LOCKHEED MARTIN
ENGINEERING

Evolving Lockheed Martin's Engineering Practices Through the Creation of a *Model-centric Digital Tapestry*

2011 NDIA Systems Engineering Conference

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Lockheed Martin Corporation

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Agenda

- Past Experiences with Model-based Engineering at Lockheed Martin: Lessons Learned and Success Stories (10 min)
- Realizing The Potential of Model-based Engineering: Developing a Model-centric Digital Tapestry (15 min)
- Strategies to Support Adoption of Model-based Engineering: Building a Skilled Workforce (5 min)
- Q&A

Please Interrupt if You Have Questions!

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Past Experiences with Model-based Engineering at Lockheed Martin

Lessons Learned and Success Stories

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History and Lessons Learned

- Define Model-based Systems Development (MBSD) vs Model-based Systems Engineering (MBSE) vs Model-based Engineering (MBE)
  - We use Model-based Systems Development (MBSD) because we are truly looking for a model-driven cross discipline approach to engineering addressing the entire product development lifecycle.
- Disparate models have been used in the development & sustainment lifecycles for decades, but a holistic, integrated approach has been missing.

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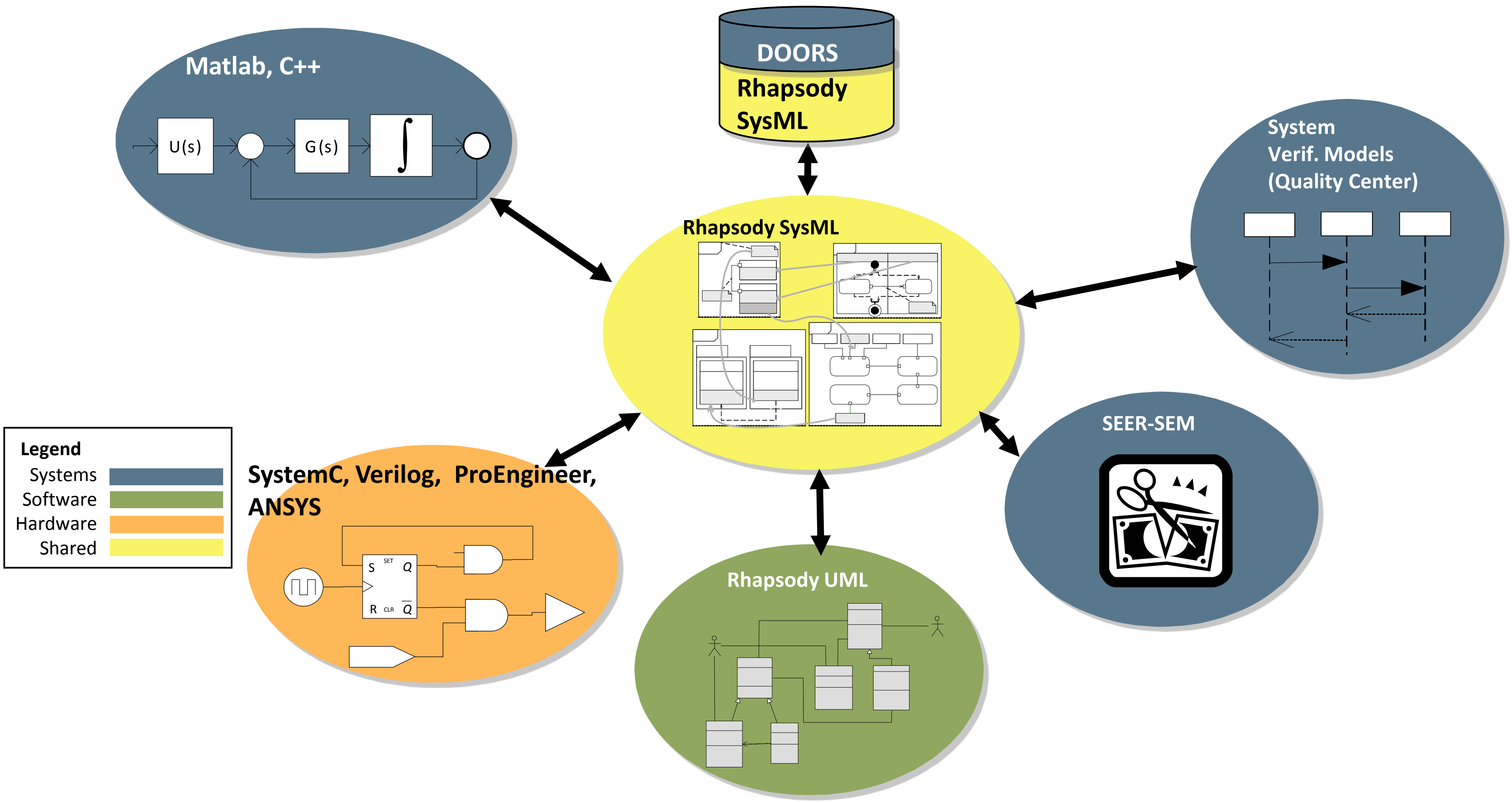
Multidisciplinary MBSD Environment



MBSD Toolset Spans the Engineering Disciplines to Integrate Requirements Decomposition, Design , Development, and Implementation

