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STEVENS
INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY

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

Model-Centric Engineering

Presented to:

Conference on Systems Engineering Research 2016

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Outline

- Context, Problem and Objectives
- Four Tasks
- Perspectives on findings
- Conclusions
- Acknowledgments
- Image credits

Problem Statement

- It takes too long to bring large-scale air vehicle systems from concept to operation
- NAVAIR is partially constrained by their own monolithic, serialized, paper-driven process

Study Objectives

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?

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

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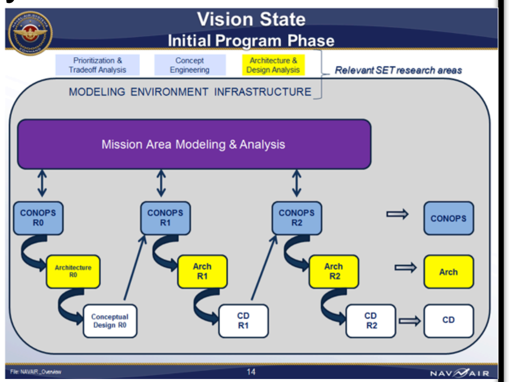
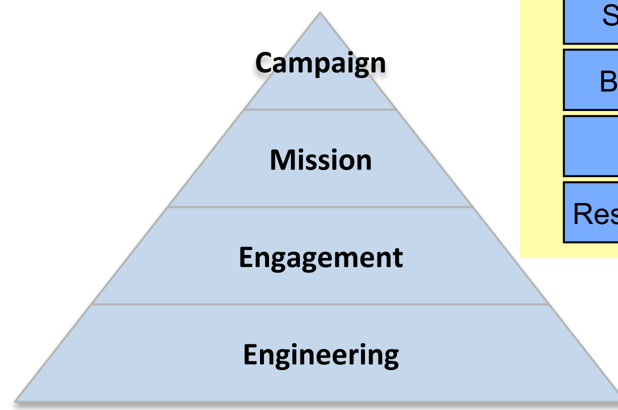
Four Tasks to Assess Technical Feasibility of *"Doing Everything with Models" (Everything Digital)*

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)

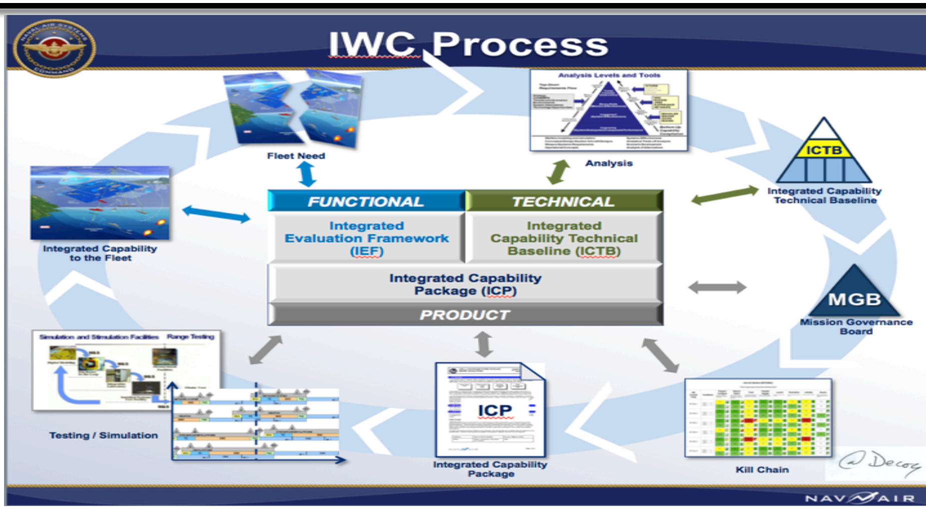


2) Develop Common Lexicon for Model Levels, Types, Uses, and Representations

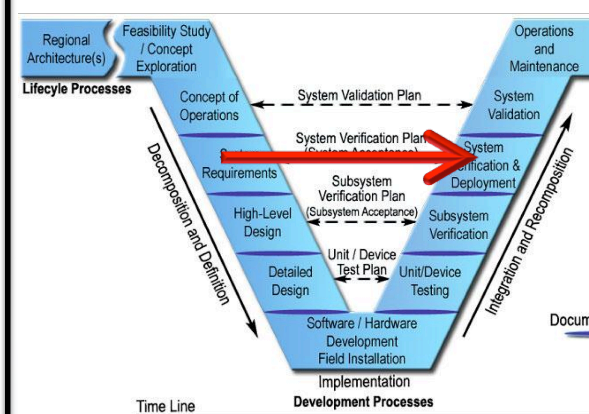


Model Types

- Structure/Interfaces
- Behavior (functions)
- Concurrency
- Resources/Environment

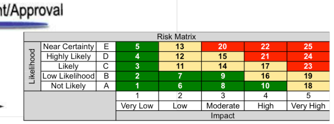


3) Model the Vision of Everything Done with Models and Relate to "As Is" process



Address two classes of risk:

