31st Annual INCOSE international symposium

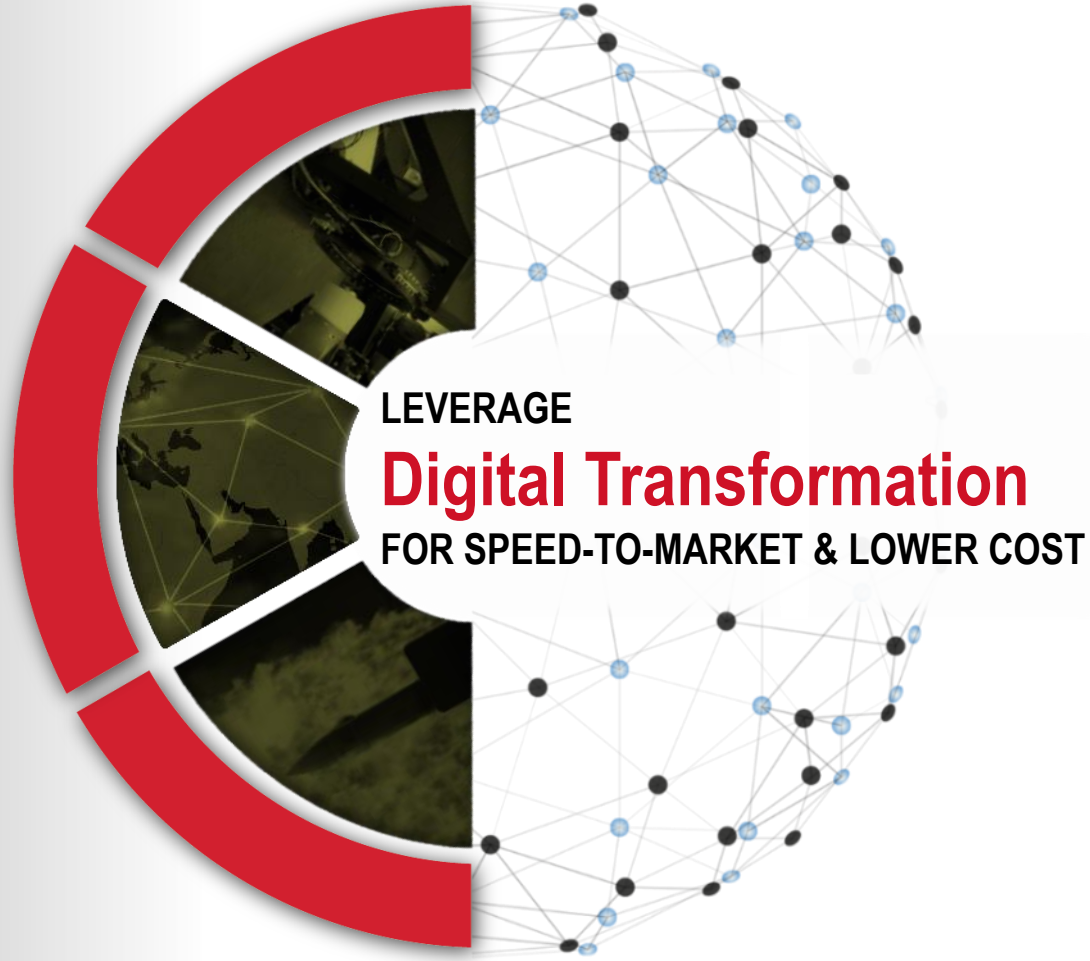
virtual event

July 17 - 22, 2021

How Missile Engineering is Taking Product Line Engineering to the Extreme at Raytheon

Jeffrey Turpin, Dr. Bobbi Young, Matt Thurman, Tom Sanderson, Liz O'Keefe, Dr. Paul Clements

Digital Transformation



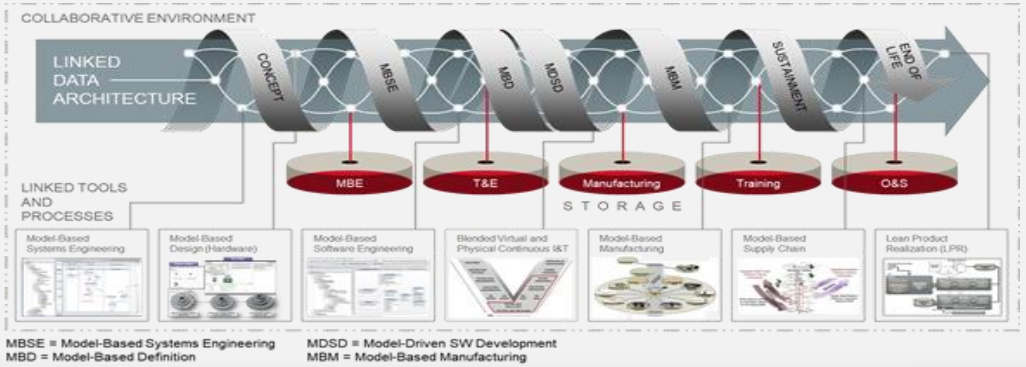
GOAL

Ability to rapidly develop and compose affordable systems through the use of modular open systems components that are connected through consensus-based standards and linked through a digital ecosystem

BENEFITS

- Development Cost
- Development Time
- Purchasing Cost
- Production Cost
- Production Time
- Capital Investment