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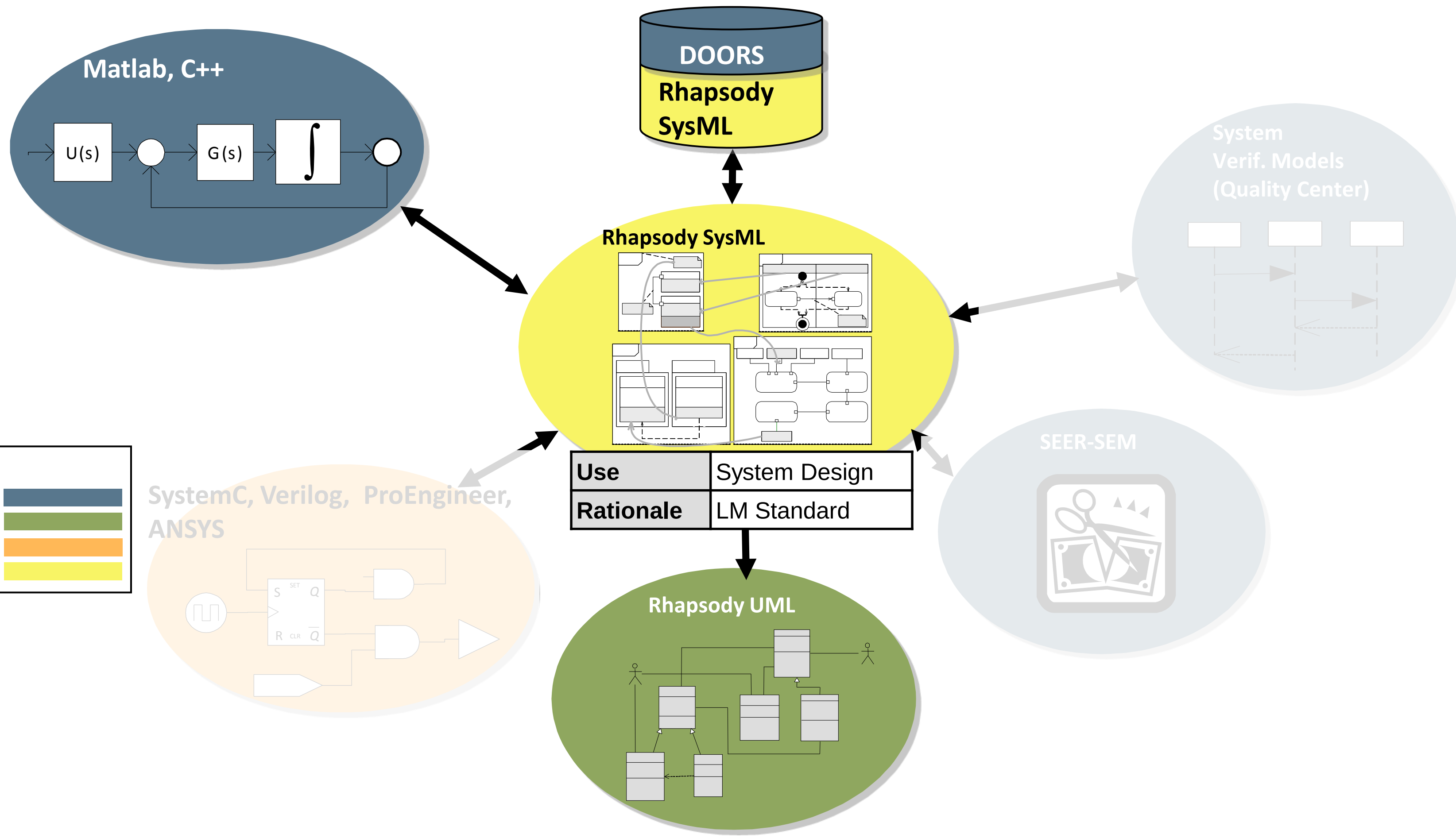
A Starting Point: Systems, Software and Algorithms



Use	System Design
Rationale	LM Standard

For New Teams, Scoping the Activity is Crucial…
Tackling the Best Integrated Subset of Disciplines is a Good Starting Point.

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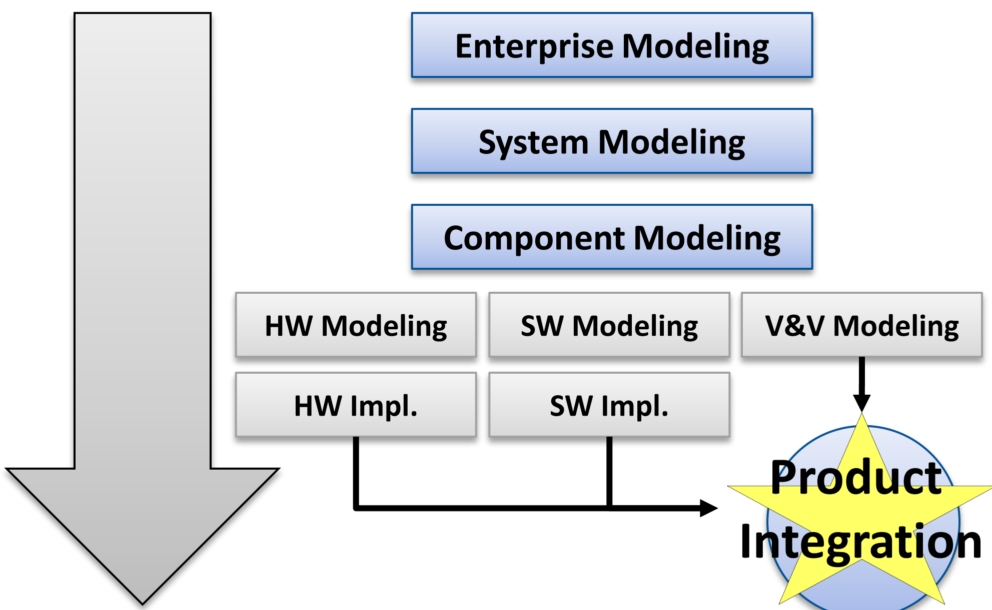
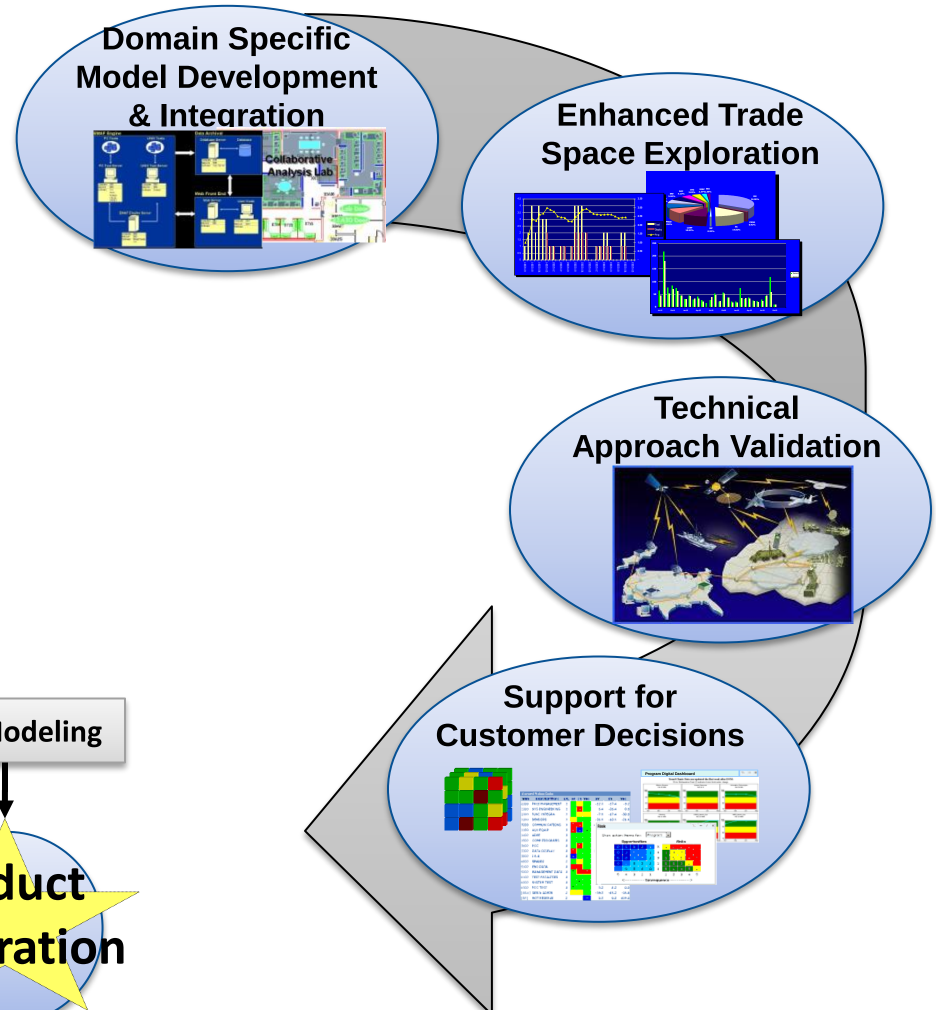
Enabling our Engineers