- Airworthiness and Safety
- Program Execution



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

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

- Organizational discussed:
  - 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
- **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 have heard used too

Use Dynamic Models and Surrogates to Support Continuous "Virtual V&V"

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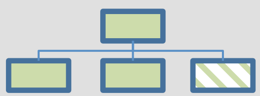
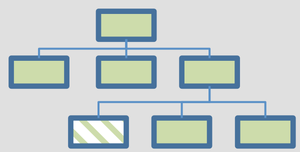
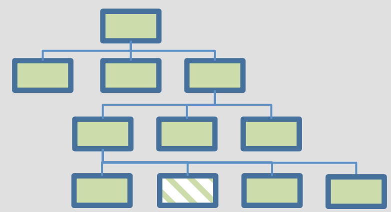
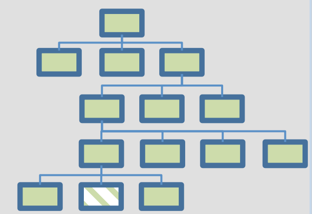
- Integration of computational capabilities, models, software, hardware, platforms, and humans-in-the-loop allows us to assess the system design in the face of changing mission needs

Phase:	SRR	SFR	PDR	CDR
Design/ Payload Maturity: (w/Models)	 High level need: Aircraft	 Mid level need: take off, land, fly	 Lower level need: Employ legacy weapons	 Lowest level need: employ advanced weapons; stealth, etc.
V&V Focus:	Operational level models	High level performance. (Aero, some P&FQ)	Macro-level integration, some system functionality, full P&FQ	Full integration and systems functionality

Surrogates, traditional materials, hardware, processes

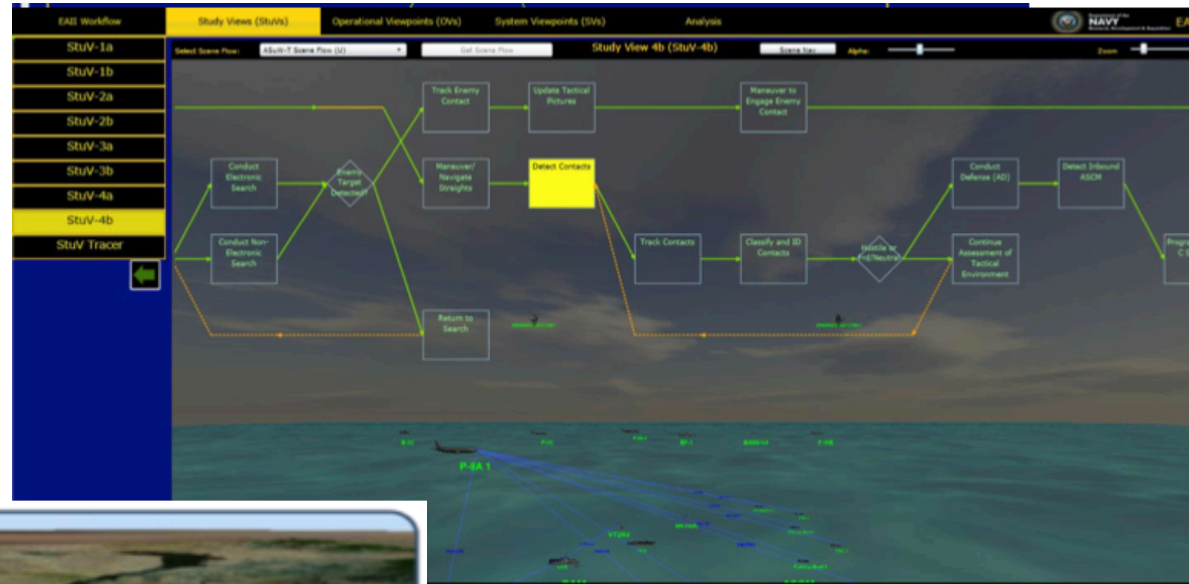
Base airframe with some advanced materials (composites) hardware (SIL assets)

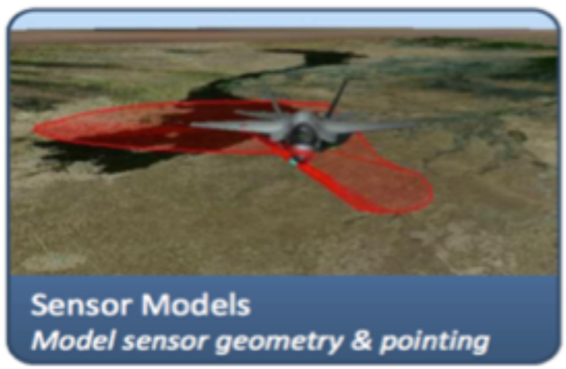
Final Config: advanced materials (composites/exotics) advanced hardware, final avionics

