

Stevens Institute of Technology & Systems Engineering Research Center (SERC)

Systems Engineering Transformation through Model Centric Engineering

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Distribution A - Approved for public release

- Problem, Objectives and Terminology (Phase I)
- Bottom Line (Up Front)
- Current research thrusts
- Perspectives new RT-157/RT-170 (Phase II)
- Status
- Conclusions and Impacts
- Backup: past RT-48/118/141 (Phase I)
- Acknowledgments
- Acronyms and Image credits

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Problem statement (Phase I):

It takes too long to bring large-scale air vehicle systems from concept to operation

Primary question:

Is it **Technically Feasible** to have a **Radical Transformation** through Model Based Systems Engineering (MBSE) and achieve a **25 percent reduction** in the **time** to develop large-scale air vehicle system (using computer/digital models)?

Corollary:

How do we know that models/simulations used to assess **Performance** have the needed **Integrity** to ensure predictions are accurate (i.e., that we can trust the models)?

Sponsor's Vision at Kickoff Meeting: Cross-Domain, Multi-Physics, Models Integration

Continuous refinement of models through cross-domain & multidisciplinary analysis supporting virtual V&V from CONOPS to manufacturing



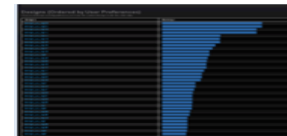
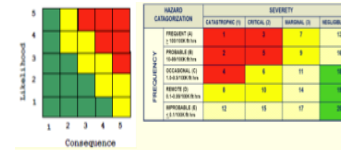
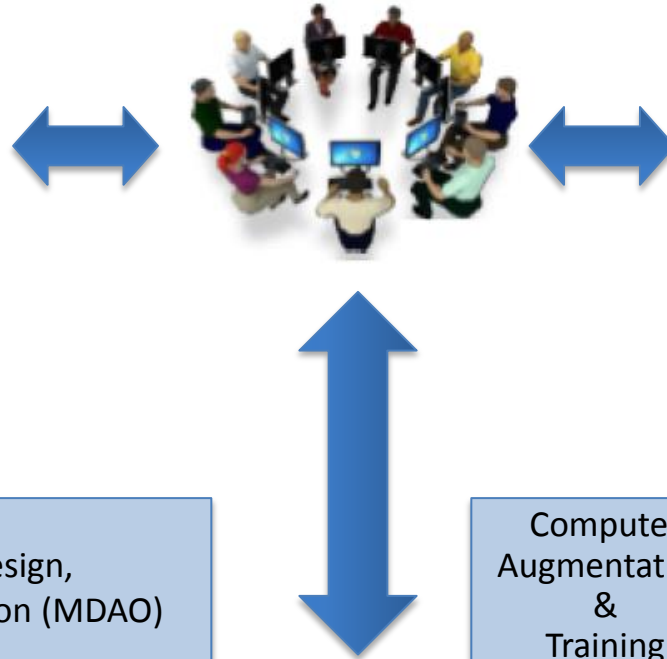
Integrated Environment to Produce Digital System Model:
Single Source of Technical Truth

Model Based System Engineering (MBSE) versus Model-Centric Engineering (MCE)

- Over 30 organizational discussions “most holistic approach...”:
 - Model-Based Engineering (MBE), Integrated Model-Centric Engineering, Interactive Model-Centric Systems Engineering (IMCSE), Model-Driven Development, Model-Driven Engineering (MDE), and even Model-Based Enterprise, which brings in more focus on manufacturability
 - Digital Thread envisions frameworks that merges physics-based models generated by (cross)discipline engineers during detailed design process with MBSE’s conceptual and top-level architectural models, resulting in a single authoritative representation of the system [West, Pyster, INCOSE 2015]
- **MCE** characterizes the goal of integrating different model types with simulations, surrogates, systems and components at different levels of abstraction and fidelity across discipline throughout the lifecycle with manufacturability constraints
- We could have used the words Digital Engineering, which we do

Conceptual Reference Model: Integrated Environment for Iterative Tradespace Analysis of Problem and Design Space

Appropriate Views for Stakeholders



“Web” Interface integrated with Rich Visualizations

Rich Modeling Interfaces

Multidiscipline Design, Analysis and Optimization (MDAO)

Computer Augmentation & Training

Continuous Workflow Orchestration

DocGen

Single Source of Technical Truth:
 Tool Agnostic, Semantically Precise Cross Domain Integration & Interoperability enabled by HPC



PLM

Performance

Integrity

Cost & Schedule

“Illities”

Knowledge

...

Systems, Surrogates & Platforms

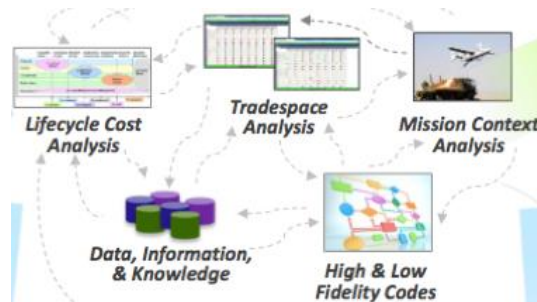
Scope of Data Collection for Task 1

Traced to Evidence (not exhaustive)

Discussion Topics (not exhaustive)	Instances Where Discussed (not exhaustive)												Characteristics						From Kickoff Briefing					
	NASA/JPL	A	B	C	Altair	GE	Sandia	DARPA META (VB)	DARPA META (BAE)	Model Center	Automotive	CREATE	Performance	Integrity	Affordability	Risk	Methodology	Single Source of Truth	Prioritization & Tradeoff Analysis	Concept Engineering	Architecture & Design Analysis	Design & Test Reuse & Synthesis	Active System Characterization	Human-System Integration
Modeling CONOPS	x															x	x	x	x				x	
Modeling Patterns	x								x					x		x	x	x		x	x	x		
Multi-Physics Modeling and Simulation		x	x	x	x			x	x		x	x	x	x					x	x	x	x	x	
Multi-Discipline/Domain Analysis and Optimization	x	x	x	x	x	x	x	x	x	x			x	x	x	x		x	x		x	x	x	
Mission-to-System-level Simulation Integration	x	x	x													x		x	x	x	x	x	x	x
Affordability Analysis			x				x						x	x	x	x			x		x	x	x	
Quantification of Margins			x				x						x	x	x	x	x		x		x	x	x	
Requirement Generation (from Models)	x		x					x									x	x	x		x	x		
Tool Agnostic Digital Representation	x	x			x				x								x	x	x	x		x	x	x
Model Measures (through formal checks)	x		x			x		x	x							x	x	x			x	x		
Modeling and Sim for Manufacturability			x			x		x					x	x	x	x	x	x	x	x	x	x	x	
Process Automation (workflows)	x				x				x	x							x	x			x			
Iterative/Agile Use of MCE	x	x	x							x							x				x	x		
High Performance Computing	x	x	x		x		x	x			x	x	x	x	x				x	x	x		x	
Platform-based and Surrogates	x	x	x								x									x	x	x	x	
3D Environments and Visualization	x	x	x	x	x	x	x	x			x		x	x					x	x		x	x	x
Immersive Environments		x	x								x									x			x	x
Domain-specific Modeling Languages	x	x	x	x	x	x	x	x	x		x		x	x			x			x	x	x		
Set-based Design		x				x							x	x	x	x			x	x	x			
Model Validation/qualification/trust							x					x		x		x	x		x		x	x		
Modeling Environment and Infrastructure	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x		x	x	x	x	x