- Expertise Utilizing Model Based Practices And Integrated Tool Suites Allows More Variables And Trade Permutations To Optimize A Design And Find The Best Value Solution Faster





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Adding Value through MBSD

Interface Management	•Interface baseline maintained through SysML IBDs and Message model elements. •Documents HW & SW interfaces consistently and ties system behaviors to interfaces. •Scripts can be used to auto-generate interface software directly from the model.
Technical Budget Management	•Budgets (size, weight, power, performance, cost) easily managed & maintained in the model. •Engineers enter budget values at lowest leaf level in model (allocated and actual). •Custom budget script runs to accurately roll up budgets to higher levels up to the system level
Test & Integration	•The test context, test cases, and test architecture can be captured in SysML. •Test cases can be electronically linked to requirements with *verification* relationships. •Test procedures described in SysML activity diagrams.
Requirements Mapping	•Requirements Decomposition Consistently Maintained within Architecture Model •As requirements evolve, component Impact assessment is easily evaluated through the model •Requirements Lineage Easily Traced , TPMs easily tagged and identified.
Document Generation	•Storing information in a model-based database allows for easy data manipulation and extraction. •Documentation generated from the model is always up-to-date and consistent •Labor spent on Document generation can be shifted to more critical tasks

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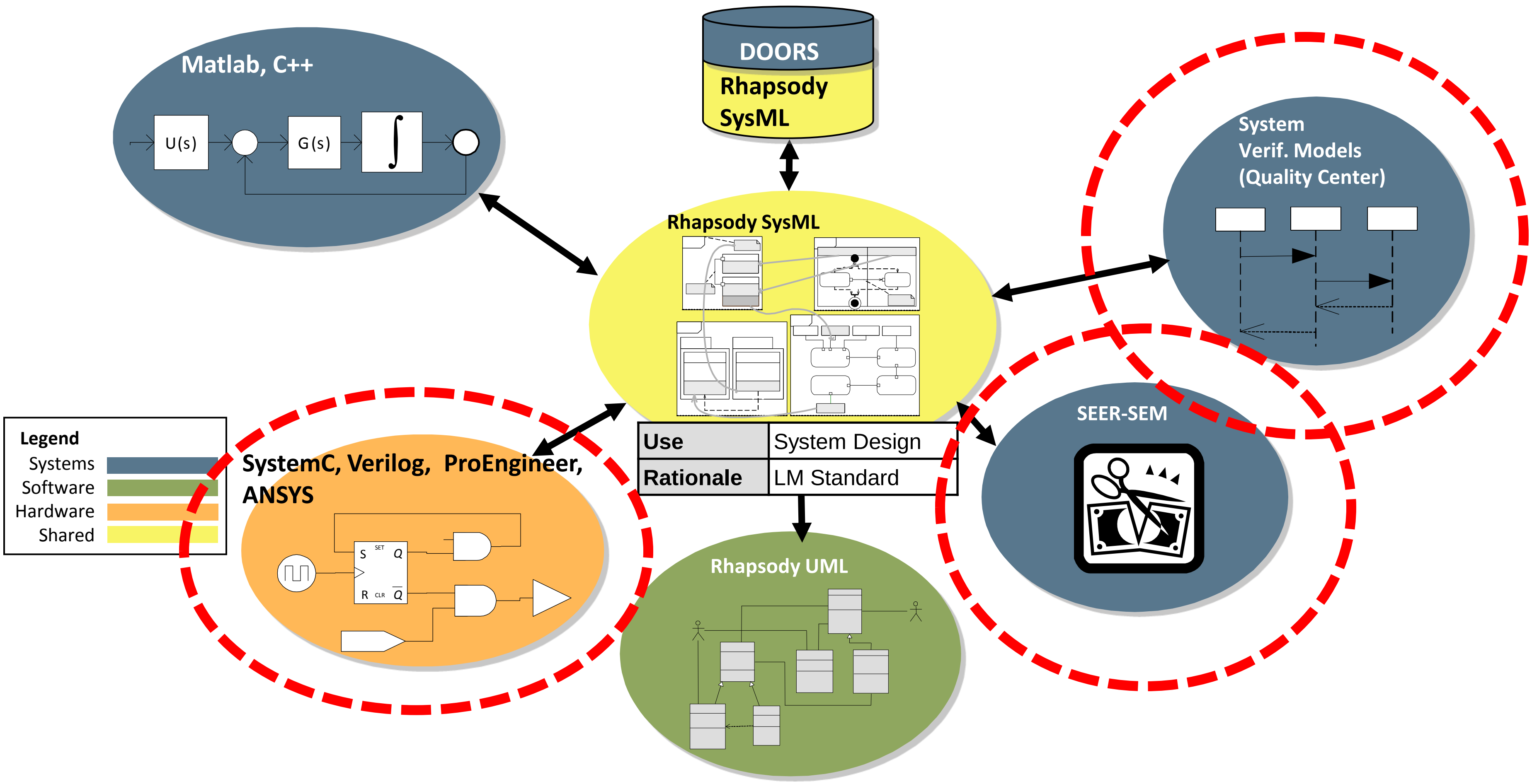
Revisiting Additional Disciplines for Integration