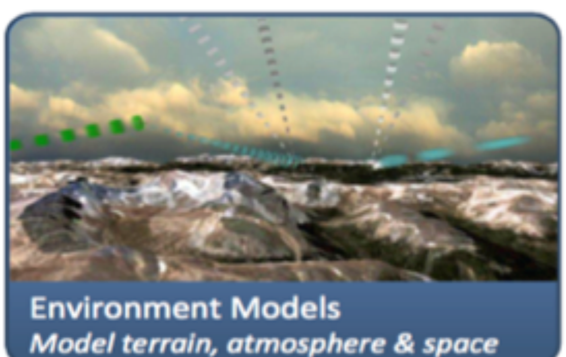
**Derived from Ernest S. "Turk" Tavares, Jr. and Larry Smith

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

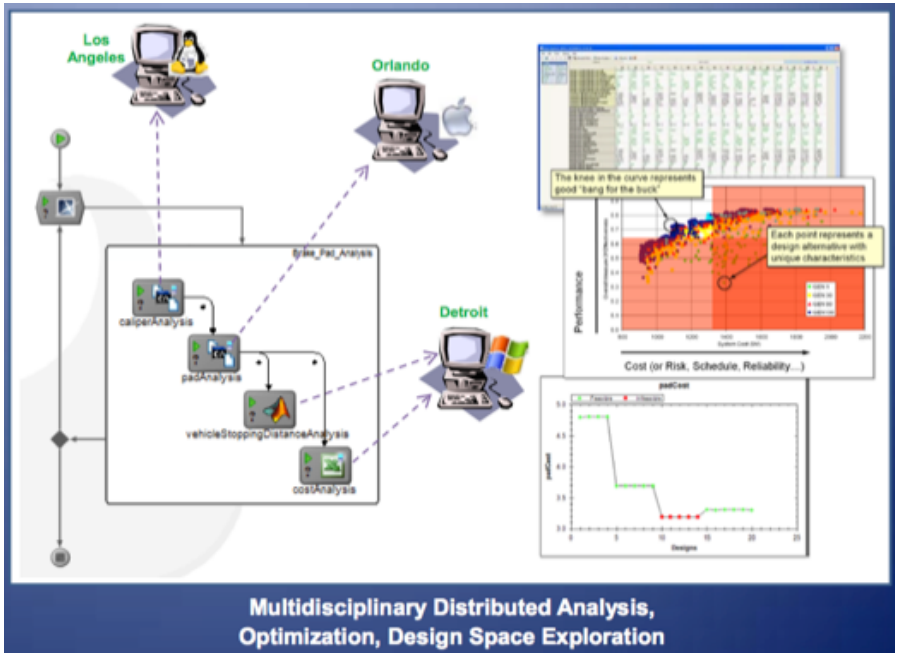






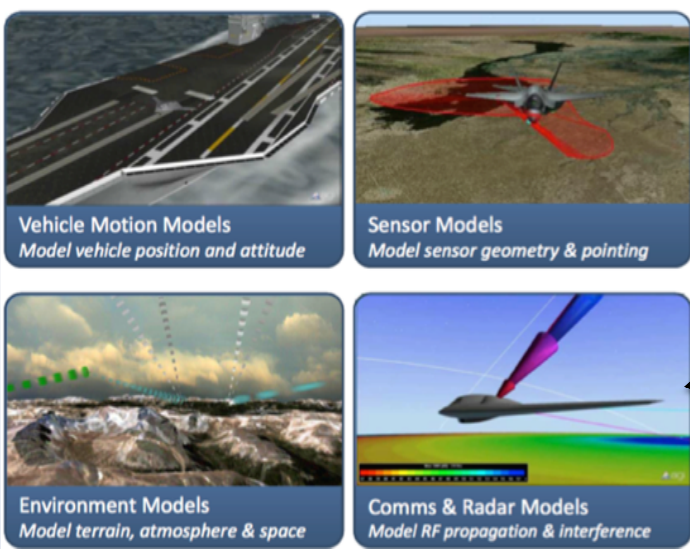
*Joint Capabilities Integration and Development System (JCIDS)