FRAMEWORK

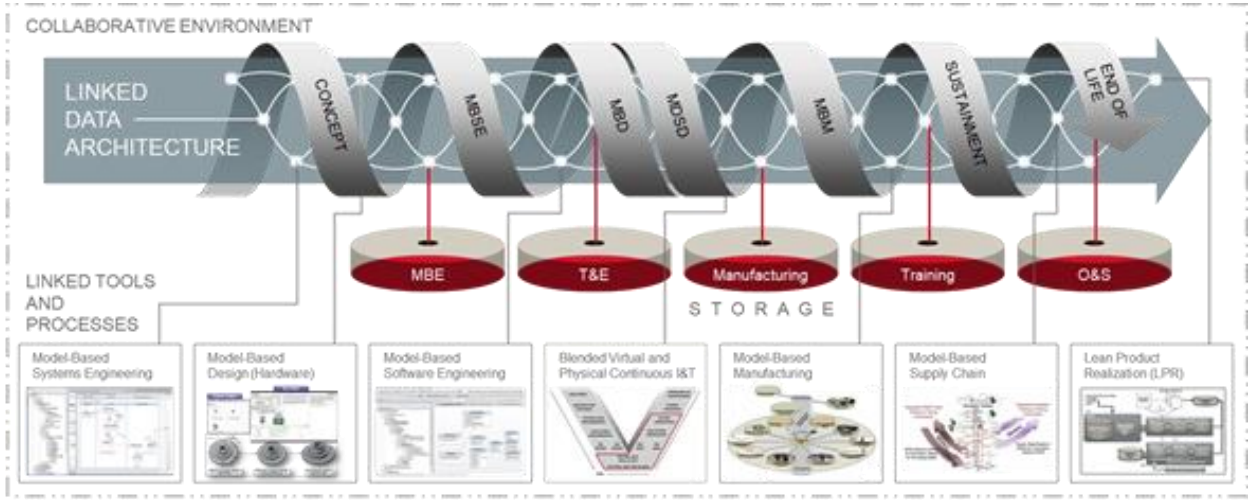


Digital Engineering: MBE and PLE

Digital Engineering Goals for Transformation

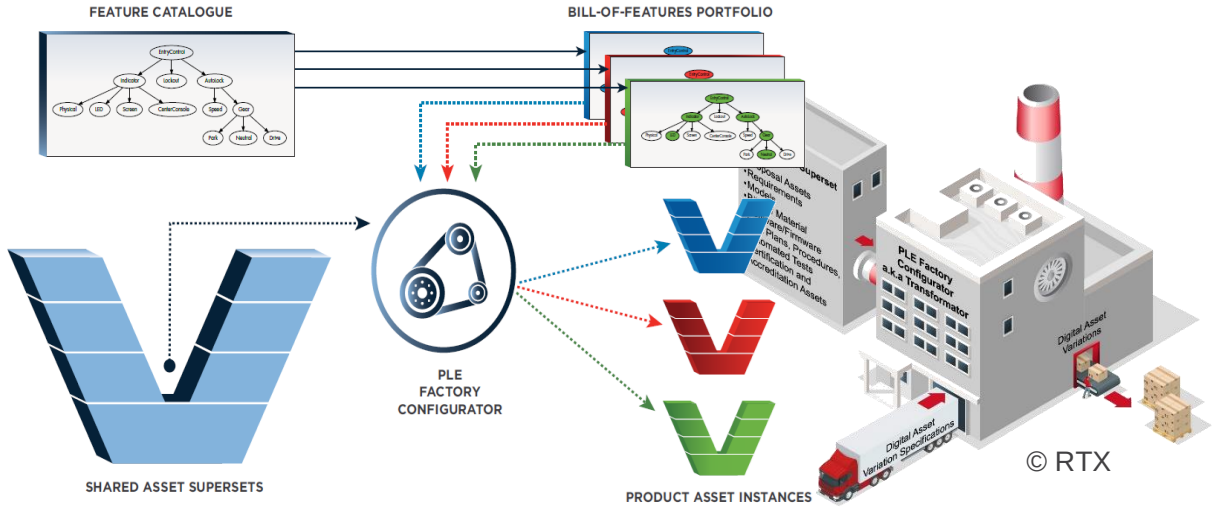
- MBE: “Leverage” the transformation to digital representations and communications through digital artifacts
- FB-PLE: “Integrate” tenets of Product Line Engineering with Feature Based Variation to manage Product offerings
- Ecosystem with interconnected infrastructure, environment, and methodology to exchange digital artifacts from an authoritative source of truth

Model Based Engineering (MBE)