Extension of MBSD Integration Concepts into Verification, Costing, Electronics, Mechanical and Manufacturing Disciplines Shows Promise

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Realizing The Potential of Model-based Engineering

Developing a Model-centric Digital Tapestry

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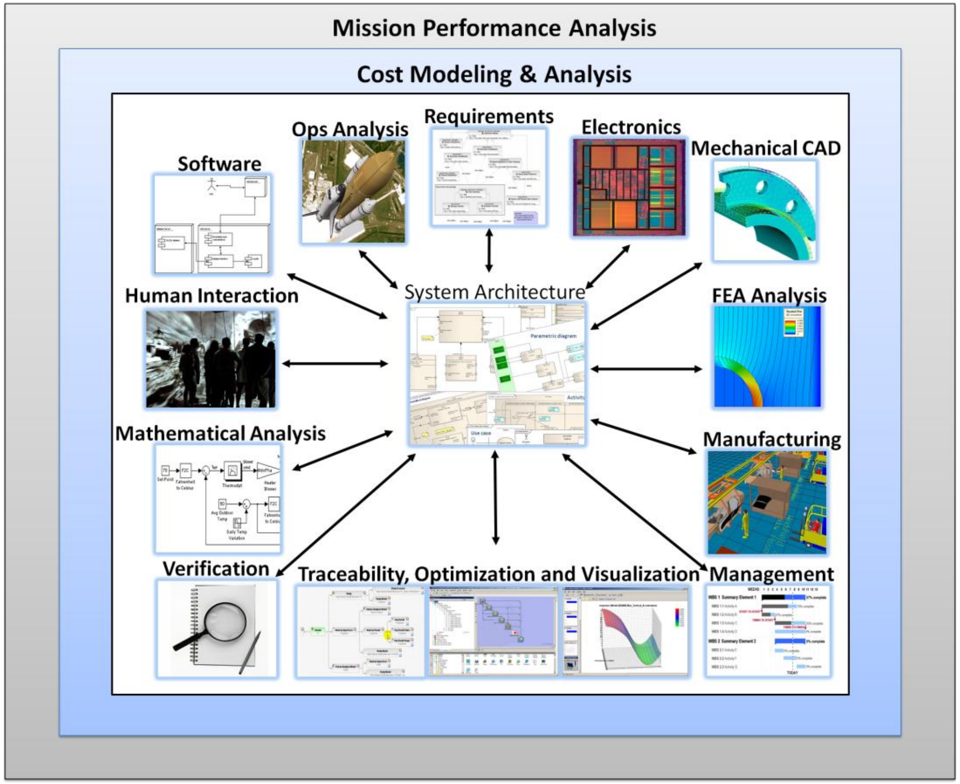
SysML: An Enabler for the Digital Tapestry

- A well defined System Architecture Model (SAM) is the loom that weaves the many threads of digital information together.
- The SAM helps link requirements to logical and behavioral design.
- Requirements can be fed into increasingly detailed levels of domain specific modeling.
- By viewing the SAM as the hub of the digital tapestry, an integration pattern emerges enabling cross-domain connectivity with a minimal set of required integrations.



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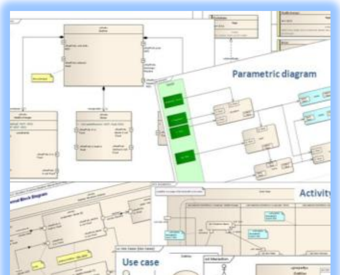
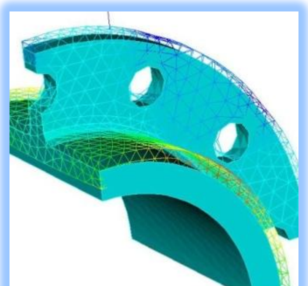
Existing Modeling Activities

- Most engineers leverages *focused* modeling activities across various disciplines.
- Capability to support integration across discipline lines tends to be limited or missing.
- Existing integrations tend to be “point to point”



Architecture

Cost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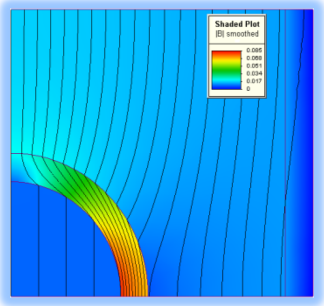
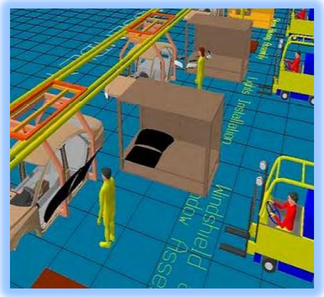


