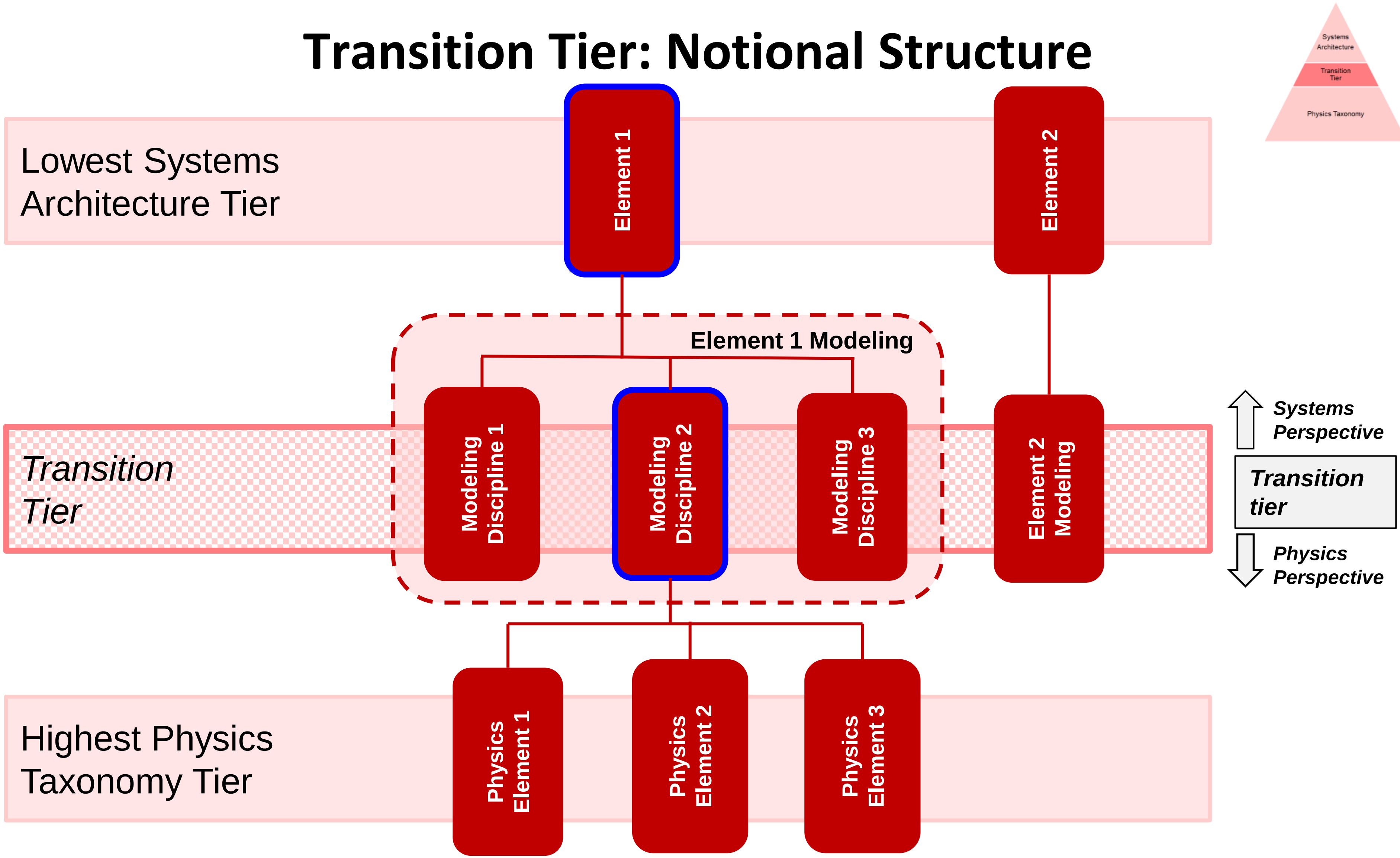


Systems Architecture: Notional Structure

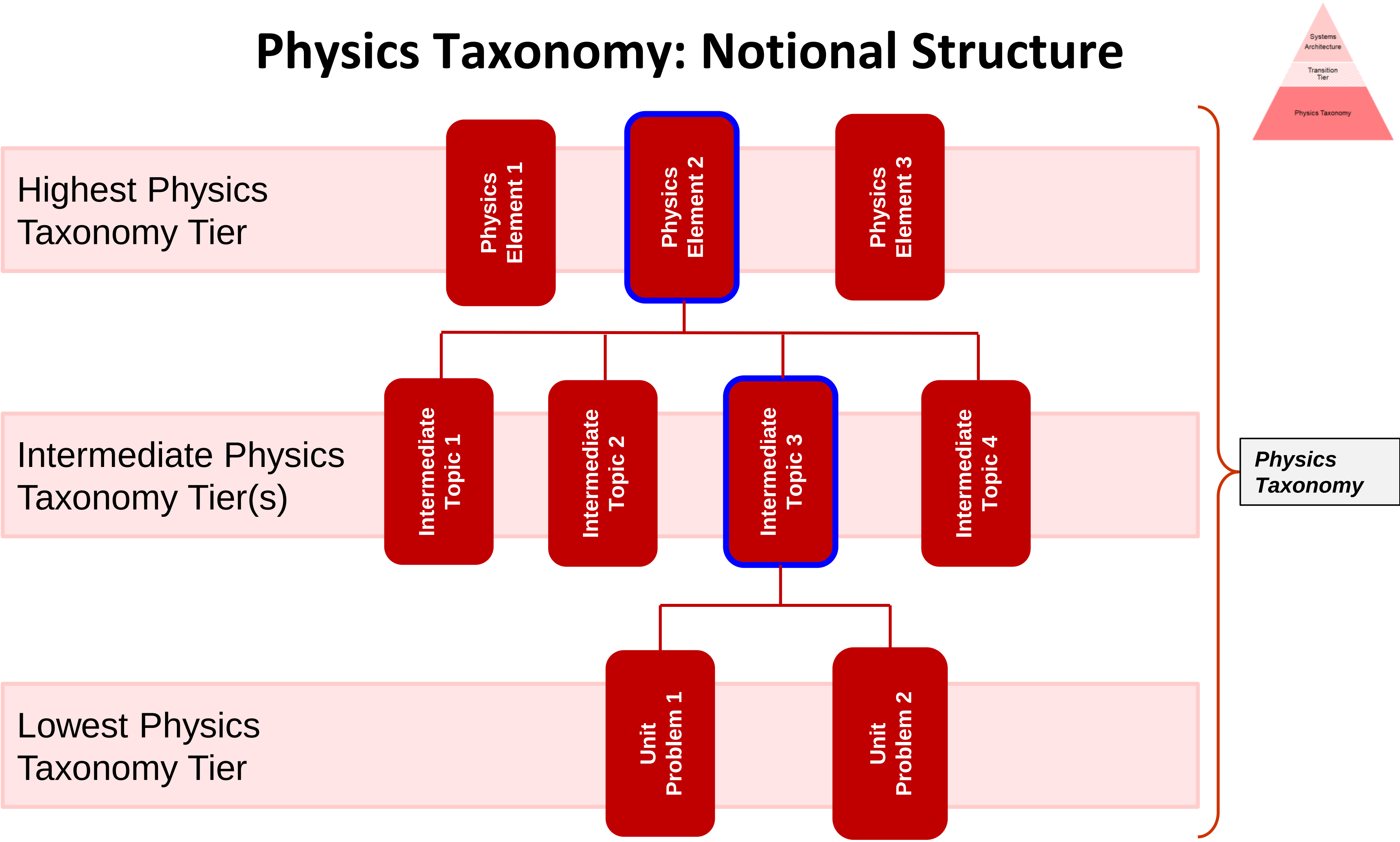