1) Model Cross-Domain Integration

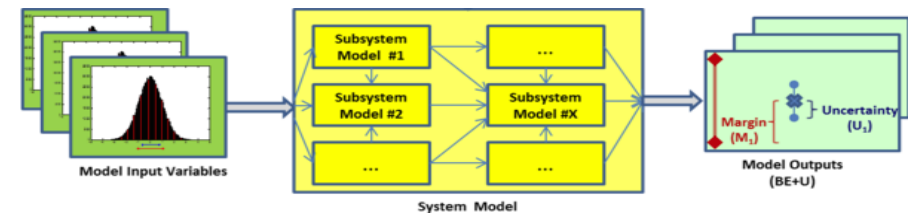
Targeted discussions with Government, Industry & Academia on developing and operating in modeling framework enabling cross-domain model integration & Single Source of Technical Truth (SSTT) methodology



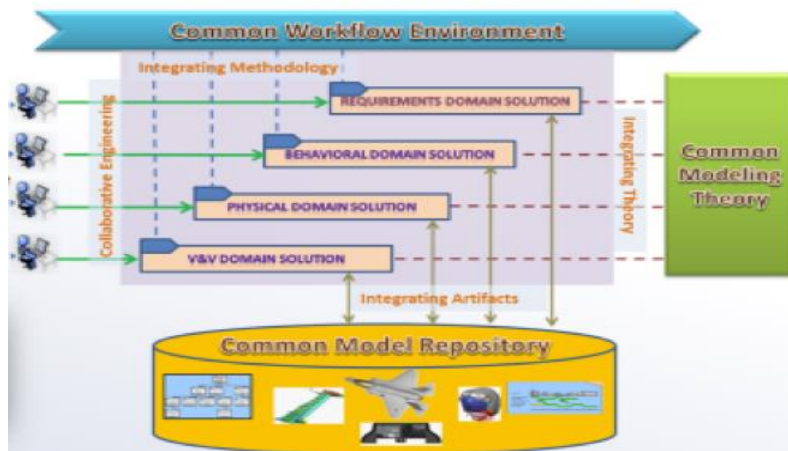
2) Model Integrity

Define Methodologies for Model Integrity and Uncertainty Quantification:

- Provide trust in model-based predictions, with Quantification of Margins & Uncertainties
- Framework for integrating risk and understanding uncertainty in the data

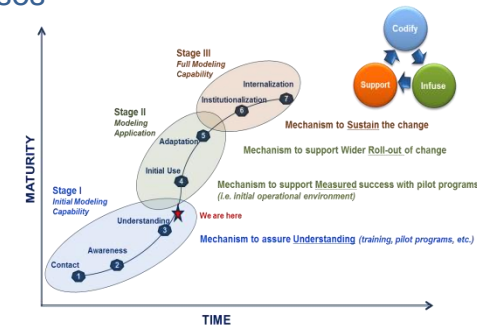


Model-Centric Methodology



Develop a roadmap to rollout capabilities addressing all five perspectives in parallel:

1. Technologies and infrastructure for SSTT
2. Methodologies and processes
3. People, competencies and SSTT interfaces
4. Operational & contractual paradigms for transformed interactions with industry
5. Governance



3) Modeling Methodology Implementation at NAVAIR

4) SE Transformation Roadmap

- Organizations (with a few exceptions) were unwilling to share quantitative data
- Qualitative data in the aggregate suggests that MCE technologies and methods are advancing and adoption is accelerating

NAVAIR Executive Leadership Response:

- NAVAIR must move quickly to keep pace with other organizations that have adopted MCE
- NAVAIR must transform in order to perform effective oversight of primes that are using modern modeling methods for system development

March 2016: Change of Command has Accelerated the Systems Engineering Transformation and Broadened the Scope

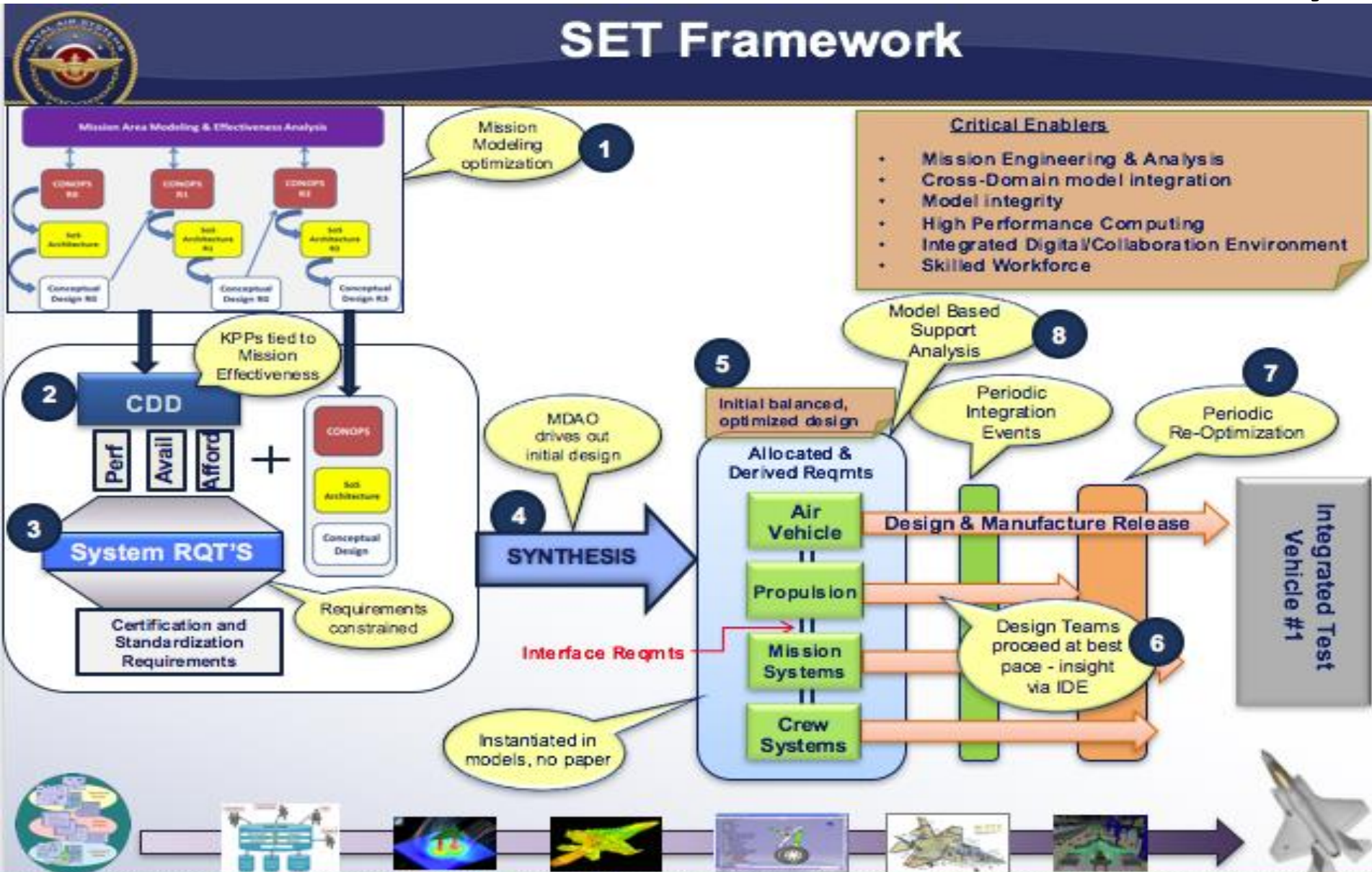
Model-Centric Engineering Can Enable New Types of Coordination

- In a “Digital Engineering” environment, government and industry need to work in a different way