Performance


Manufacturing

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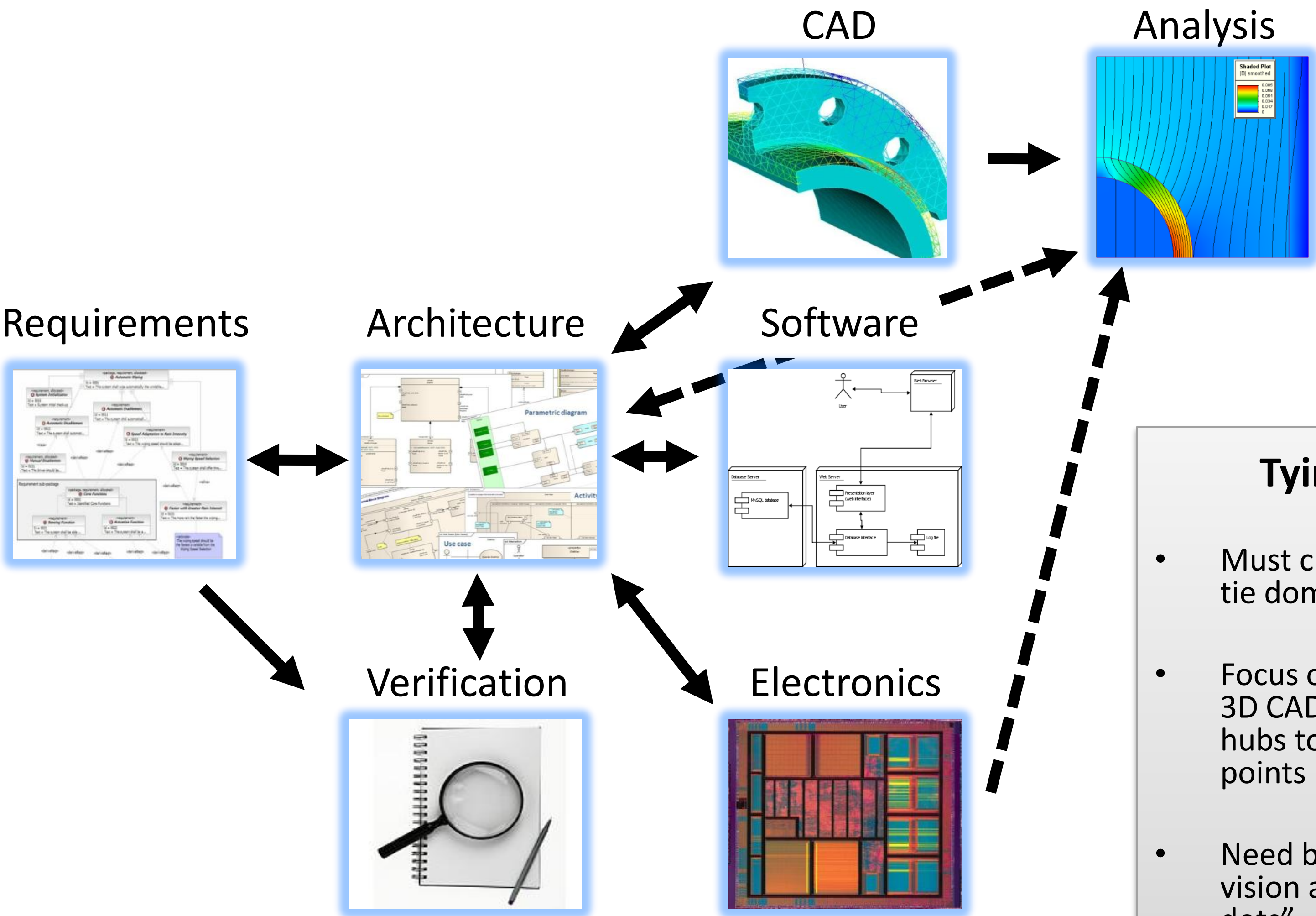
Turning Threads Into A Tapestry



Tying It All Together

- Must create the right "glue" to tie domains together.
- Focus on the Architecture and 3D CAD models as the central hubs to minimize integration points
- Need business area support for vision and to help "connect the dots"

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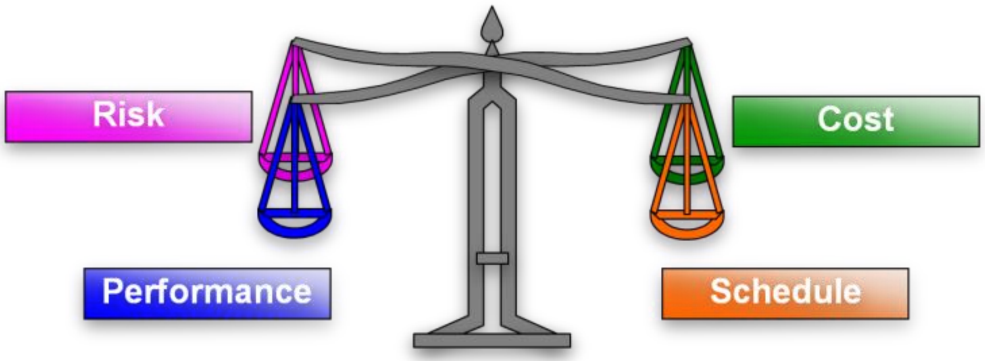
Leveraging the Tapestry: Enhancing Design Trades

- The Aerospace Industry Needs To Consider Diverse Alternative Solutions
  - More Trade Studies
  - More Performance Accuracy
  - Better Cost analysis
  - Tangible Determination of Value to Customer
- Benefits of a Model Based Engineering Approach (Speed, Accuracy, Traceability) Are Enablers
  - Improved Practices & Tools Enable Engineers to Enlarge the Solution Space