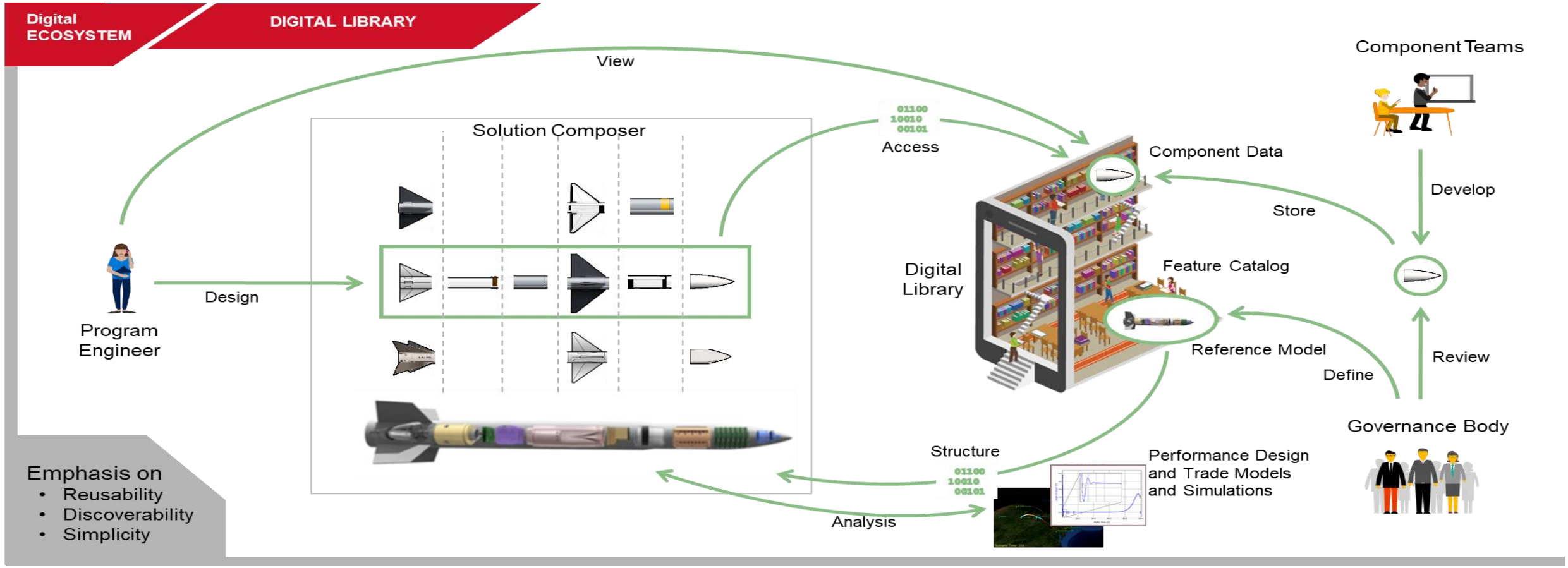


MBSE = Model-Based Systems Engineering
MBD = Model-Based Definition
MDSD = Model-Driven SW Development
MBM = Model-Based Manufacturing

Feature-based Product Line Engineering (FbPLE)



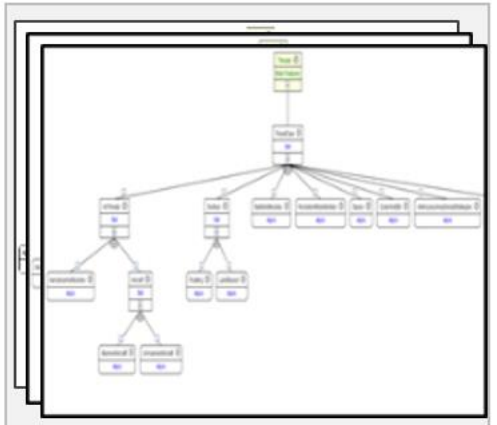
Digital Ecosystem



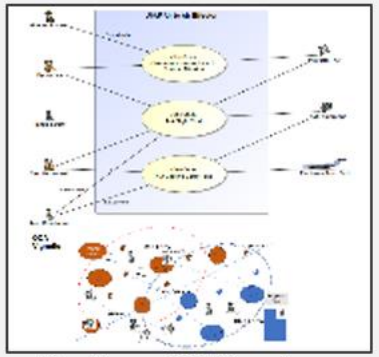
MBSE: Reference Missile Model Library of Reusable Modeling Elements and Behavior

Reference Missile Models

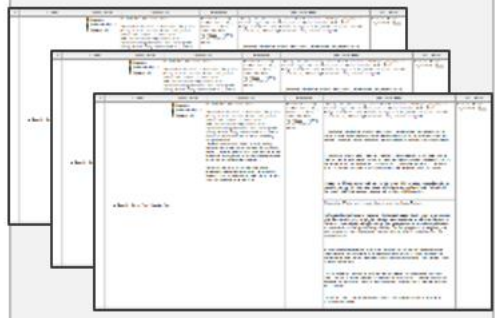
Composable Design Parameters



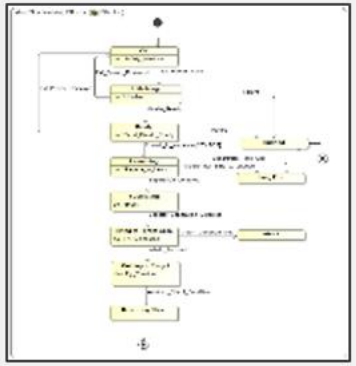
Feature Models



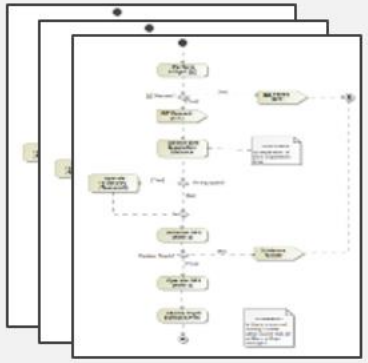
Defined Mission Use Cases



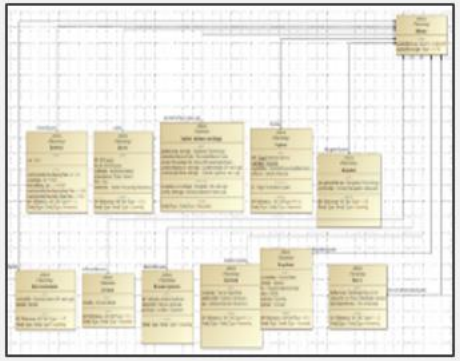
Operational Description for Missions



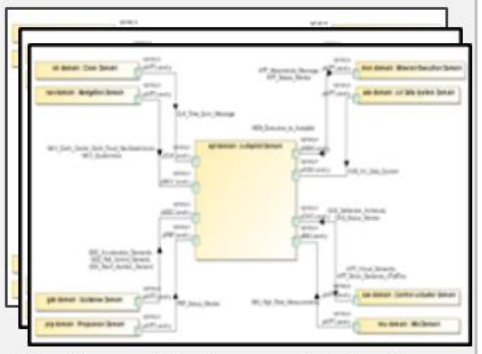
Common State Machine with Variant Behaviors