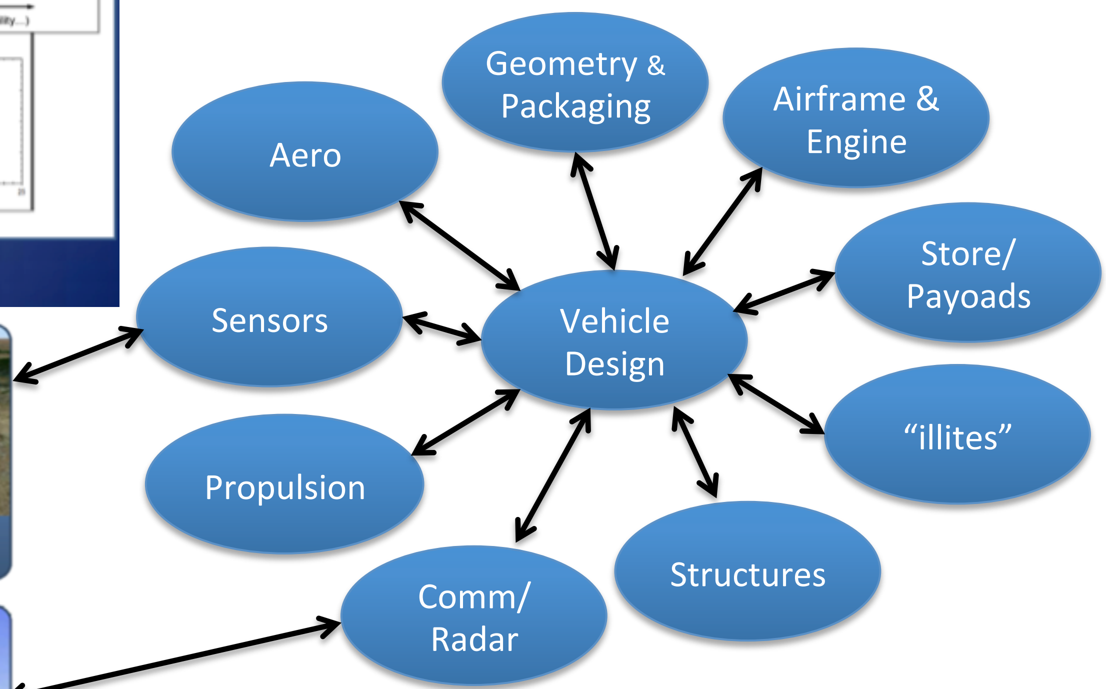
Multidisciplinary Design, Analysis and Optimization Supports Tradespace Analysis Across Disciplines



Multidisciplinary Distributed Analysis, Optimization, Design Space Exploration

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





Detailed Design from Associated Disciplines and Competencies

Cycle-time Reduction Indications
Change in Focus of MDAO

Design Method	Relative Time Spent				Iteration Duration		Number of Possible Iterations*
					Initial	Subsequent	
Legacy	8%	32%	50%	10%	6 wks	4 wks	2.5
MDO	26%	18%	8%	48%	14 wks	1.5 hrs	>1,000**

* assuming a 12 week period
** after process set-up has been completed

Specification (e.g. determining tasks, staffing, and what information is used and produced)

Execution (e.g. generating options and running analyses)

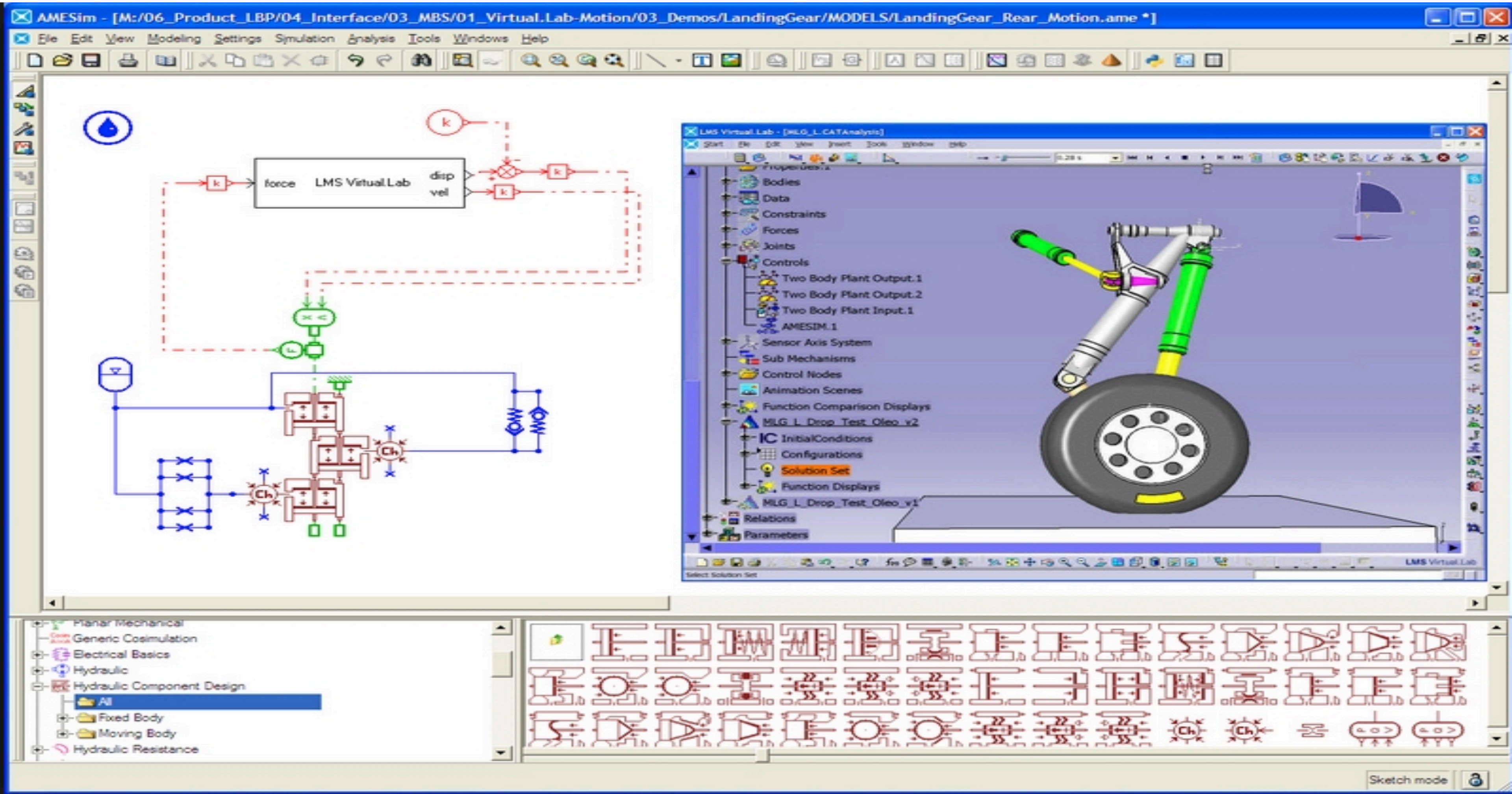
Management (e.g. representing, documenting and coordinating existing information)