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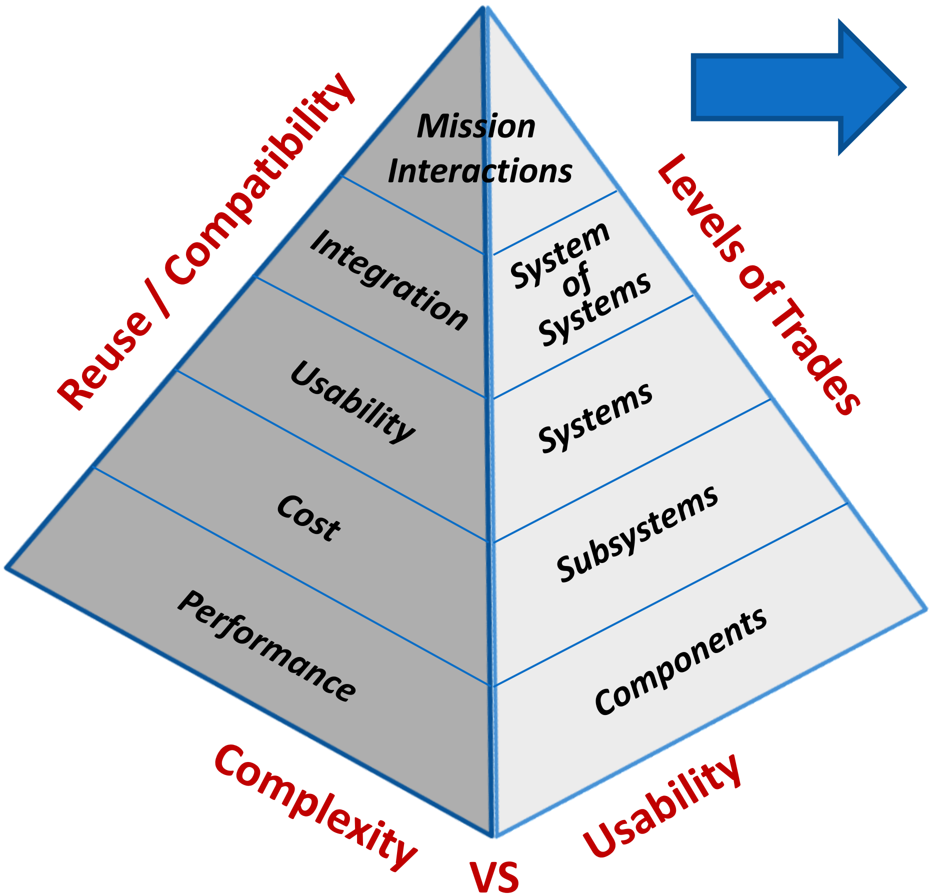
Expand, Accelerate and Validate Trades



Calls for and Integrated Digital Analysis Thread for Performance, Cost, Usability and Compatibility Accelerates Trade Analysis

- ✓ *Model Based*
- ✓ *Standards Based*
- ✓ *Integrated / Compatible Tools*
- ✓ *Technical Progress Validation*
- ✓ *Mission Performance and Force Compatibility*
- ✓ *Customer Inclusion*

Customer Business Climate Demands More Levels and Complexity of Trades to build Compatible Affordable Useable Solutions

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Key Components and Integrated Tools for Enhanced Trades

- **Leveraging system architecture models and integrated domain models to trace requirements to product design**
- **Integrating analysis models and tools into a common model-driven framework to drive performance, cost, and schedule analyses**
- **Integrated visualization and dashboards to track performance, completeness and customer value of the solution space**
- **Utilize subject matter expertise to develop standardized distributed analyses**

Model Type	Example Tool
Systems Engineering (SysML)	Rhapsody
Systems Engineering (Requirements Database)	DOORS
Performance Analysis (Vehicle Dynamics)	Adams
Mathematical Analysis	Matlab
Data Analysis	Excel
Cost Modeling	SEER
Model Integration/Work Flow	Model Center

Providing Glue Between MBSD, Affordability and Performance Analysis

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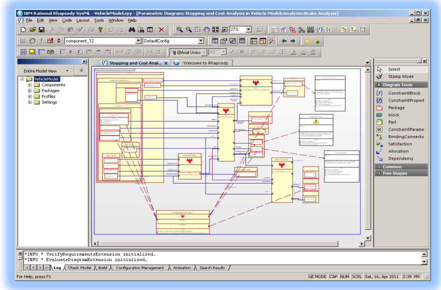
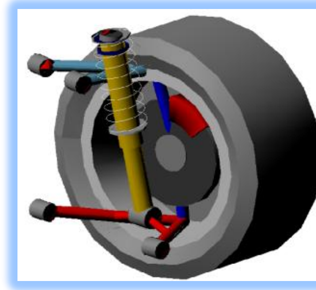
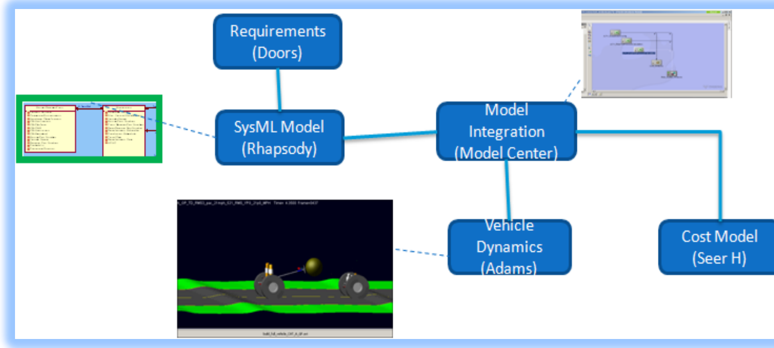
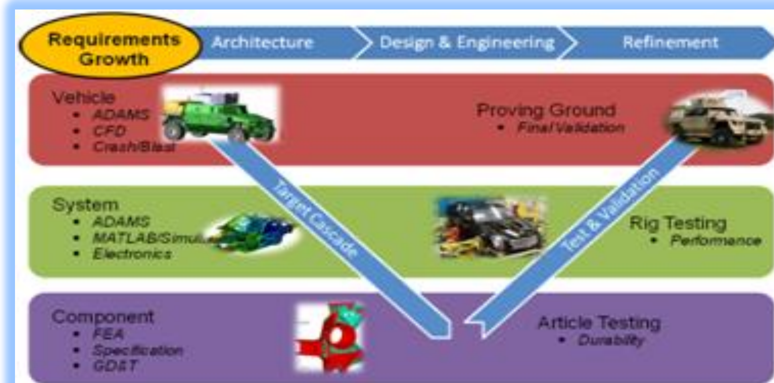
LM Case Study
SysML Driven Subsystem Optimization