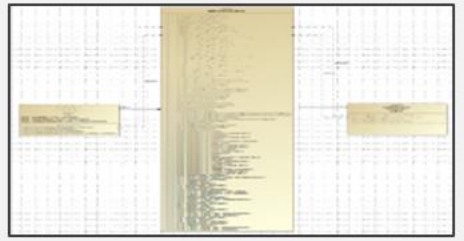
Activity Flows



Architecture Structure



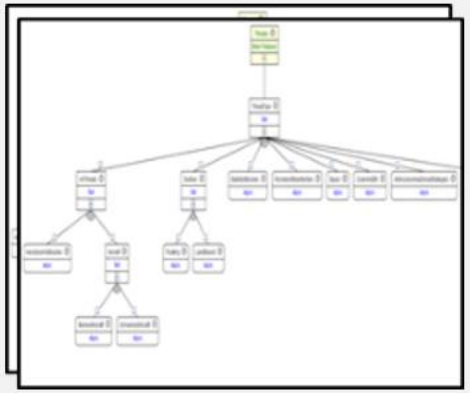
Defined Internal Ports and Interfaces



Open Systems Architecture Interfaces

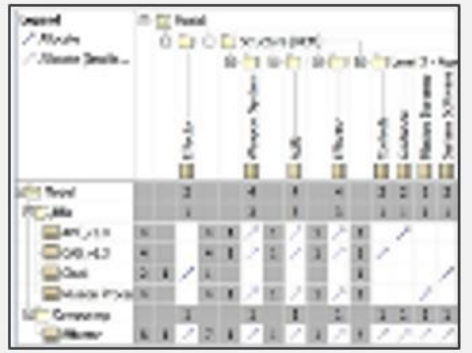
MBSE: Missile Composing with Open Systems Architecture Compliance

Composing a Missile Model

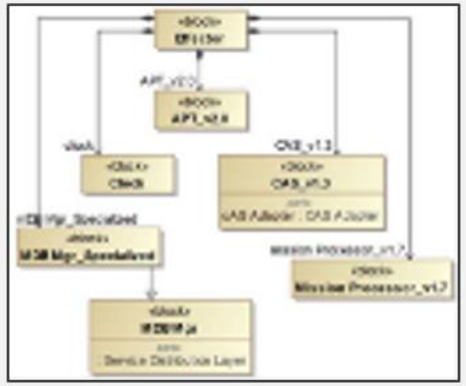


Feature Models Identify Component Selections

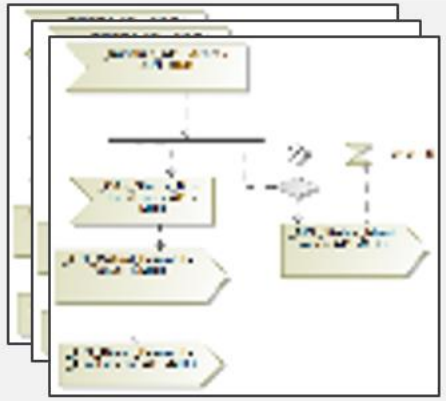
Missile Model Populated with Feature Selected Components



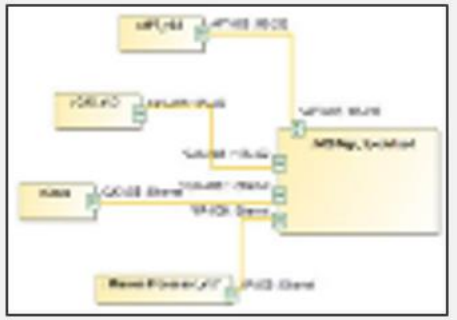
Components Mapped to Architecture Domains