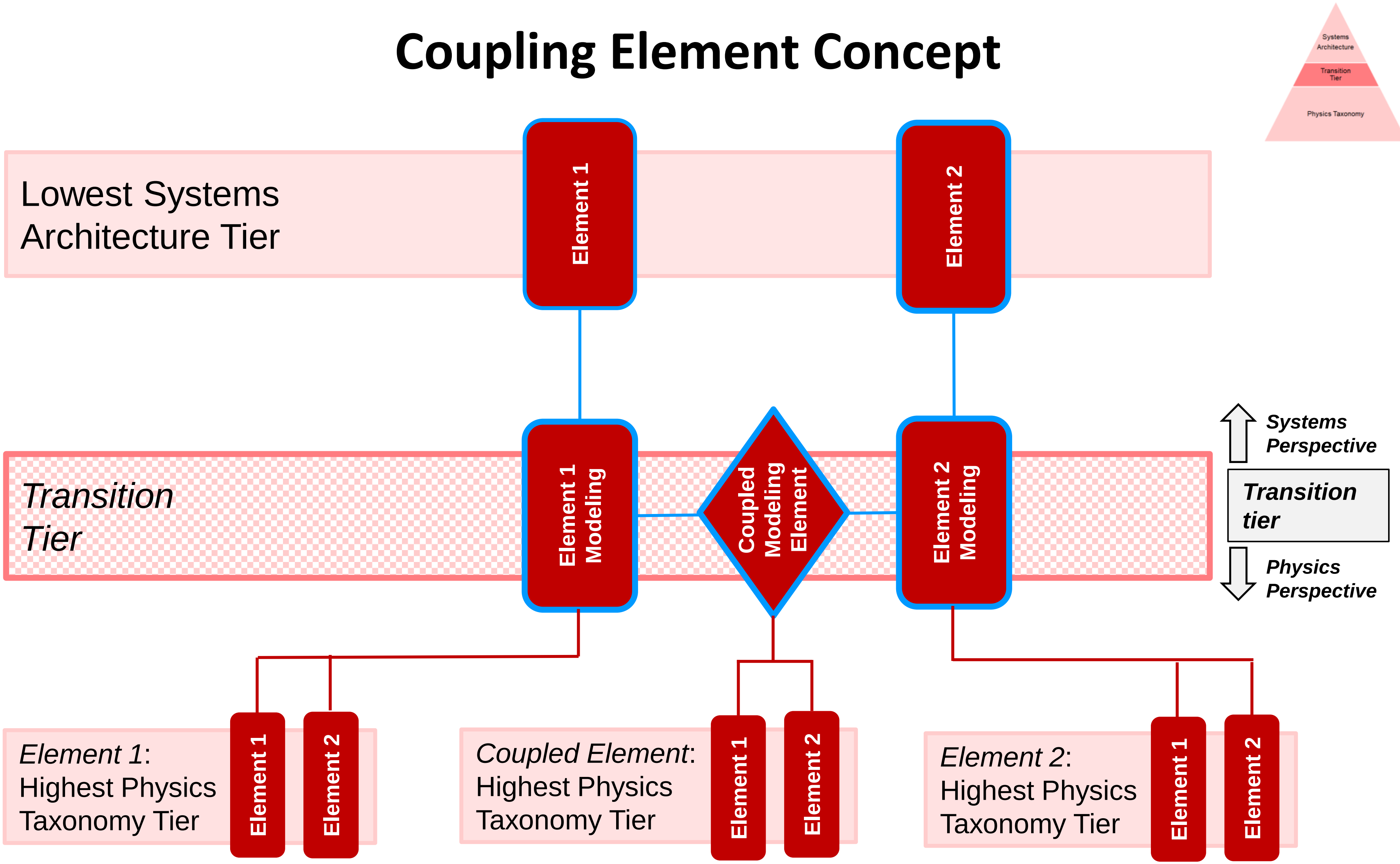
Transition Tier: Notional Structure

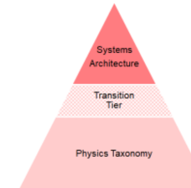


Physics Taxonomy: Notional Structure