Framework for New Operational Paradigm Between Government and Industry

SET Framework



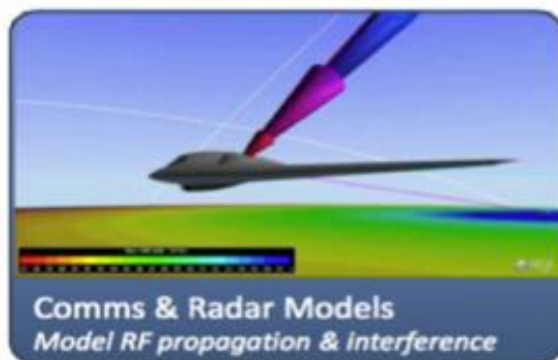
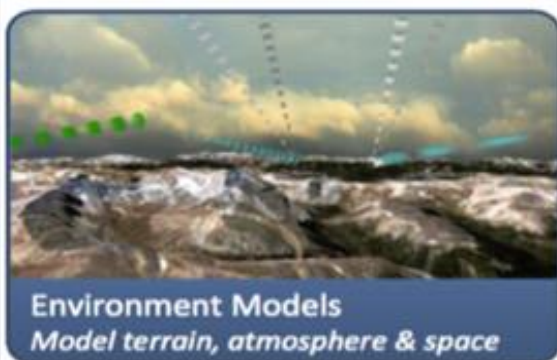
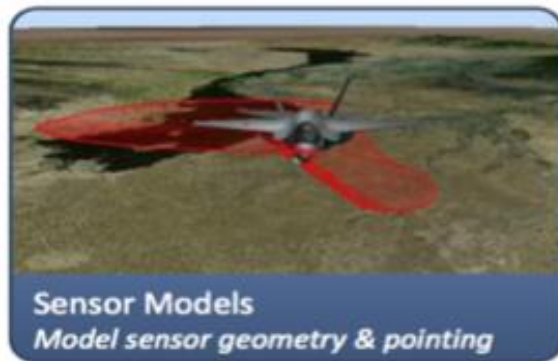


RT-157 Perspectives



Dynamic CONOPS Integrated with Mission Simulations to Better Understand Needed System Capabilities

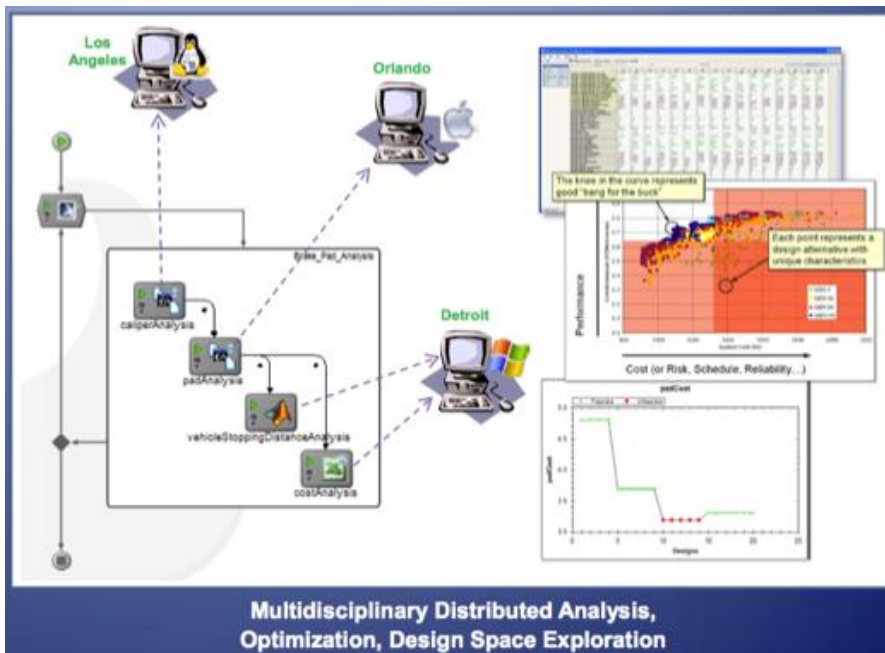
Simulated-based
Study Views Method
Structures and Formalizes
the JCIDS* Concepts prior
to DoDAF Modeling



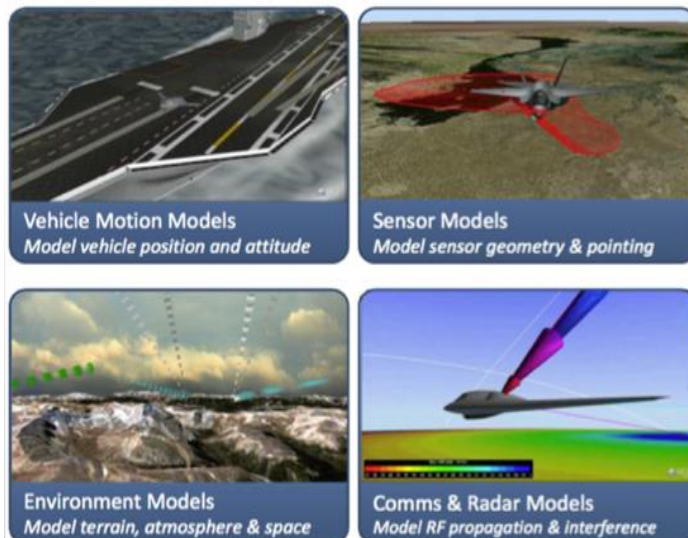
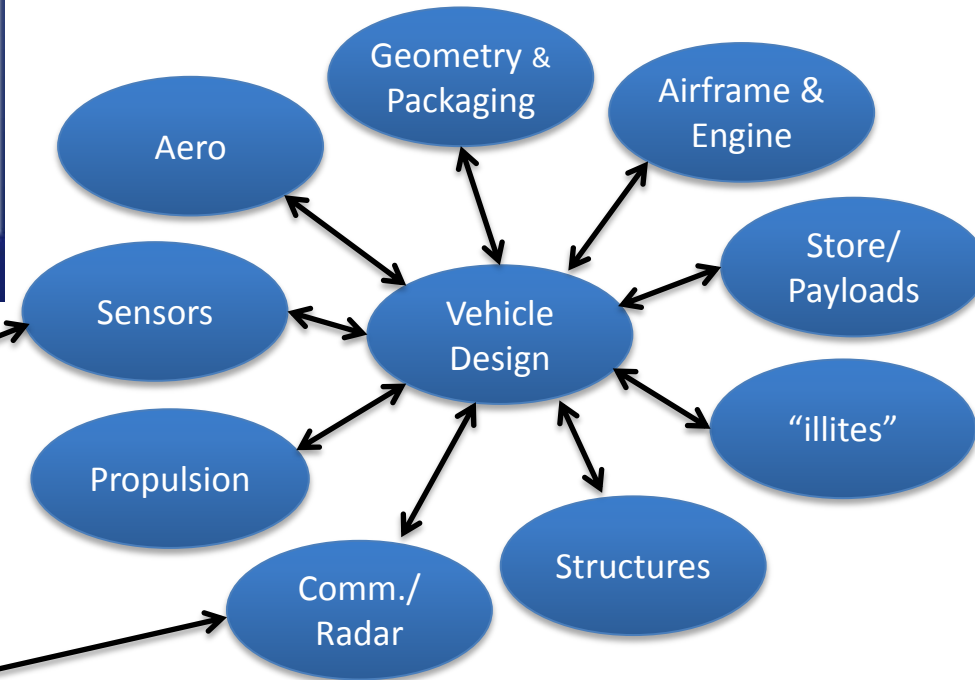
*Joint Capabilities Integration and Development System (JCIDS)