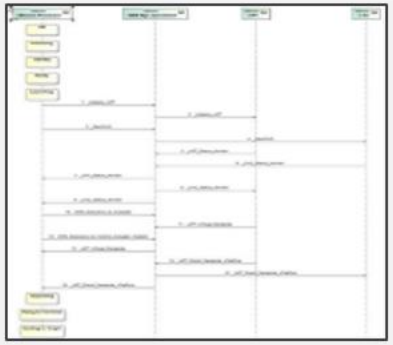
Generate Block Diagram



State and Activity Flows



Validate Open Systems Architecture Compliant Interfaces



Interface Simulation Generated Sequence Diagrams

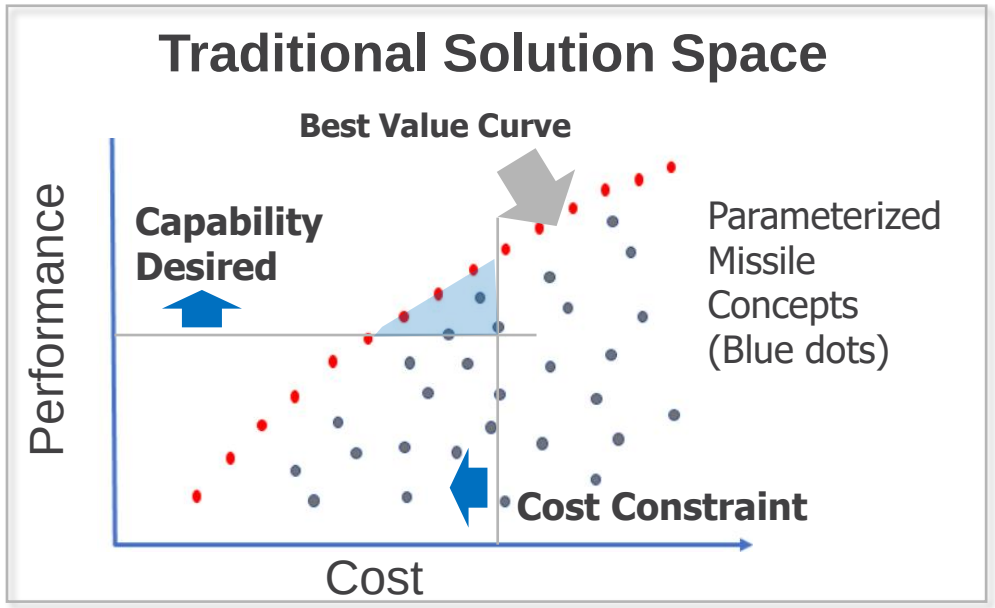
Analysis of Alternatives Simulations

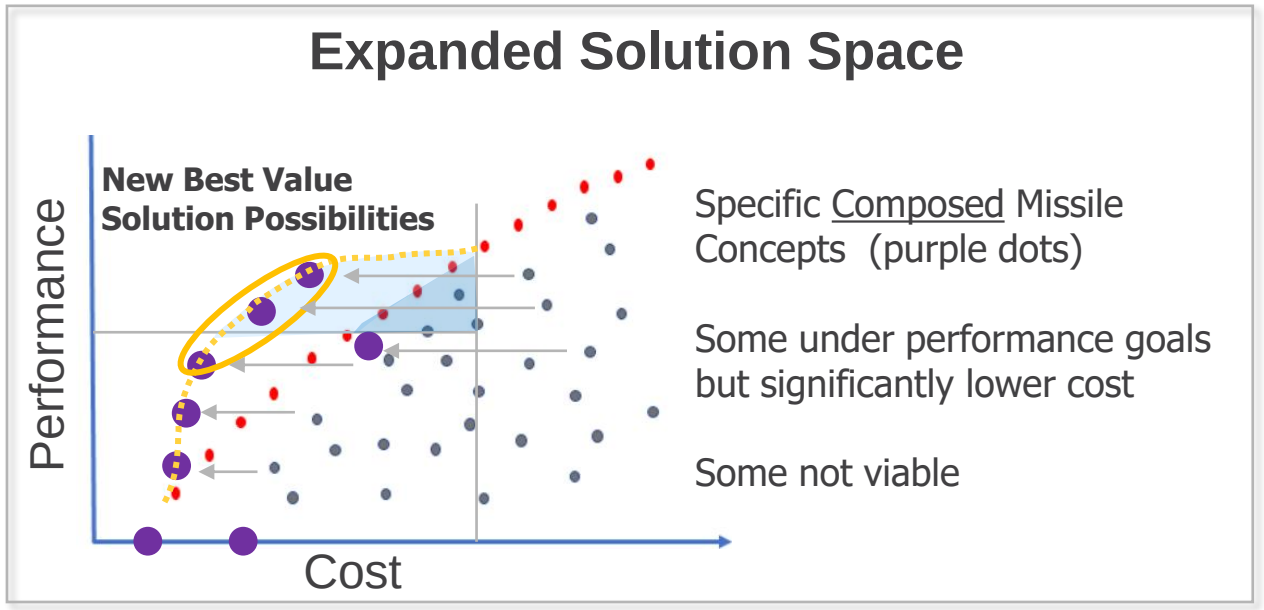
6 Degrees of Freedom Performance Simulation

Generate System Design Specifications and Interface Specifications

Trade Space Design: Composing Disruptively-Lower-Cost Solutions

- Proliferation of modular design configurations (purple dots)
  - Fall on a LOWER cost curve than parametric solutions
  - Performance evaluated in simulations using composed configuration input files



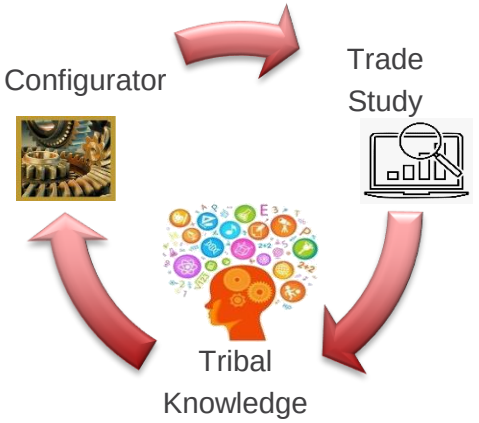


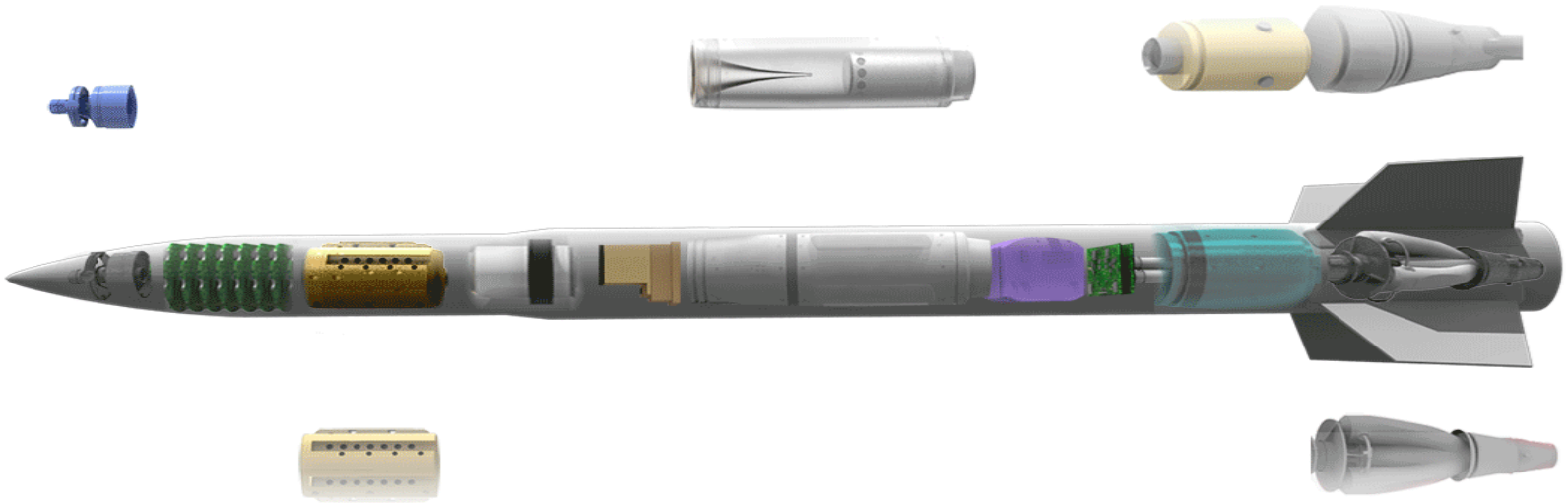
Trade Space Selection using Proliferation