Reasoning (e.g. interpreting results, choosing options)

Forest Flager and John Haymaker, A Comparison of Multidisciplinary Design, Analysis and Optimization Processes in the Building Construction and Aerospace, Stanford, December 2009

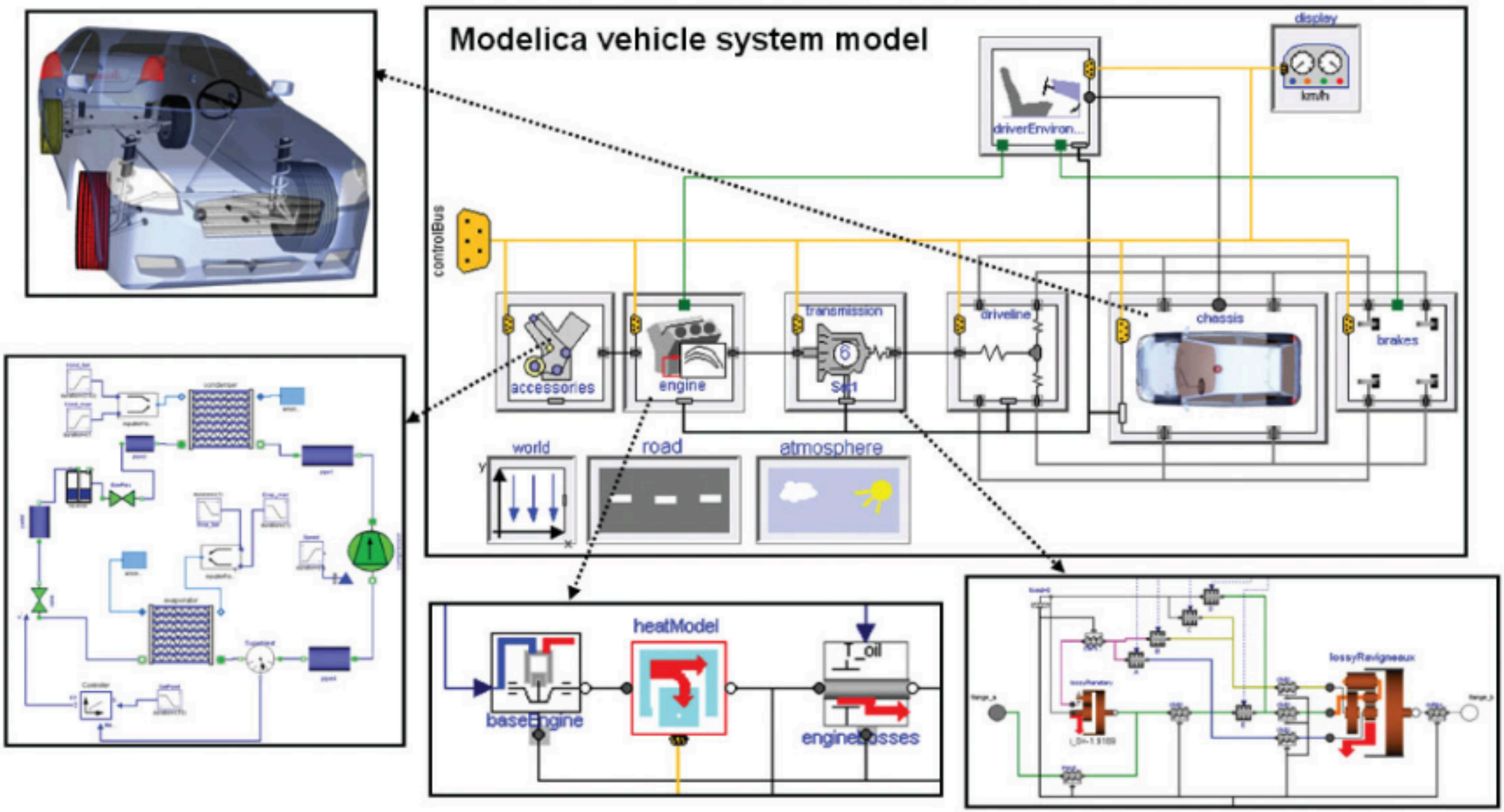
1D, 2D & 3D Models have Simulation and Analysis Capabilities