Multidisciplinary Design, Analysis and Optimization

Supports Tradespace Analysis Across Disciplines

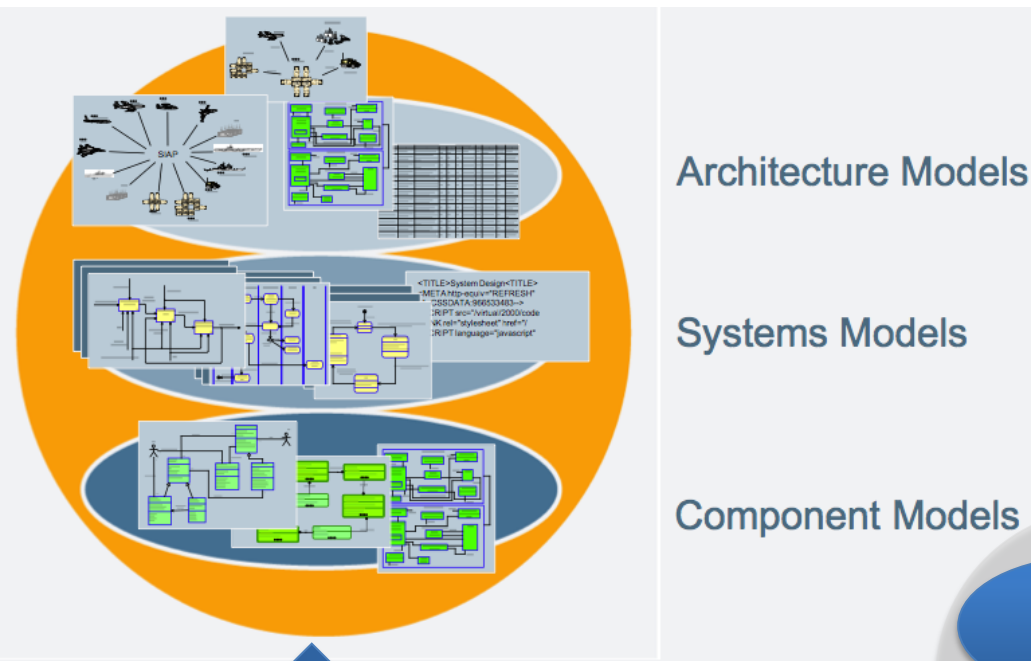


MDAO Implements Workflow with Solvers to Evaluate Trades Systematically Driven by Design of Experiment

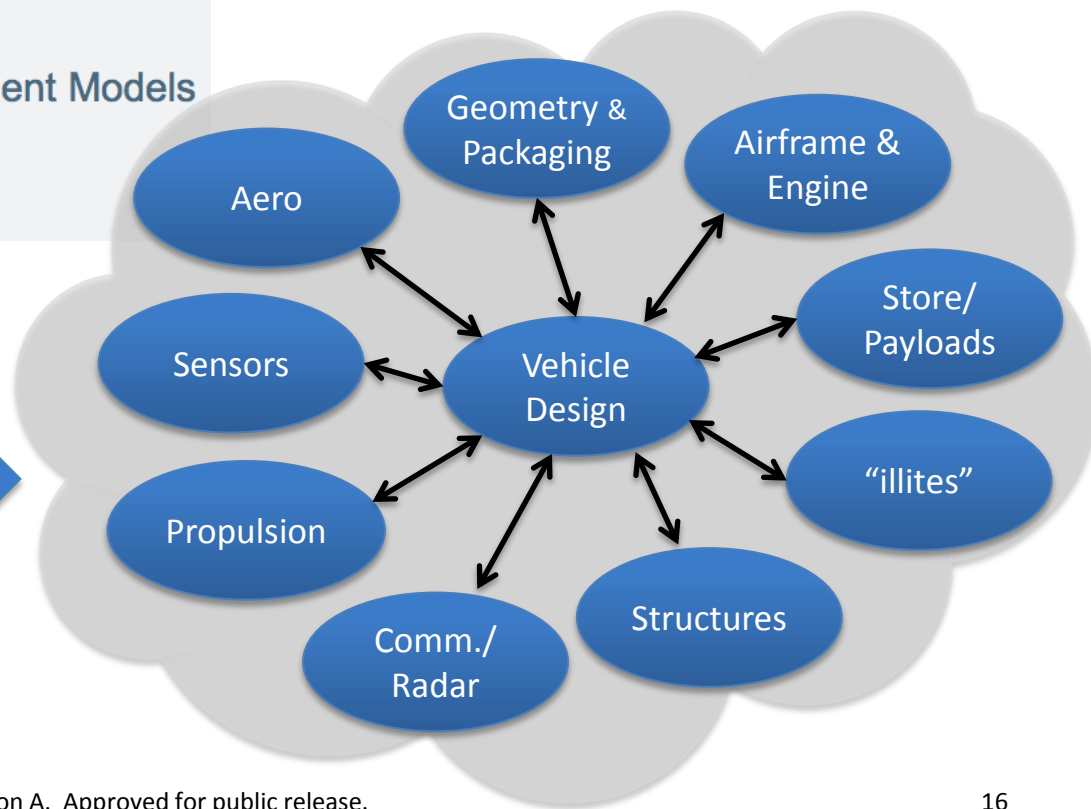
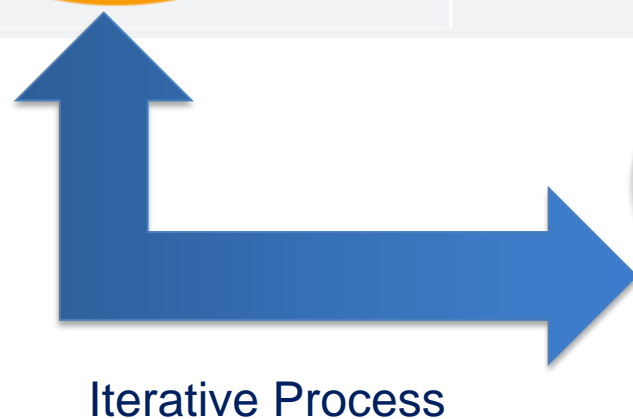


Detailed Design from Associated Disciplines and Competencies

Need to Better Integrate Multiple Levels of System Models with Discipline-Specific Designs