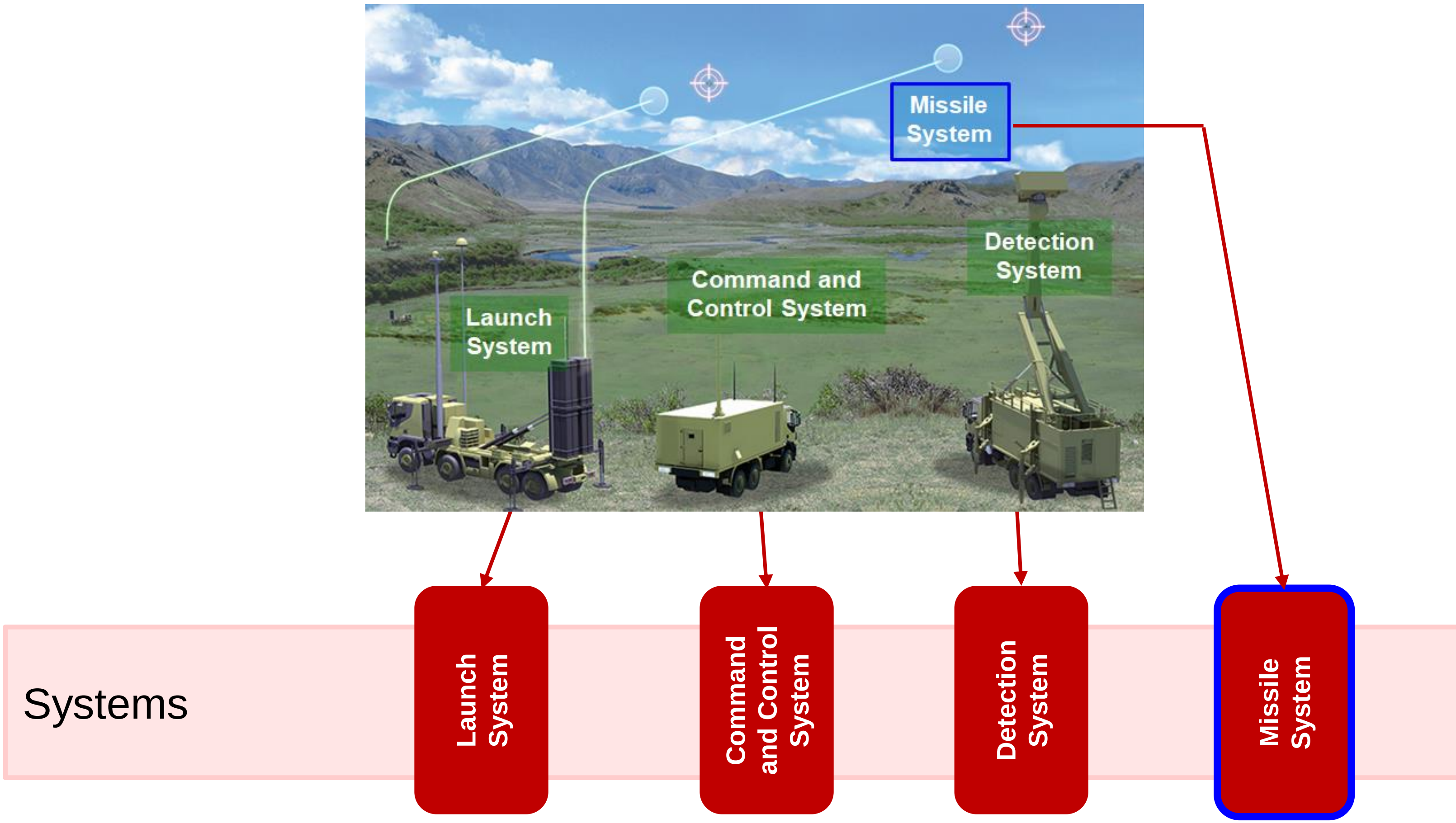
Coupling Element Concept



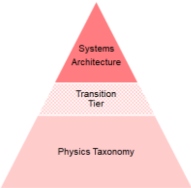