Digital Library

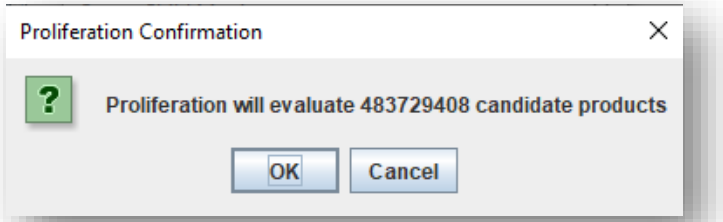
Dynamic Rule-based System:

- Mission rules
- Platform rules
- Physics-based rules
- Interface rules

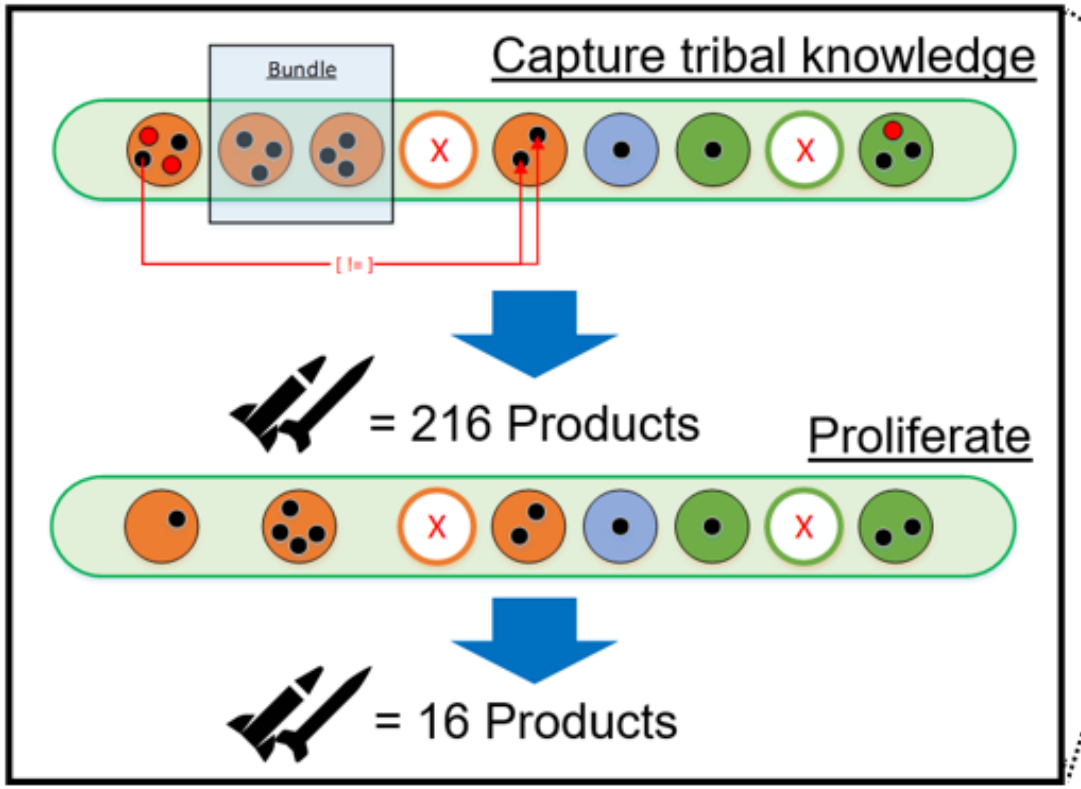


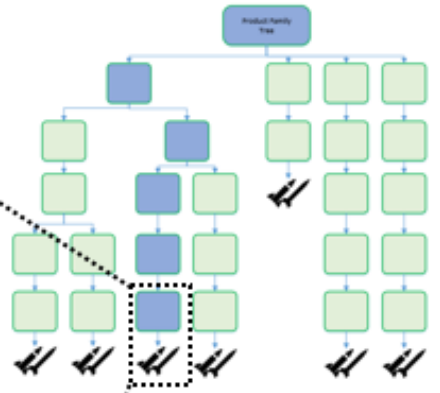


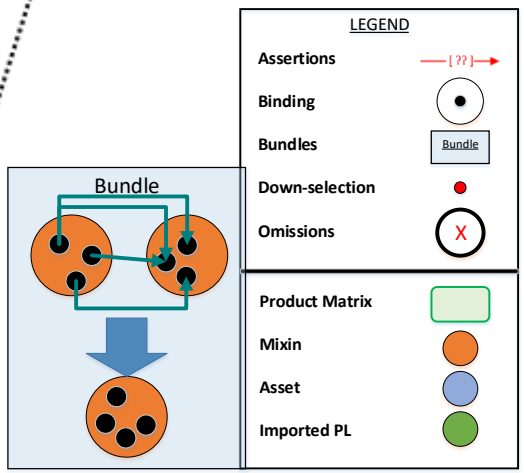
Techniques to Pare Down the Trade Space



- Product Family Tree
- Omissions
- Binding
- Down-selections
- Bundles
- Assertions







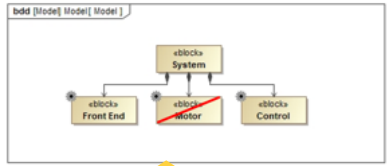
Enabling Teams-of-Teams

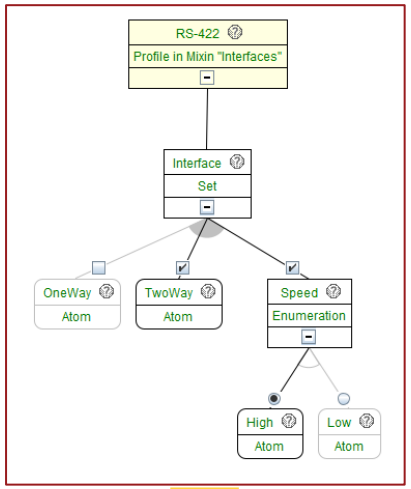
Allowing teams-of-teams to produce systems-of-systems that are modeled as product-lines-of-product-lines