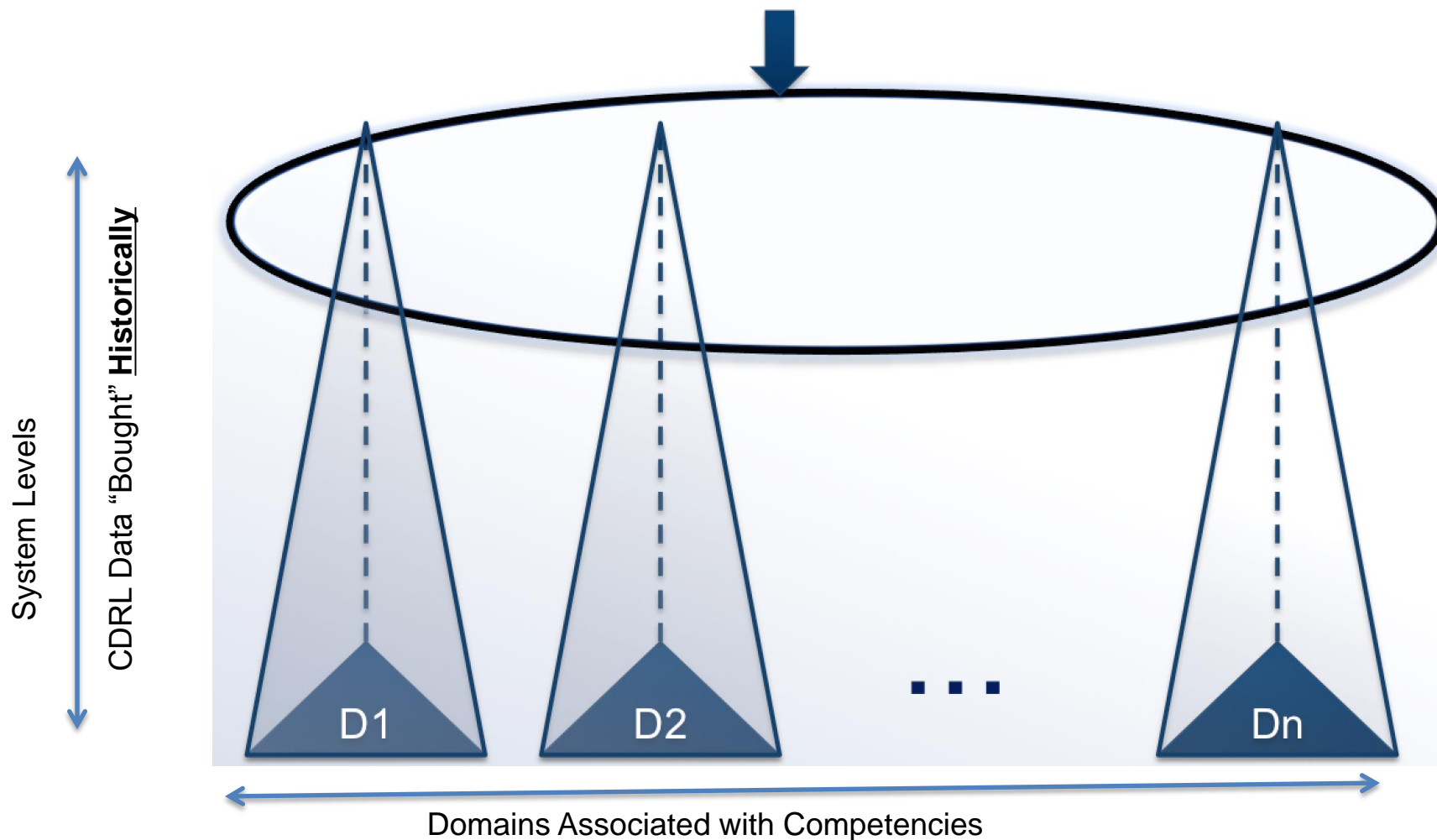
Architectural, System and Component Models Define the Cross-Domain Integration and Bring in Detailed Behaviors



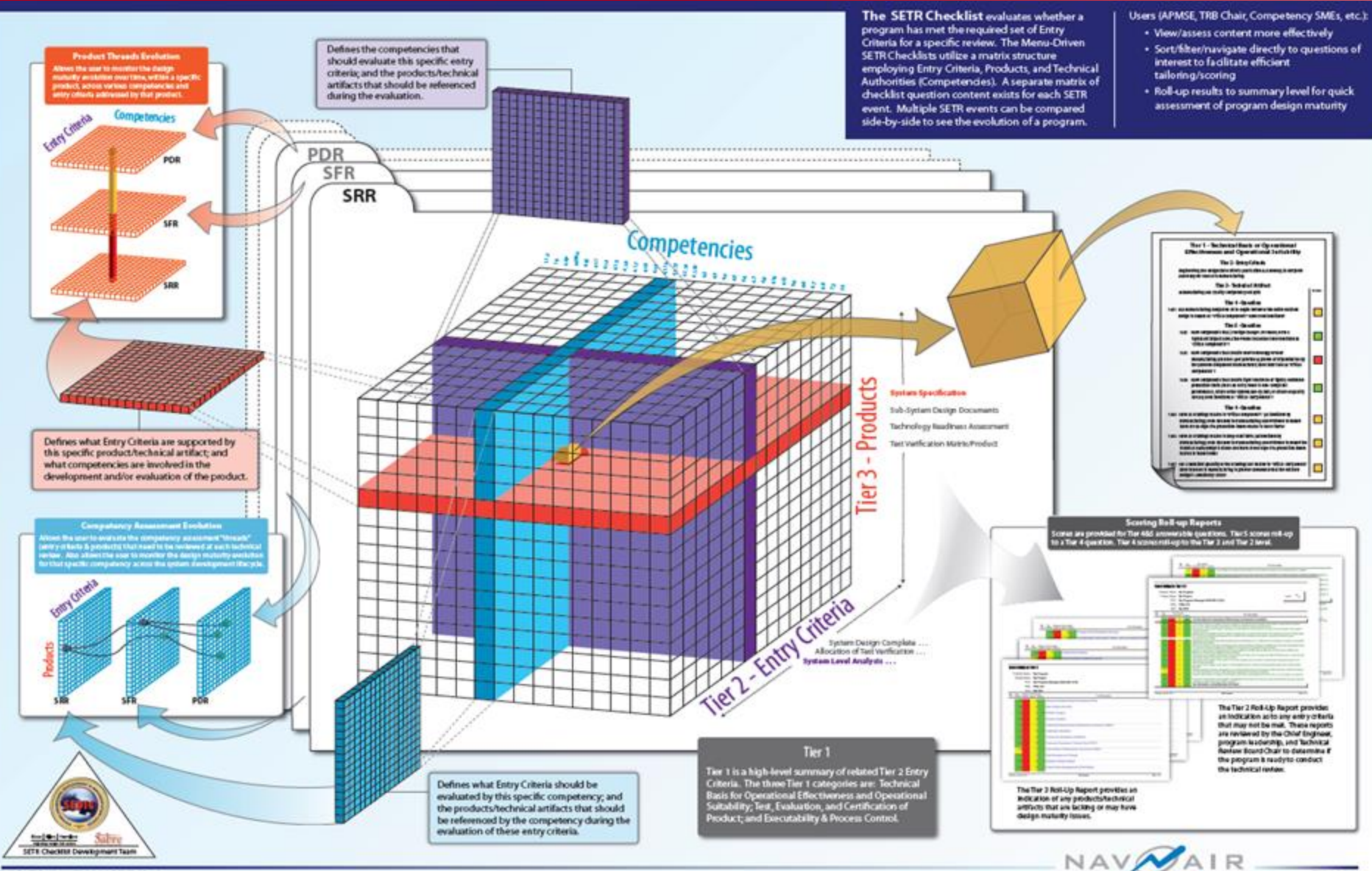
Re-define Required Engineering Data and Associated Contract Language

Near Term Transformation

Focus on Value and Risk-Driven “Digital CDRLs”
That Relate to Key Cross-Domain System