- Focused primarily on physics-based design with increasing support for cross-domain analysis



Platform-based Approaches with Virtual Integration Help Automakers Deliver Vehicle Faster

- Standards such as Modelica and Functional Mockup Interface enable cross-domain co-simulation (primarily physics-based)



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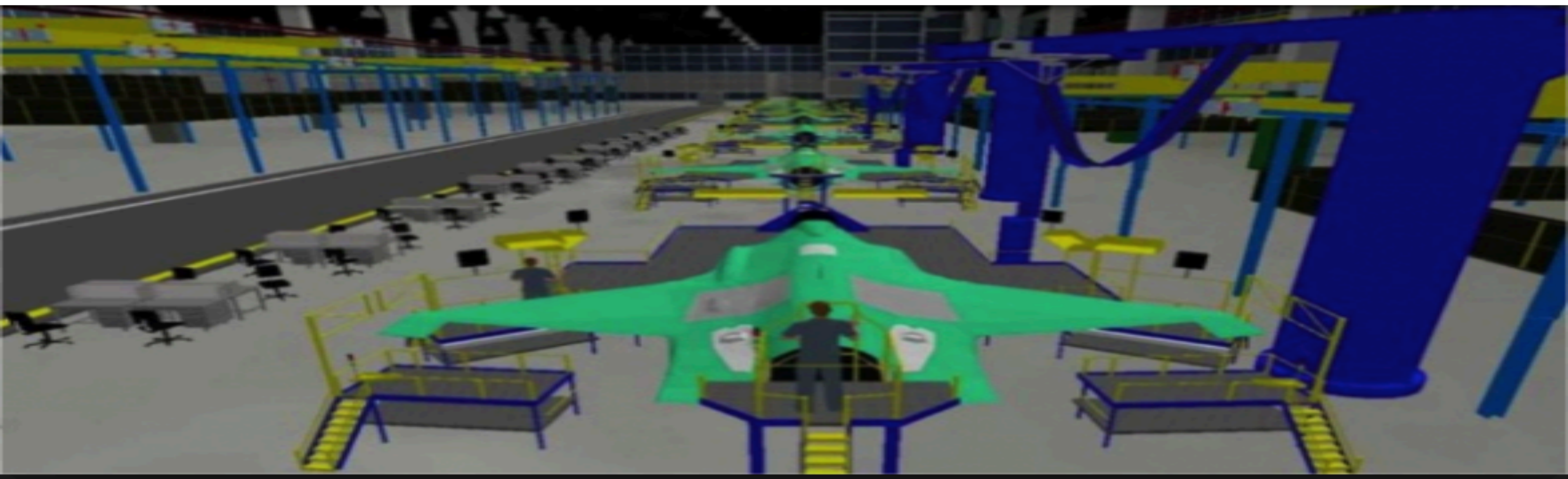
Organizations are Modeling and Simulating Manufacturing Before Tooling