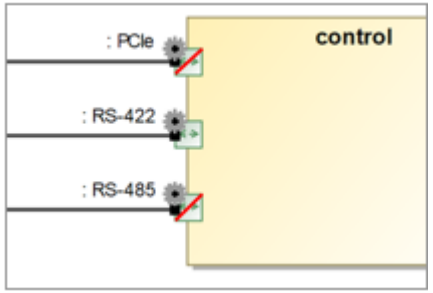
Technical Data Package (TDP) Generation using FbPLE

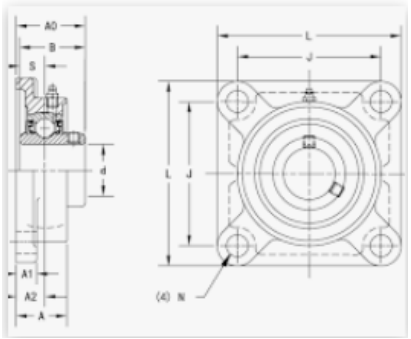
Configurable Items:

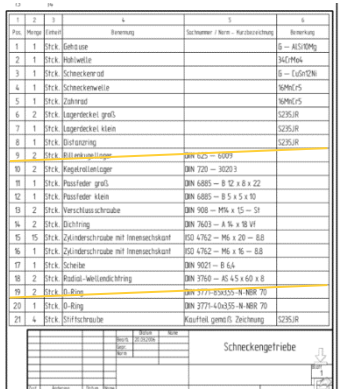
- Architectural Models
- Interface Documentation
- Technical Drawings
- Component models
  - Requirements
  - Design Elements: software, firmware, hardware
- Design Documentation
  - Bill of Materials
  - User and Training Manuals











TST_4879	**2 Requirements**		**2 Requirements**
TST_4883	**2.1 Performance Requirements**		**2.1 Performance Requirements**
TST_4881	The system shall have a mass of 1lb +/- 0.5lbs	When (Performance >= (Mass)) Select;	The system shall have a mass of 1lb +/- 0.5lbs
TST_4880	The sytem shall operate at a frequency of _HZ_	When (Performance >= (Frequency)) Select { Apply "_HZ_" -> "500"; }	The sytem shall operate at a frequency of 500
TST_4884	**2.2 Non-Functional Requirements**		**2.2 Non-Functional Requirements**
TST_4882	The system shall be colored red as defined by the RGB value [255,0,0]	When (Functional >= (Red)) Select;	

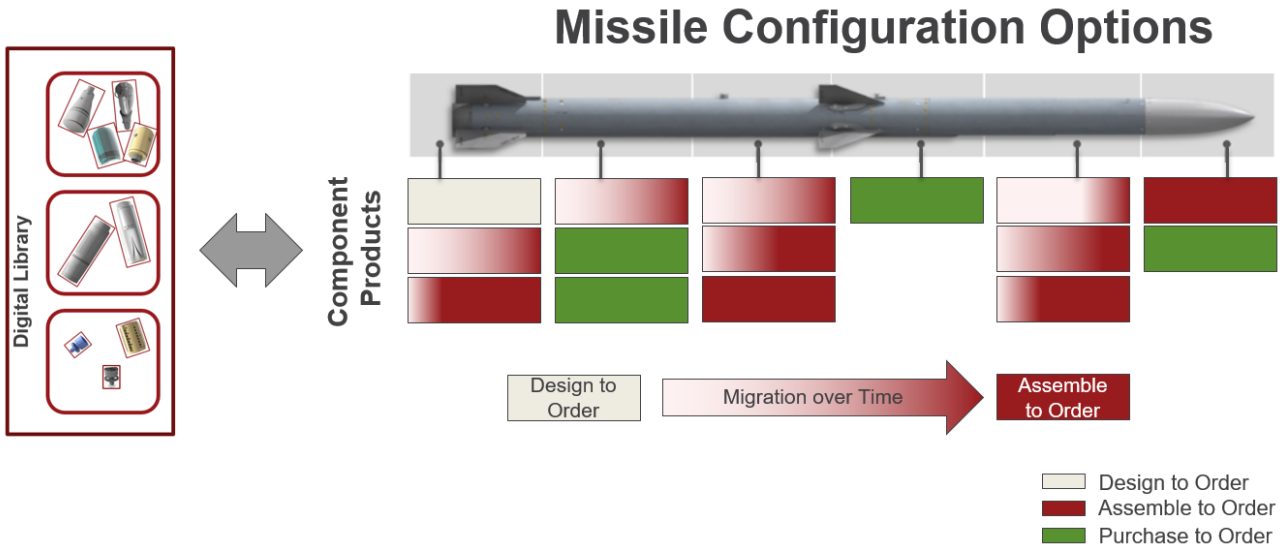
Component Design Acceleration and Cost Avoidance

TIME TO MARKET

- Accelerates reaching major milestones (SRR/PDR/CDR) in a few weeks/months
- Increased cost avoidance with each new product added to the product line of missile products
- Reduce program development time by having defined functional and interface specification configured in the model

EFFICIENCY

- Ability to rapidly develop and compose affordable systems using modular open system components connected through consensus-based standards
- Provides visualization to assess the impact of variation on product designs enabling informed and deliberate cost benefit decisions
- Common approach to identifying variant features across the portfolio of missiles