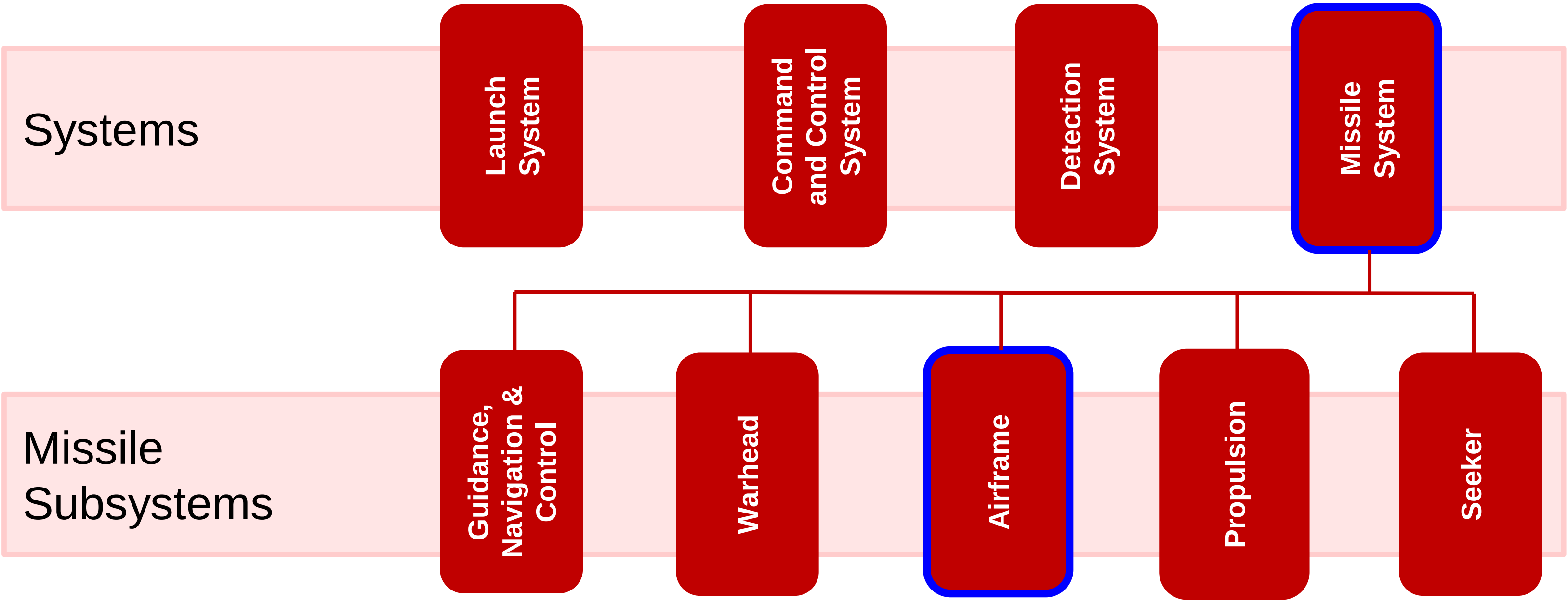
Model Validation Hierarchy Example

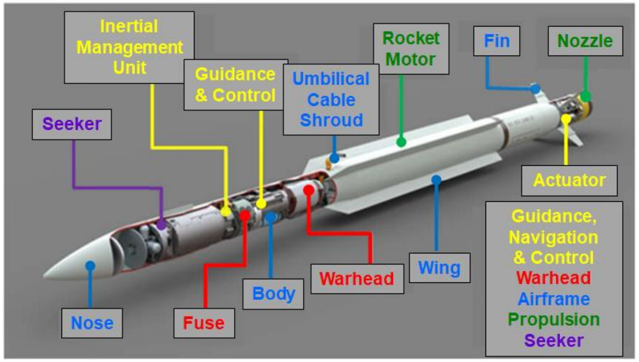
Ground-Based Air Defense System (GBADS)