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



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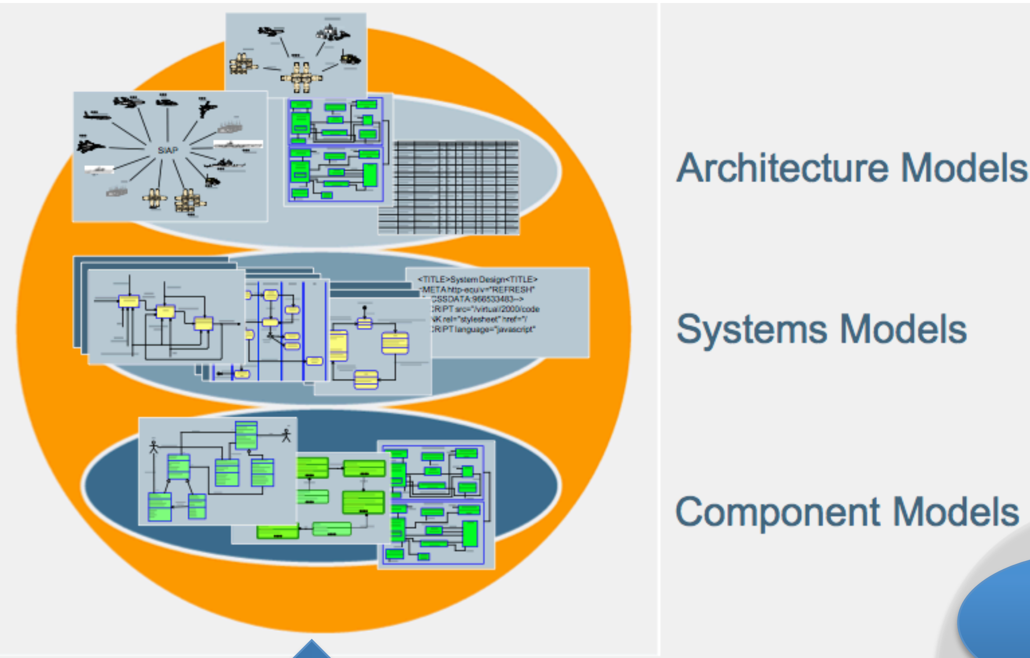
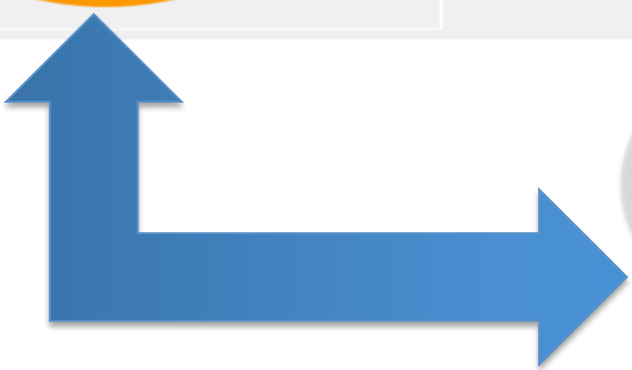
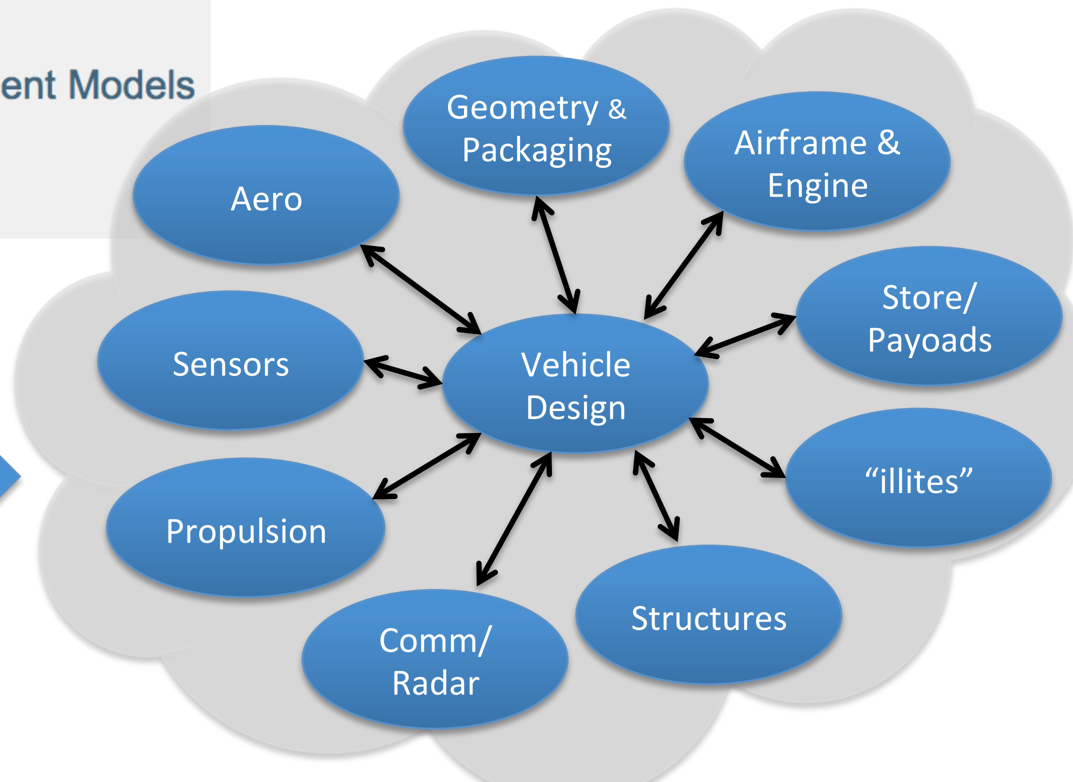
Need to Better Integrate Multiple Levels of System Models with Discipline-Specific Designs



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





Iterative Process

Other Enablers for the "End State" Envisioned by NAVAIR

- A tool agnostic approach to share semantically rich data across domains/disciplines…
- Computer augmentation
  - —Digital assistance will understand what we are trying to model through advances in machine learning and integrated visualization
  - —Operate as knowledge librarian helping us to model some aspects of the problem or solution at an accelerating pace
- Explosion of interactive visualizations to understand data and information derived from a "sea" of models with HPC computing capabilities
- Emerging impacts of **Social Computing** provides mass communication, enabling **dynamic** and **continuous orchestration of work** and information for **real-time decision-making**

Scope of Data Collection for Task 1 (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 Tech 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			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-Discpline/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 (thru 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	x	x