- Pilot Objective
  - Elaborate the modeling capability to demonstrate robust integration of requirements, analysis and design
  - Leverage Design of Experimentation techniques to analyze the design trade space
- Pilot Challenges
  - Developing a Suspension System that meets ride and handling qualities under the full range of loading conditions at minimum cost and weight
  - Considering conventional, adjustable, active and position dependent shock absorber designs
- Demonstrated integration of Rhapsody, SEER, Matlab, Excel and MSC.Adams using Model Center
  - Focused on verifying an enhanced ability to investigate performance









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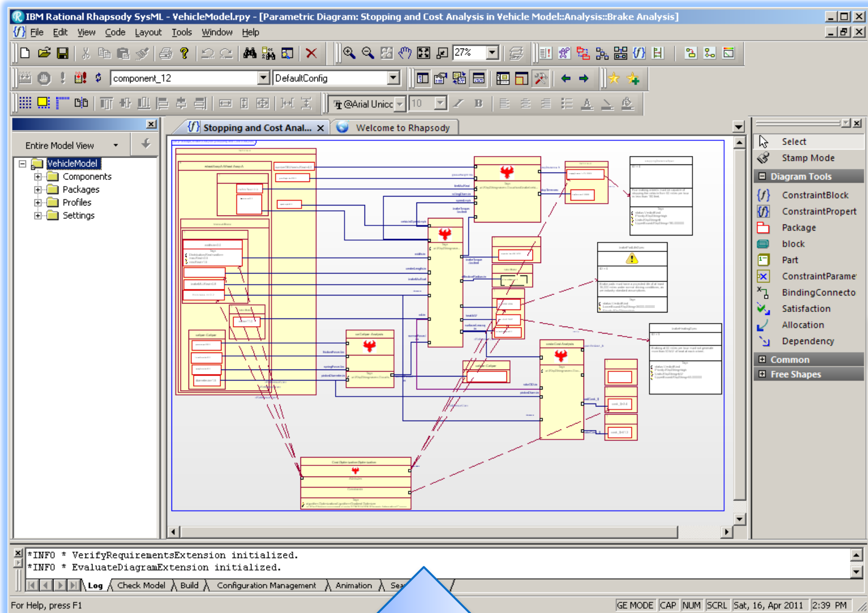
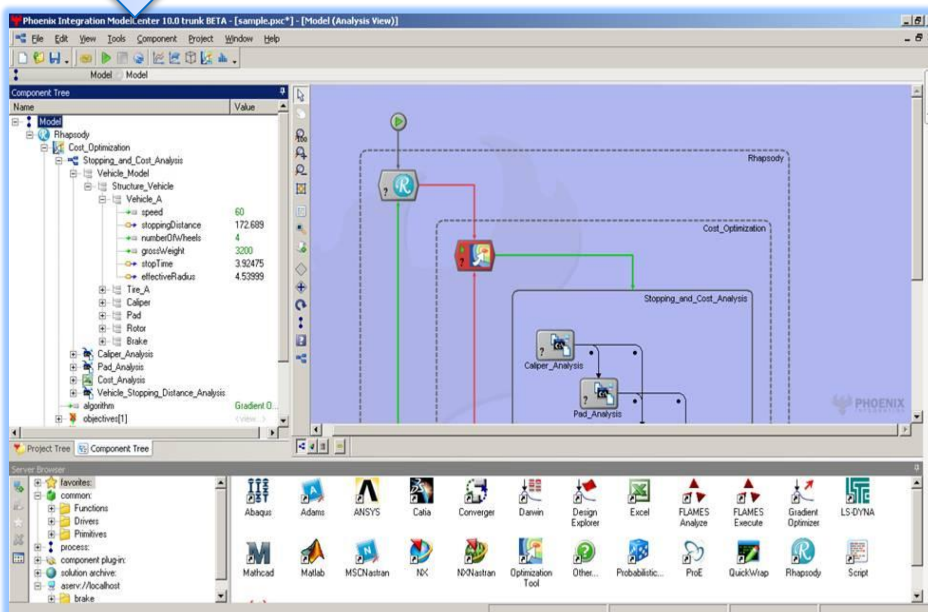
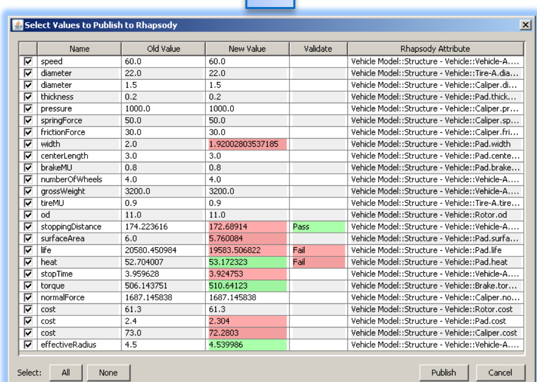
Enhanced Tooling Beginning to Enable Integrated Model-based Analysis



- LM has worked with Phoenix Integration to begin defining an integration between SysML and Model Center™
- Focused on rapid integration and trades and allowing engineers to use the right tool for each job.