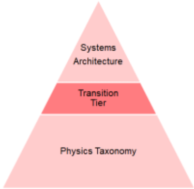
Expansion of the Missile System Element

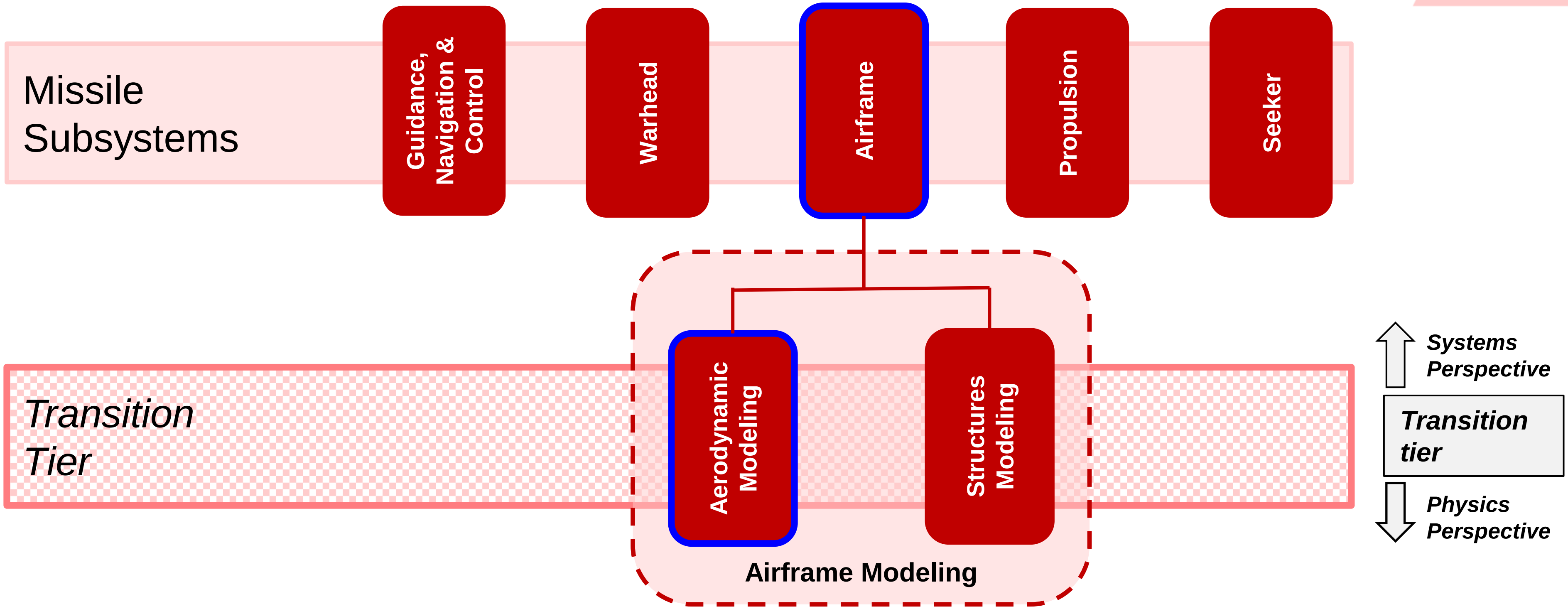




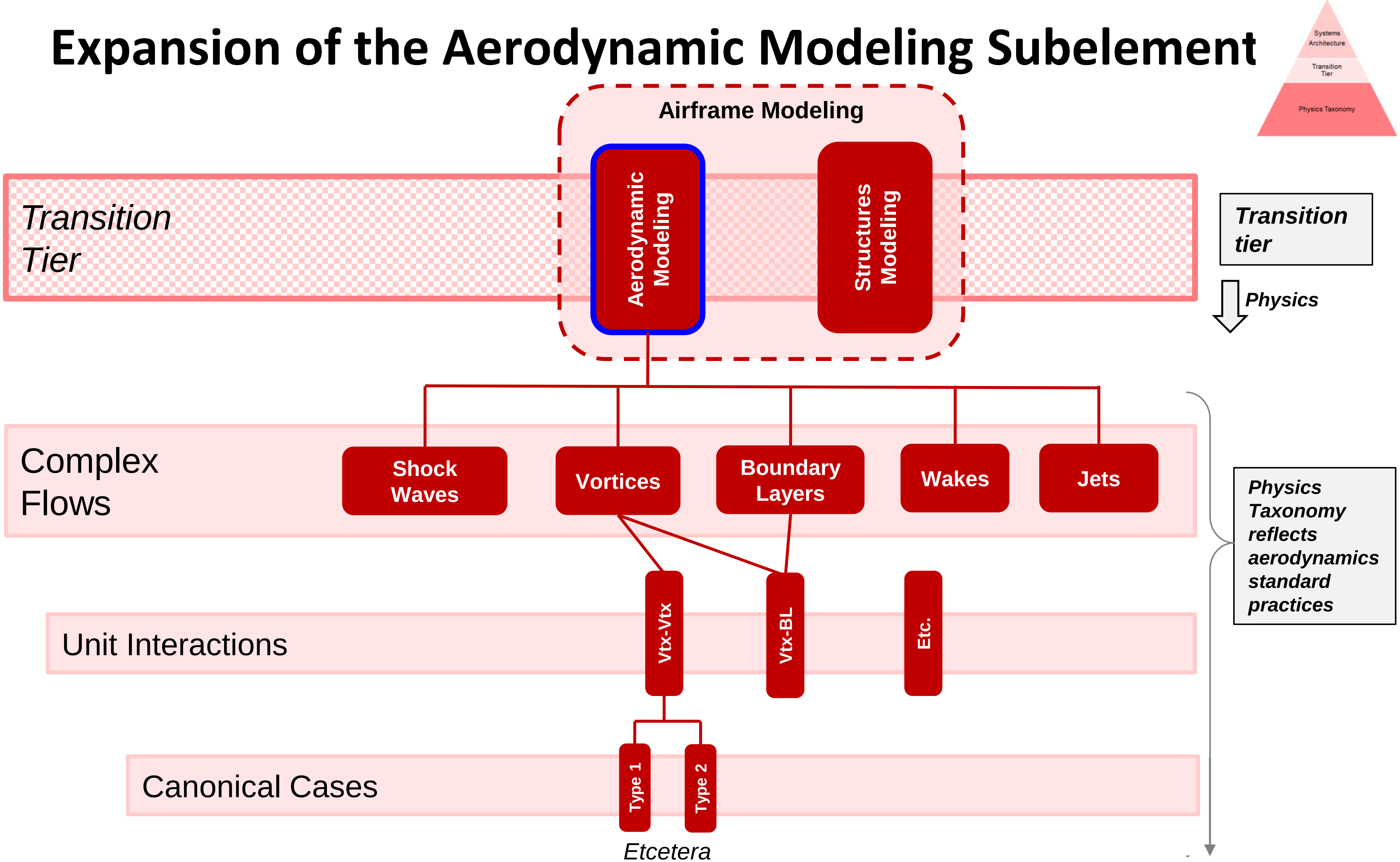