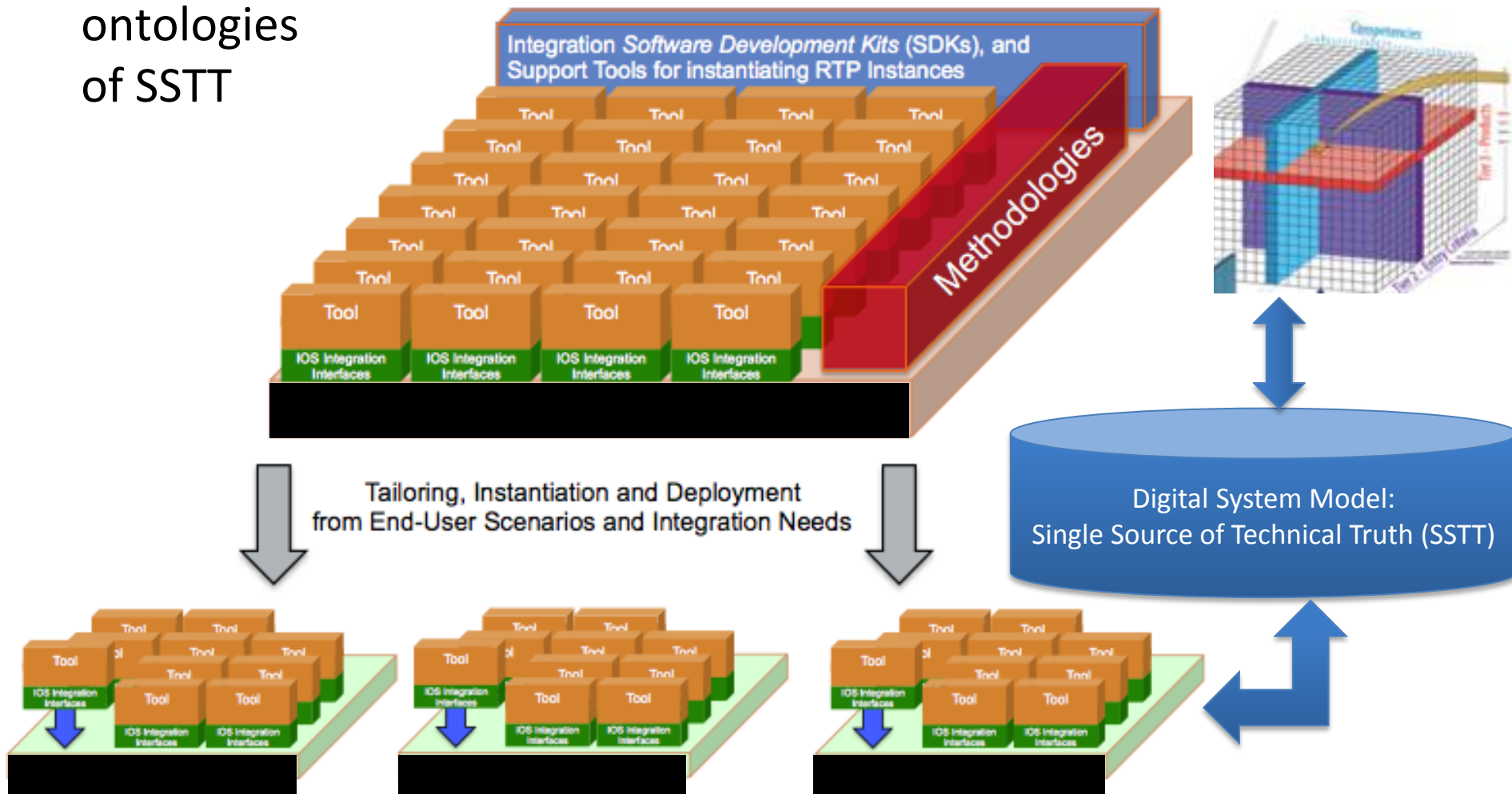


Structure of SETR Checklist Questions



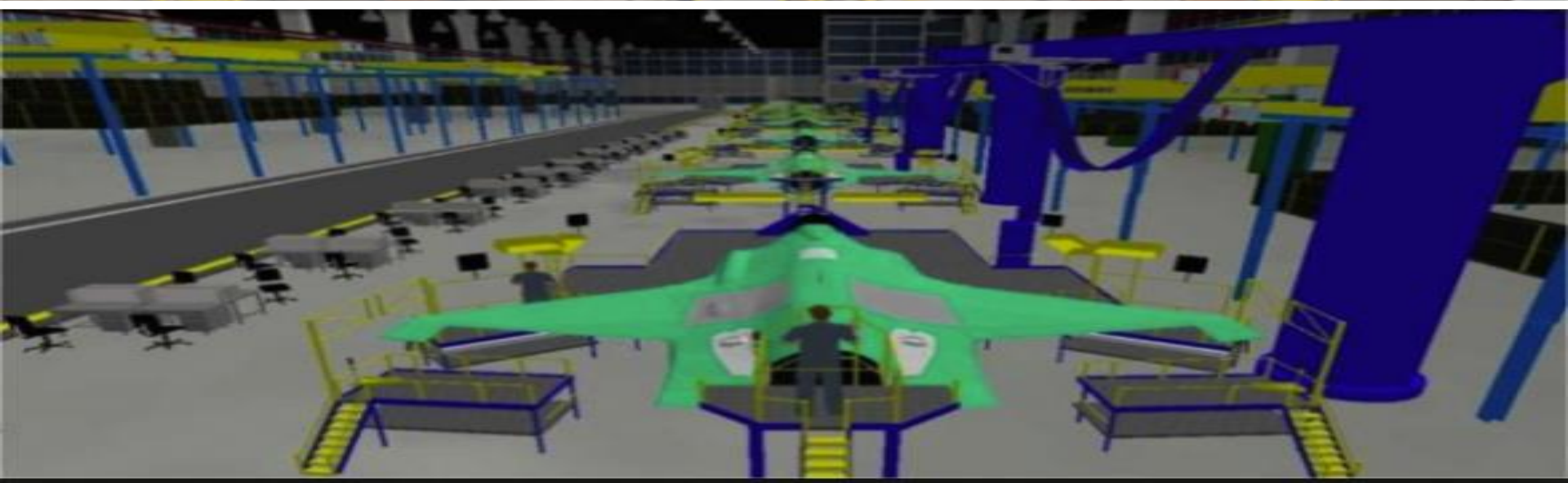
Methodologies are Critical Because Commercial Tools are Method Agnostic

Cross-domain methodologies ensure tool usage produces complete and consistent information compliant with ontologies of SSTT