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☑	diameter	1.5	1.5		Vehicle Model::Structure - Vehicle::Caliper.di...
☑	thickness	0.2	0.2		Vehicle Model::Structure - Vehicle::Pad.thick...
☑	pressure	1000.0	1000.0		Vehicle Model::Structure - Vehicle::Caliper.pr...
☑	springForce	50.0	50.0		Vehicle Model::Structure - Vehicle::Caliper.sp...
☑	frictionForce	30.0	30.0		Vehicle Model::Structure - Vehicle::Caliper.fri...
☑	width	2.0	1.92002803537185		Vehicle Model::Structure - Vehicle::Pad.width
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☑	brakeMU	0.8	0.8		Vehicle Model::Structure - Vehicle::Pad.brake...
☑	numberOfWheels	4.0	4.0		Vehicle Model::Structure - Vehicle::Vehicle-A....
☑	grossWeight	3200.0	3200.0		Vehicle Model::Structure - Vehicle::Vehicle-A....
☑	tireMU	0.9	0.9		Vehicle Model::Structure - Vehicle::Tire-A.tire...
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☑	stoppingDistance	174.223616	172.68914	Pass	Vehicle Model::Structure - Vehicle::Vehicle-A....
☑	surfaceArea	6.0	5.760084		Vehicle Model::Structure - Vehicle::Pad.surfa...
☑	life	20580.450984	19583.506822	Fail	Vehicle Model::Structure - Vehicle::Pad.life
☑	heat	52.704007	53.172323	Fail	Vehicle Model::Structure - Vehicle::Pad.heat
☑	stopTime	3.959628	3.924753		Vehicle Model::Structure - Vehicle::Vehicle-A....
☑	torque	506.143751	510.64123		Vehicle Model::Structure - Vehicle::Brake.tor...
☑	normalForce	1687.145838	1687.145838		Vehicle Model::Structure - Vehicle::Caliper.no...
☑	cost	61.3	61.3		Vehicle Model::Structure - Vehicle::Rotor.cost
☑	cost	2.4	2.304		Vehicle Model::Structure - Vehicle::Pad.cost
☑	cost	73.0	72.2803		Vehicle Model::Structure - Vehicle::Caliper.cost
☑	effectiveRadius	4.5	4.539986		Vehicle Model::Structure - Vehicle::Vehicle-A....

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Strategies to Support Adoption of Model-based Engineering

Building a Skilled Workforce

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Changing the Workforce

- Changing the way the Aerospace & Defense business develops capabilities is more than just a technical problem!
- Technical credibility is crucial but…
  - Value needs to clearly demonstrated
  - A skilled workforce must be developed
  - Early adopter programs can't be allowed to fail

Human behavior flows from three main sources: desire, emotion, and knowledge - Plato

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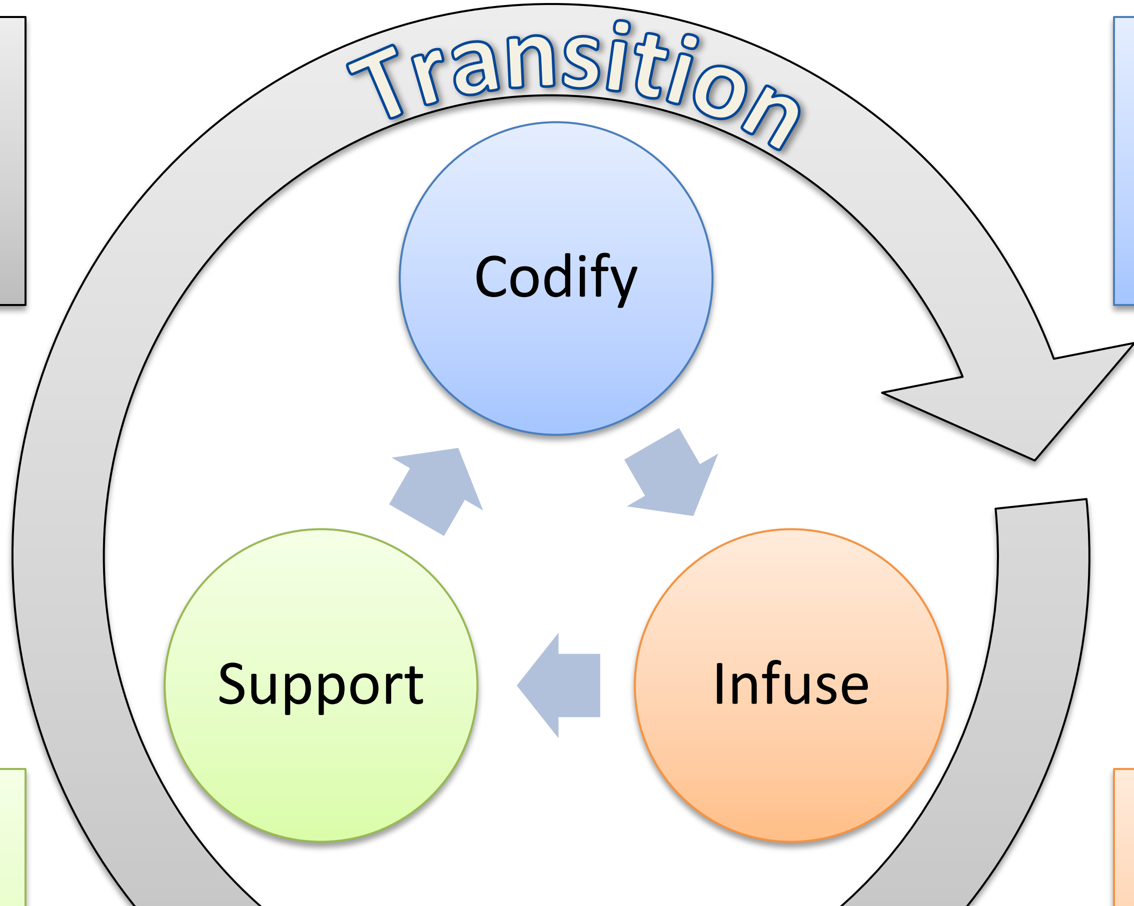
How to Transition & Sustain A Practice

Developing Self Sufficiency is Key to Transitioning a Practice

Drive Adoption Through Programs & Capture Pilots



Offer Necessary Training & Provide "Reach-back" Support

Infusing MBSD into Lockheed Martin's Engineering Culture

Build A Base of Practitioners, Experts & Champions

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Questions?

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