Expansion of the Airframe Subsystem Element

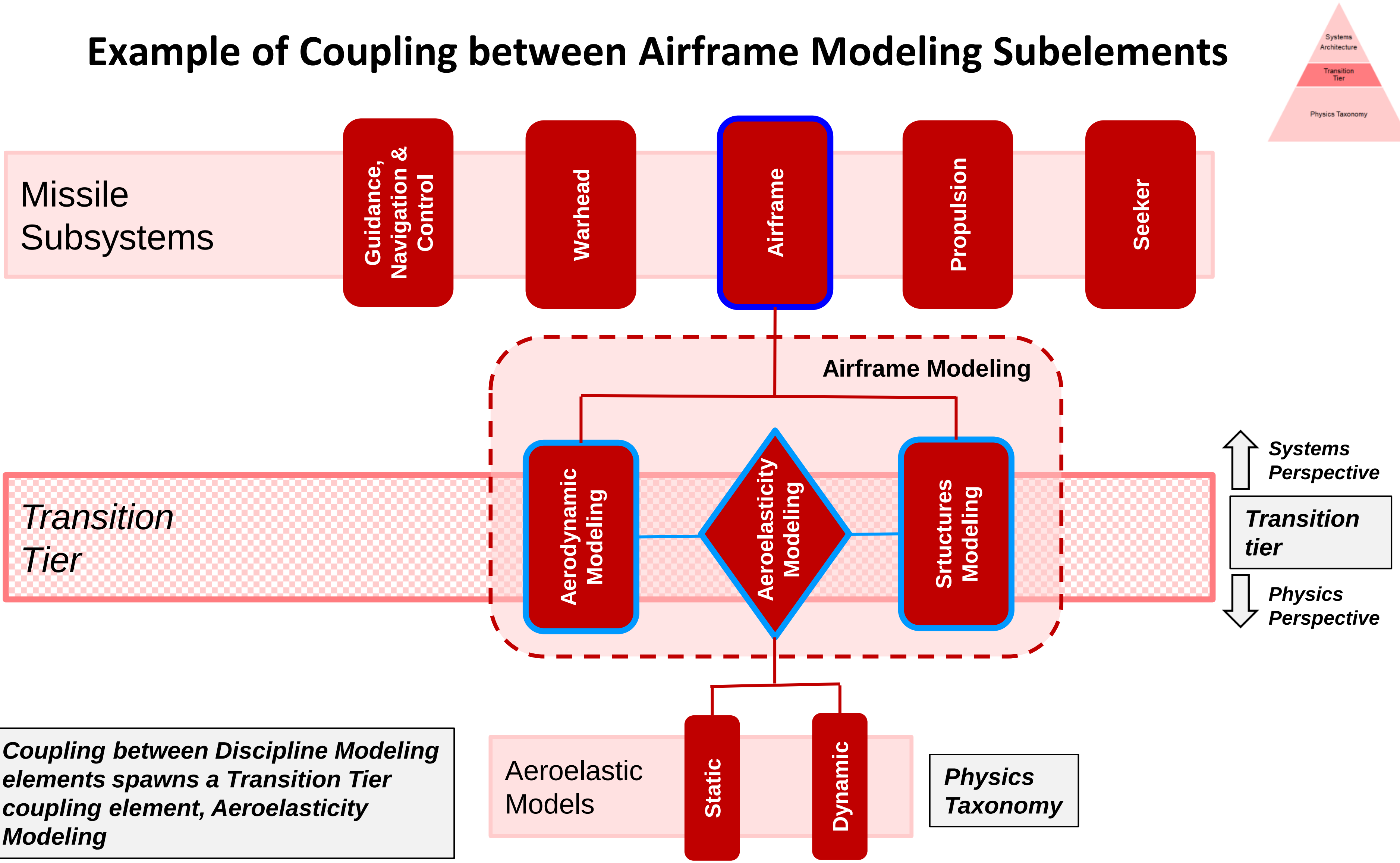




Expansion of the Aerodynamic Modeling Subelement



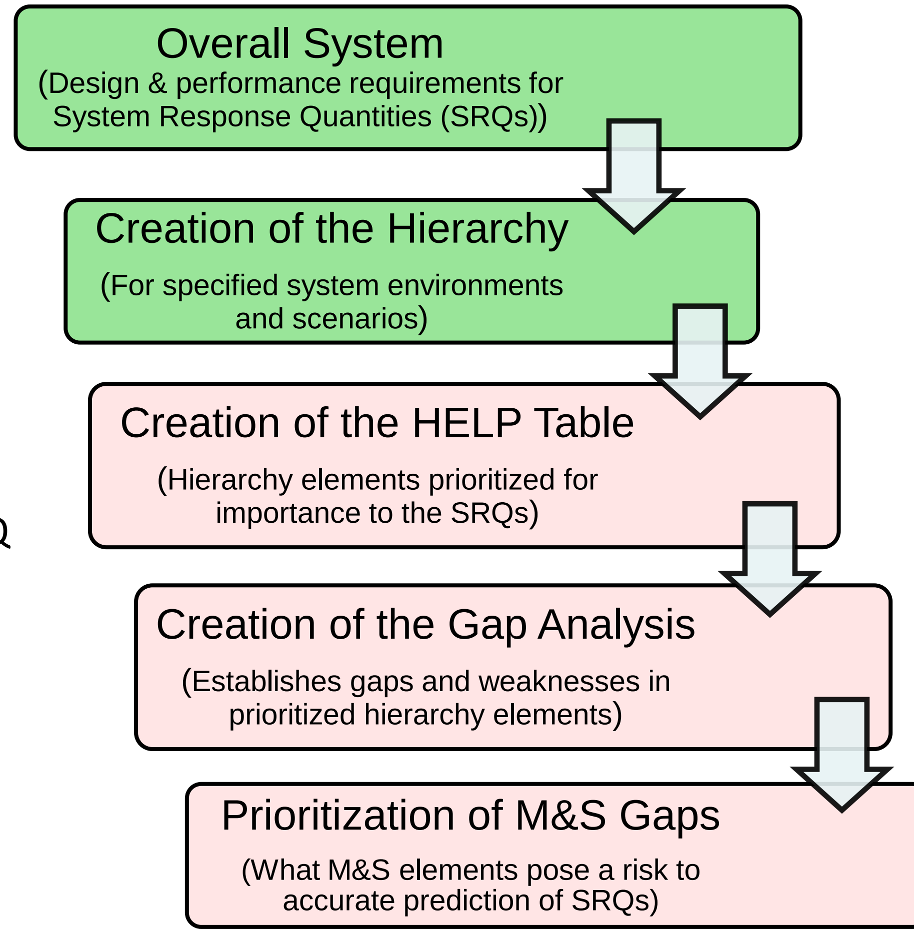
Example of Coupling between Airframe Modeling Subelements



Coupling between Discipline Modeling elements spawns a Transition Tier coupling element, Aeroelasticity Modeling