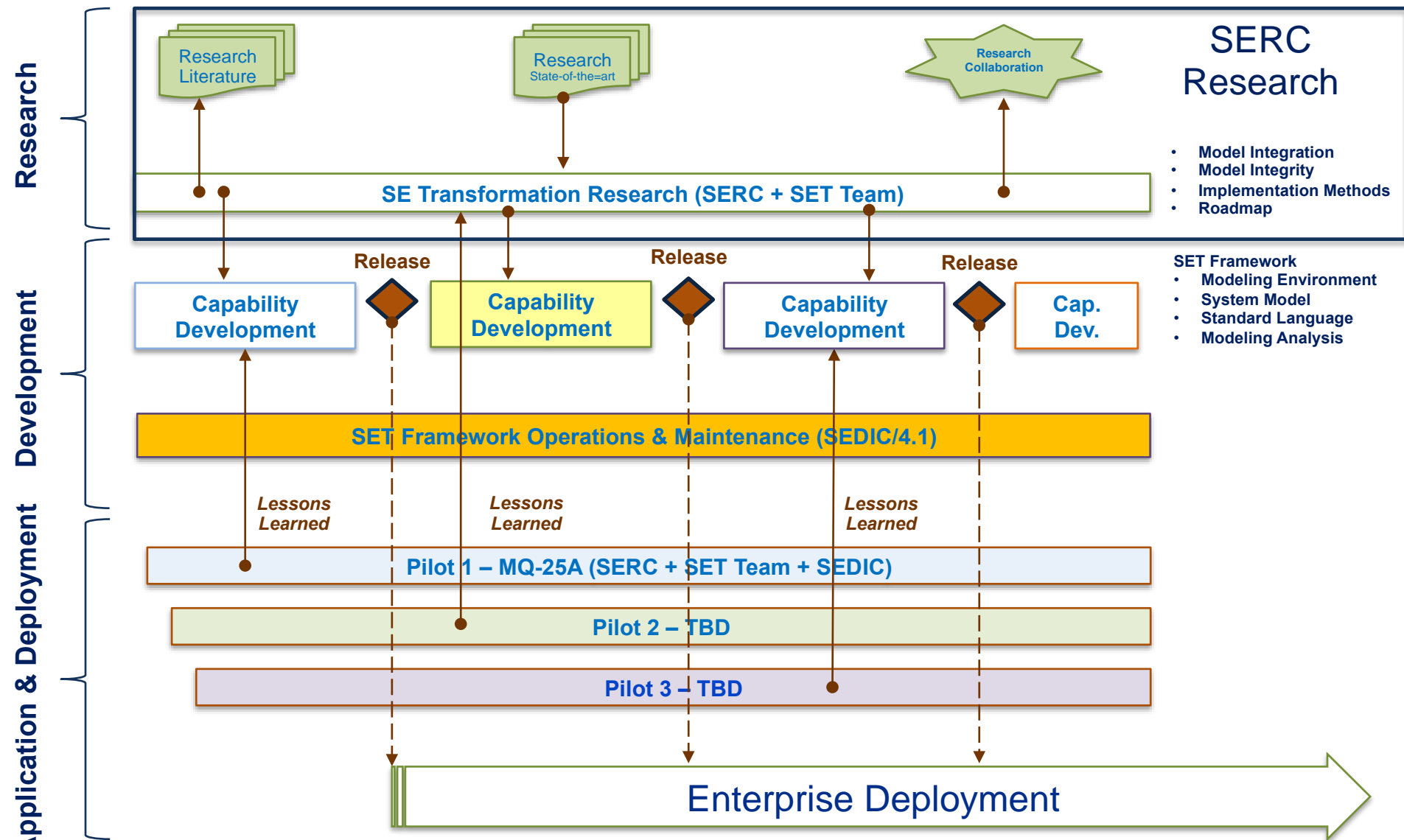


Organizations are Modeling and Simulating Manufacturing Before Tooling

- Set-based delays design selection and increasingly factors in manufacturability



SE Transformation “Role-out” Strategy



Status Against Framework Research (1/3) – Contracting through Digital Engineering

- Developing surrogate UAV to demonstrate how models represent requirement at logical and functional levels
 - Concept can be part of a SOW and RFP for new contractual vehicle based on Digital Engineering for competitive down select (NDIA involved in this effort)
 - Illustrate links from system models to MDAO and other types of models
 - Models support validation of requirements and provides a means for verification planning and basis of estimate for testing
 - Examples already presented at working sessions and included in RT-157 Interim Technical Report
- Developing models of methods and processes to illustrate linkage between mission, system, reference and MDAO, etc. models
- Plan is to develop “surrogate” UAV model as a means for illustrating what needs to be modeled beyond DoDAF focused on net-ready views

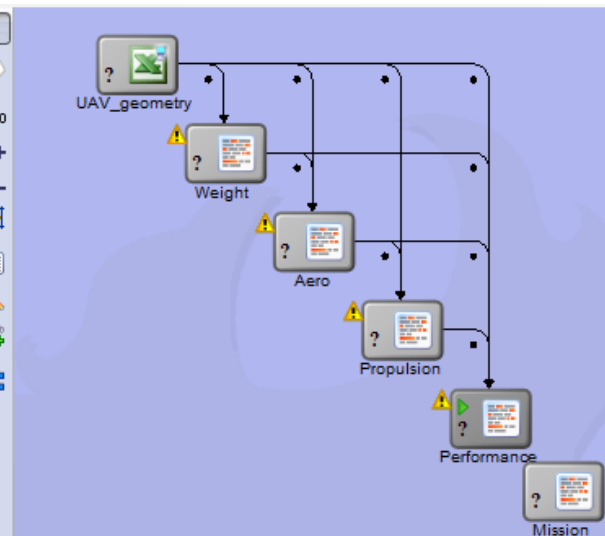
Status Against Framework Research (2/3) – MDAO Example Relevant to UAV

- Developed MDAO workflow for example of KPP (range) using UAV Weight, Aero, Propulsion, Performance, which links back to system model to illustrate method:
 - Defining sequence of workflows (scenarios)
 - Identifying a set of inputs and outputs (parameters)
 - Define a Design of Experiments (DoE) and use analyses such as sensitivity analysis and visualizations to understand the key parameter to scope
 - Use Optimization using solvers with key parameters and define different (key objective functions – on outputs) to determine set of solutions (results often provided as a table of possible solutions)
 - Use visualizations to understand relationships of different solutions
 - Concept applicable at mission, system and subsystems

Component Tree

Name	Value
Model	
UAV_geometry	
emptyWeight	40000
takeoffGrossWeight	50000
avionicsWeight	40
structureWeight	380
subsystemWeight	120
fuelWeight	500
payloadWeight	0
stallSpeed	120
maxSpeed	350
designFlightSpeed	300
MALE	40000
wingArea	500
totalPayload	0
Weight	
Aero	
Propulsion	
thrustCoefficient	0.995
propulsion	31500
flightVelocity	700

Distr



Status Against Framework Research (3/3) – Model Integrity

- Steven's PhD candidate Col. Timothy West (advisor Mark Blackburn) runs wind tunnels at Arnold Engineering Development Complex
- Research involves a proposed methodology to use Sandia National Laboratory (SNL) DAKOTA Toolkit with DoD Computational Research and Engineering Acquisition Tools and Environments (CREATE) Air Vehicle (AV) family of computational tools (e.g., CFD, FEA), in order to develop an optimized wind tunnel campaign for two different aerodynamic shapes to assess the process



Aeropropulsion

F136 in J2



Aerodynamics

B-52 in 16T



Hypersonics

HTV at Tunnel 9

Conclusions and Impacts

- NAVAIR is evolving a framework for a new collaborative operational paradigm with industry
 - Conducting meetings with industry to “validate” concept and solicit recommendations for improvement and evolution
- Programs
 - NAVAIR efforts targeted to real programs
 - New contracting model/approach needed
 - New criteria for assessing “maturity” vice “milestones”
- Policy – can the current policy still work?
- Collaboration: new SERC research with US Army ARDEC targeting their needs for MCE in collaboration with NAVAIR
- Government and Industry Forum on MCE
- Digital Engineering Strategy Initiative (coordinated through DASD)
- Airspace Industry Association: CONOPS for Industry/Government Collaborative Framework
- NDIA Working Group– Using Digital Engineering for Competitive Down Select