PERFORMANCE

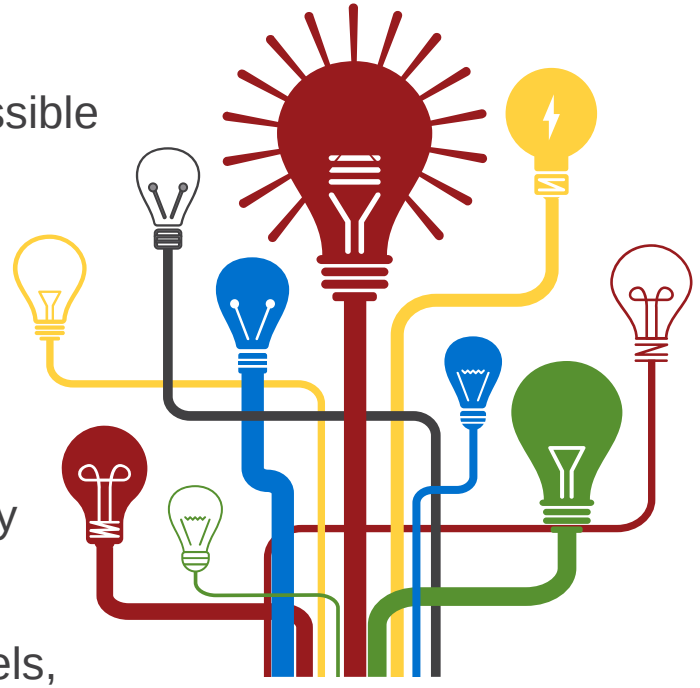
- Rapid automated configuration of operational and logical designs to meet future program's needs such as critical timelines and cost for delivery.
- Future proposals are more competitive through the ability to propose reduced NRE due to re-use
- Common missile designs reduce development and manufacturing cost using common components
- Programs gain additional capabilities from sharing improvements across adopting programs
- MOSA and interface standards compliance (WOSA, UAI) to support customer required open architectures

RISK MITIGATION

- Increases quality, reliability and reduces escapes by centralizing updates and bug fixes across adopting programs
- Reduce program execution risk by supporting programs with a core team of experienced experts

Conclusion

- Provide a subset of input parameters to generate **validations** and simulations for chosen candidates, to speed up qualification (or dis-qualification) of design candidates
- Establish a trade space by ***proliferation*** – that is, automatically generating all possible solutions -- allowing us to explore never-before-tried innovative solutions
- Manage the complexity of our product space by capturing **tribal knowledge** through configurator-provided capabilities such as product families, partial binding, component omission, feature down-selection, bundles, and assertions
- Structuring our product line as a product line of subsidiary product lines, allowing **teams-of-teams** to specialize in various subject matter areas without unnecessary FbPLE overhead
- Generate a **technical data package** for a chosen solution, including SysML models, interface control documents, requirements specifications, drawings, bills of materials, and more
- Increase process **efficiencies** and **performance** while **mitigating risk** and reducing **time to market** through a migration from a design-to-order to an assemble-to-order paradigm



Biography

Presenter:

Jeffrey Turpin has been at Raytheon for the past 7 years as a product line engineering subject matter expert and champion. He has helped Raytheon construct from the ground up their radar, missile, and combat management system production lines. Jeffrey's other engineering duties consist of system engineering; modeling, simulation, and analysis; wireless embedded systems; and artificial intelligence solutions architecture with a focus in deep and reinforcement learning. Jeffrey is also an active INCOSE Product Line Engineering International Working Group member and reviewer of the recently submitted ISO/IEC standard 26580 "Software and Systems Engineering – Methods and Tools for the Feature-Based Approach to Software and Systems Engineering

Contributors:

- **Dr. Bobbi Young** is a Systems Engineering Fellow and Certified Architect at Raytheon Technologies supporting multiple sensor and weapons systems programs and strategic initiatives. Currently, she leads an Internal Research and Development Project focusing on adoption of Product Line Engineering (PLE) across the business. She is regarded throughout Raytheon Technologies as an expert in MBSE and PLE and is a member of the Raytheon Corporate Architecture Board. She is a member of the INCOSE Product Line Engineering Working Group, Architecture Working Group, and MBSE Working Group. Bobbi is also an Adjunct Professor at Worcester Polytechnic Institute as an MBSE instructor, authored many publications on MBE and PLE, and has co-authored a book on Object Oriented Analysis and Design. She is a US Navy Commander (ret).
- **Matt Thurman** is a Systems Engineer with Raytheon Missiles and Defense with 13 years of experience in product development, Systems Engineering, and Test/Integration. He has served Raytheon for 4 years as a Systems Engineer on products ranging from artillery to air launched weapon systems. Prior to Raytheon, Matt worked in the medical device and diagnostics industry developing novel sensor and microfluidics systems.
- **Thomas Sanderson** is a Senior Principle Systems Engineer who has been with Raytheon Missiles and Defense since 2008. He has supported various programs as a Lead Subsystems Engineer for the development of electro-optical seekers and guidance sections. He has lead various technology development efforts related to novel sensors and guidance sections. He is currently leading the implementation of Product Line Engineering principles for modular power products. He has a bachelor's degree in Imaging Science from Rochester Institute of Technology's Center of Imaging Science.
- **Liz O'Keefe** is employed by DZYNE Technologies, Inc. as a Systems Architecting and Engineering Consultant supporting the Feature-Based PLE and Systems Modeling activities at Raytheon. Previously, Liz was a Raytheon Engineering Fellow and TOGAF Certified Architect, working in Weapon and Missile Systems for over 35 years. Her responsibilities included project leadership, systems engineering, architecting, analysis and integration. Liz has taught Systems Architecting with John's Hopkins University and recently completed the MIT continuing education Architecture and Systems Engineering: Models and Methods to Manage Complex Systems program. She has an MS degree from California State University at Fullerton in Electrical Engineering (EE) – Systems and a BS degree from Clarkson University in Electrical Engineering EE – Communications.
- **Dr. Paul Clements** is the Vice President of Customer Success at BigLever Software, Inc., where he works to help organizations adopt Feature-based Systems and Software Product Line Engineering. Prior to this, he was a senior member of the technical staff at Carnegie Mellon University's Software Engineering Institute, where for 17 years he worked leading or co-leading projects in software product line engineering and software architecture documentation and analysis. Prior to the SEI, Paul was a computer scientist with the U.S. Naval Research Laboratory in Washington, D. C. He is co-author of eight books and over a hundred papers on PLE and architecture

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virtual event

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