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

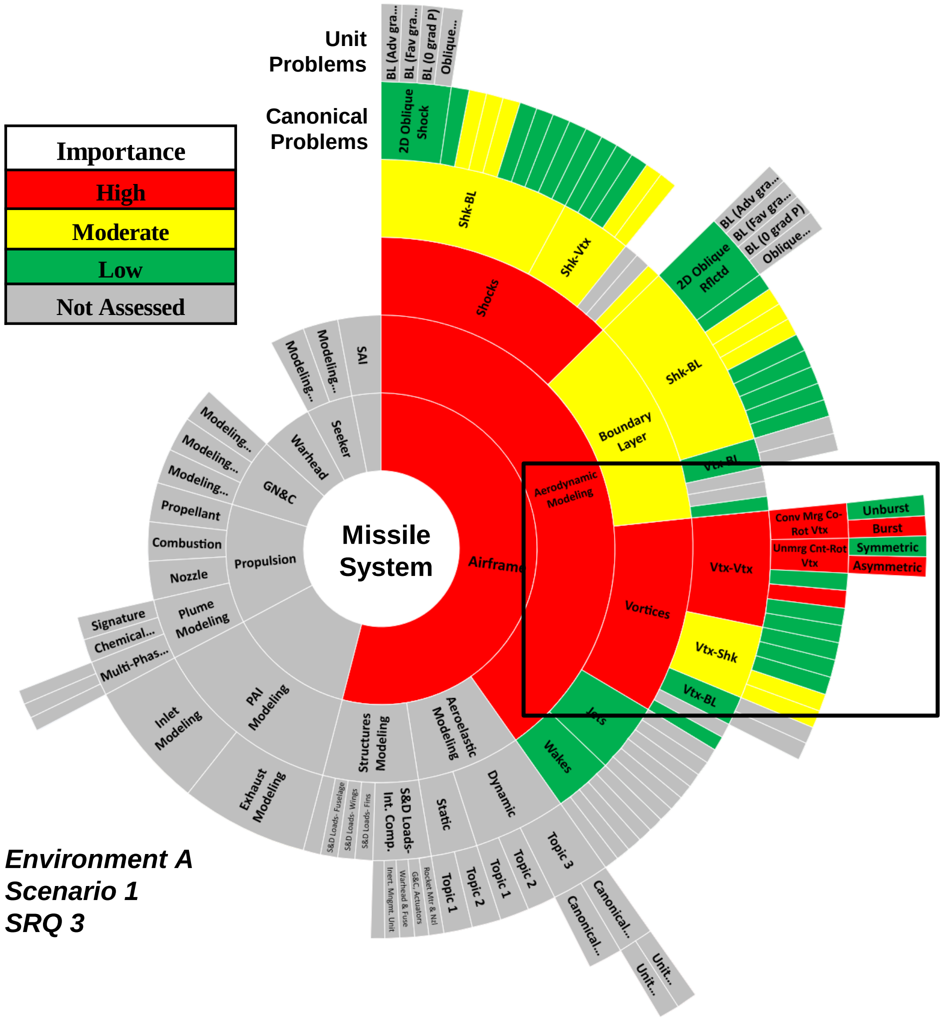
- **Shares common philosophy with a prior process**
  - Phenomena Identification and Ranking Table (PIRT)
- **Four key features of HELP table**
  - Environment and scenario under analysis
  - List of hierarchy elements for assessment
  - System Response Quantities of interest
  - Outcome from importance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

Environment A, Scenario 1

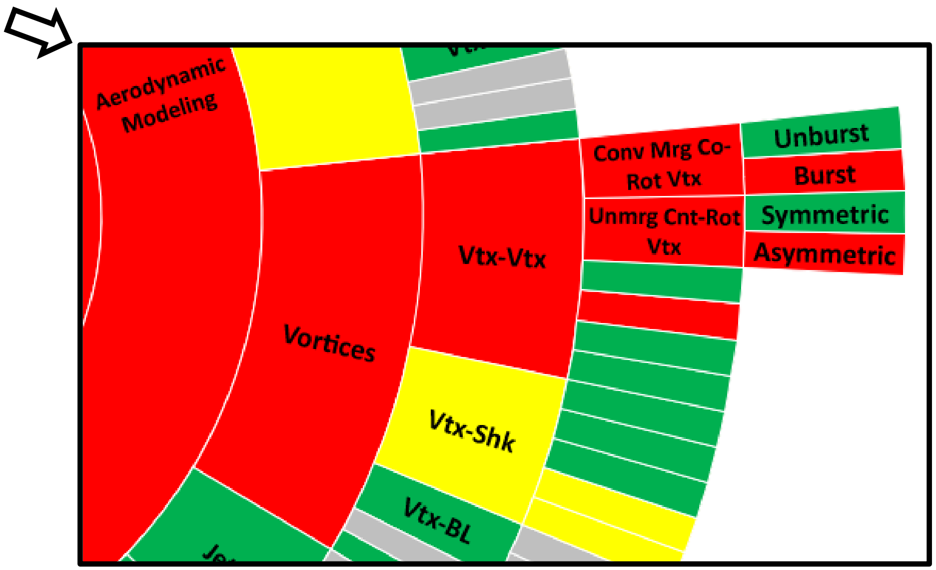
Hierarchy Elements	SRQ 1	SRQ 2	SRQ 3
A	Low	Moderate	Moderate
B	Moderate	Low	High
C	Moderate	Moderate	High
D	Low	Moderate	Low
E	High	Low	Moderate
F	Low	Moderate	High

Importance
High
Moderate
Low

HELP Table Results



- **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

- **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 separately
  - ➢ Subset of Model Validation Hierarchy elements from HELP Table
  - ➢ Column for each M&S technology
  - ➢ Outcome from capability assessment
- **Identifies M&S capability weaknesses**

Environment A, Scenario 1 – SRQ 3

Subset of Hierarchy Elements	Modeling	Verification		Validation	Uncertainty Quantification
		Code Verification	Solution Verification		
A	[green]	[yellow]	[green]	[yellow]	[red]
B	[yellow]	[green]	[green]	[red]	[red]
C	[yellow]	[yellow]	[green]	[red]	[red]
F	[green]	[red]	[green]	[yellow]	[red]

Capability
Inadequate [red]
Unknown [yellow]
Adequate [green]

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

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  - NASA
    - Transformational Tools and Technologies (TTT) Project
    - Advanced Air Transport Technology (AATT) Project
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  - Air Force Research Laboratory (AFRL)
  - NATO Science and Technology Organization (STO)

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  - TTT Enabled Dr. Luckring's participation in this ICAS Congress
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  - AFRL Review and guidance from Dr. John A. Benek
  - NATO STO Enabling the scientific collaboration for this research