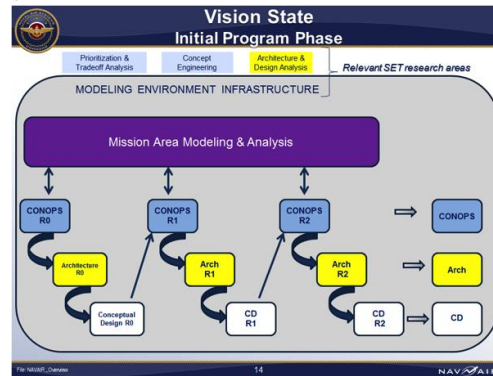


Backup RT-48/118/141 Perspectives

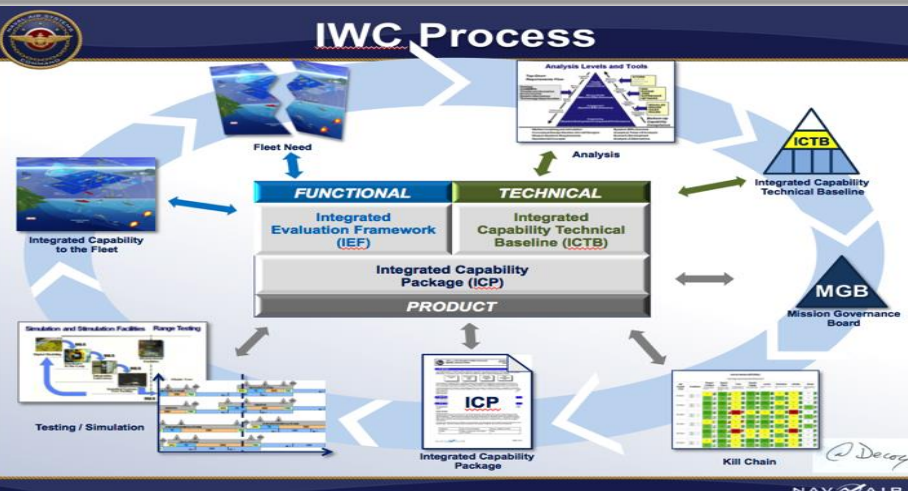
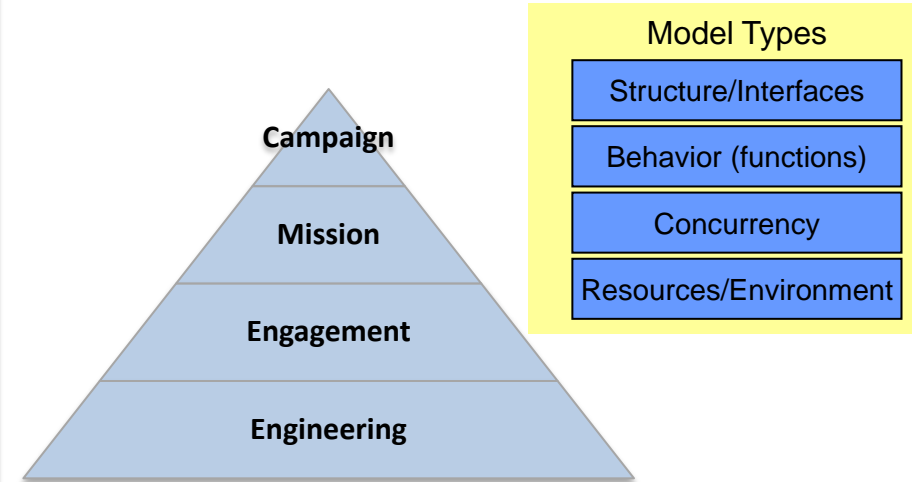
Four Tasks to Assess Technical Feasibility of “Doing Everything with Models” (Everything Digital)

1) Global scan and classification of holistic state-of-the-art MBSE

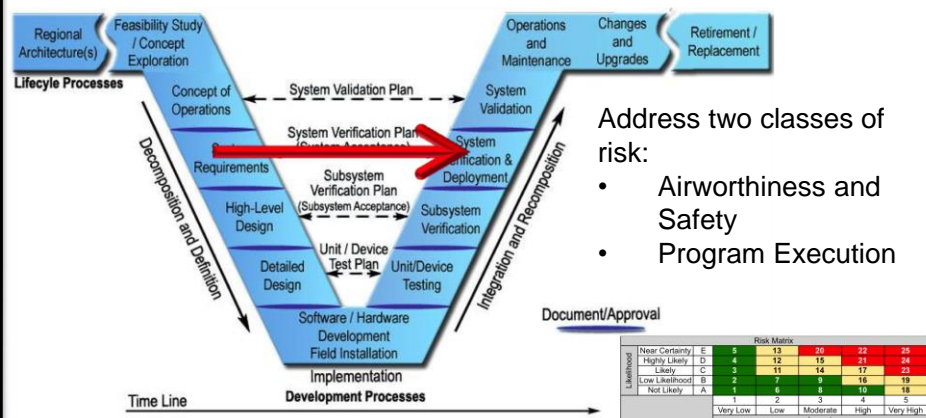
- Use discussion framework to survey government, industry and academia
- Quantify, link and trace realized modeling capabilities to Vision (task 3)



2) Develop Common Lexicon for Model Levels, Types, Uses, and Representations



3) Model the Vision of Everything Done with Models and Relate to “As Is” process



4) Fully integrate model-driven Risk Management and Decision Making

Task 1: Industry, Government and Academia Visits and Discussions

- We had open-ended discussions
 - Tell us about the most advanced and holistic approach to model-centric engineering you use or seen used**
- Did not single out specific companies
- Spectrum of information was very broad
- There really is no good way to make a comparison
- We have a report that summarizes the aggregate of what we heard

- Over 30 discussions and 21 onsite with Industry, Government and Academia, with follow-ups – our summary is not exhaustive
- Developed common lexicon of over 700 terms for model levels, types, uses, and representations, with many contributors
- Models are becoming more **dynamic and integrated across domains**, as opposed to static and isolated, enabled by HPC, **semantic precision**, and **visual analytics**
- Several strategies have been developed and applied for **quantification of model confidence**, enabled by HPC
- Answer to Sponsor: It is technically feasible to radically transform systems engineering at NAVAIR through MCSE; however, the evidence does not show conclusively that it will produce a 25% reduction in acquisition cycle time.

- We wish to acknowledge the great support of the NAVAIR sponsors and stakeholders, including stakeholders from other industry partners that have been very helpful and open about the challenges and opportunities of this promising approach to transform systems engineering.
- We want to specifically thank Dave Cohen who established the vision for this project, and our NAVAIR team, Jaime Guerrero, Gary Strauss, Brandi Gertsner, David Meiser and Ron Carlson, who has worked closely on a weekly basis in helping to collaboratively research this effort. We thank Howard Owens and Dennis Reed who have joined us in some of the organizational visits. We also thank Larry Smith, Ernest (Turk) Tavares, Eric (Tre´) Johnsen, who worked Phase I & II with us, but have left the project.
- We have had over 40 discussions with organizations from Industry, Government, and Academia, and we want to thank all of those stakeholders (over 200 people), including some from industry that will remain anonymous in recognition of our need to comply with proprietary and confidentiality agreements associated with Task 1.

- For more information contact:
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 - Stevens Institute of Technology

CDD	Capability Description Document	MCSE	Model-Centric System Engineering
CONOPS	Concept of Operations	MDAO	Multidisciplinary Design Analysis and Optimization
CDR	Critical Design Review	MDE	Model-Driven Engineering
CDRL	Contract Data Requirements List	NAVAIR	Naval Air Systems Command
CFD	Computational Fluid Dynamics	OV	Operational View
DARPA	Defense Advanced Research Project Agency	P&FQ	Performance and Flight Quality
DASD	Deputy Assistant Secretary of Defense	PDR	Preliminary Design Review
DoD	Department of Defense	PLM	Product Lifecycle Management
DoE	Design of Experiments	RT	Research Task
FEA	Finite Element Analysis	SLOC	Software Lines Of Code
HPC	High Performance Computing	SE	Systems Engineering
IMCE	Integrated Model-Centric Engineering	SET	Systems Engineering Transformation
IMCSE	Interactive Model-centric Systems Engineering	SERC	System Engineering Research Center
IoT	Internet of Things	SETR	Systems Engineering Technical Review
JCIDS	Joint Capabilities Integration and Development System	SFR	System Functional Review
KPP	Key Performance Parameter	SRR	System Requirements Review
MBSE	Model-based System Engineering	SoS	System of Systems
MBE	Model-Based Engineering	SOW	Statement of Work
MCE	Model-Centric Engineering	SSTT	Single Source of Technical Truth
		SV	System View
		UAV	Unmanned Air Vehicle
		V&V	Verification and Validation

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