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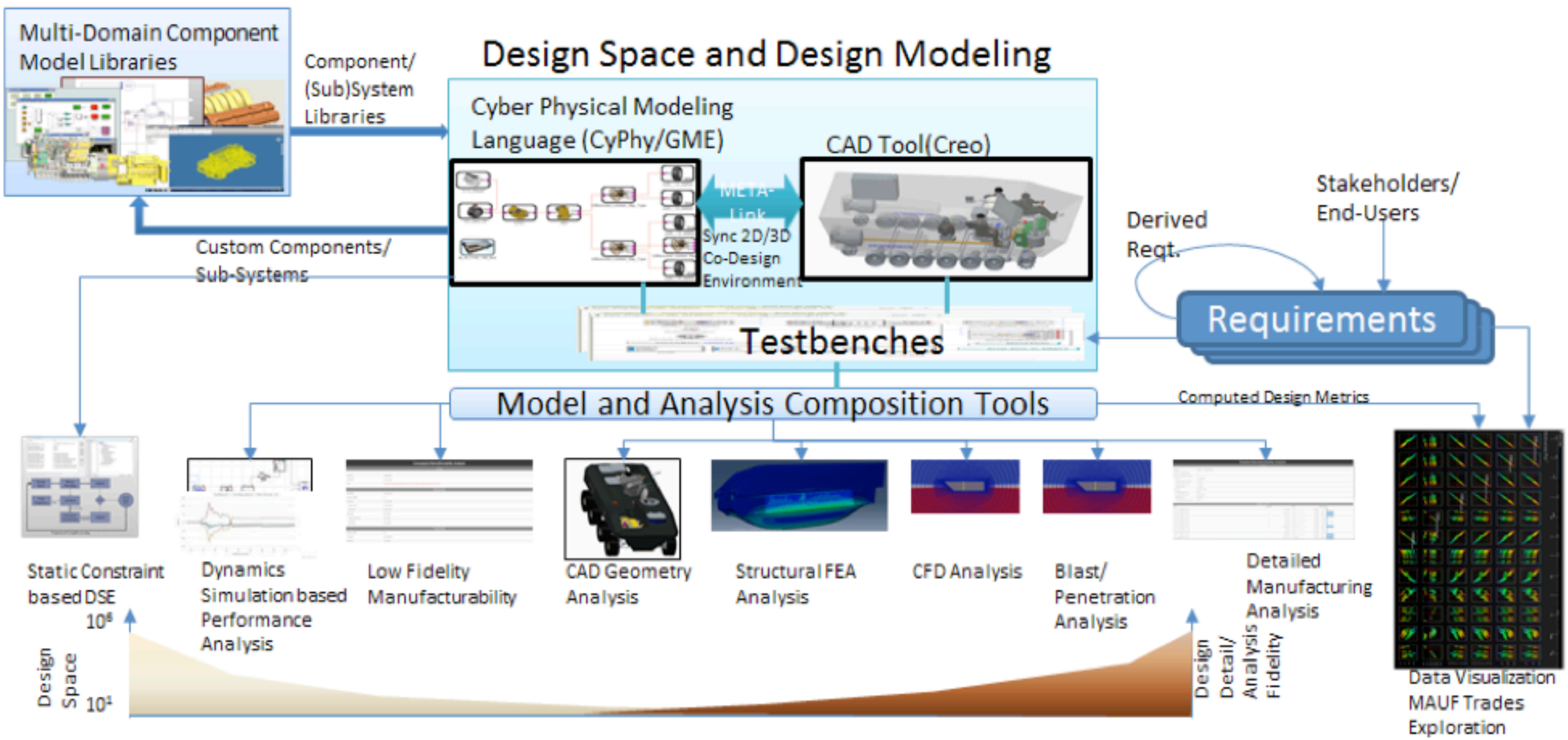
DARPA META Concept – MCE Instantiation

- More continuous and iterative using successive refinement of tradespace alternatives, with considerations for manufacturability leading to "executable requirements" with continuous test at increasing levels of fidelity



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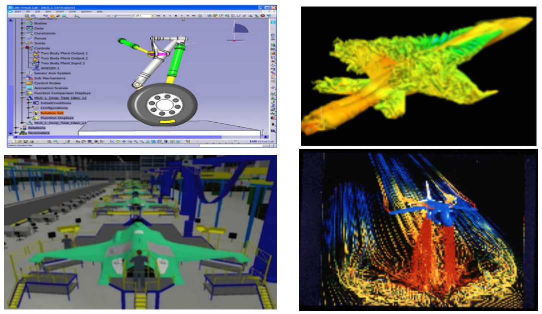
Conceptual Reference Model: Integrated Environment for Iterative Tradespace Analysis of Problem and Design Space

Appropriate Views for Stakeholders



Rich Modeling Interfaces

"Web" Interface integrated with Rich Visualizations

Multidiscipline Design, Analysis and Optimization (MDAO)	Computer Augmentation & Training	Continuous Workflow Orchestration	DocGen

Secure Plugin

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

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Are we nearing a tipping point driven by the Industrial Internet?

- Mission-level simulations are being integrated with system simulation, digital assets & products providing a new world of services for customer, developer, and operational interactions

Leaders are Embracing Change and Adapting To Use Digital Strategies Faster Than Others

- Enabling digital technologies are changing how companies are doing business using models-centric engineering
- They use model-centric environments for customer engagements, but also for design engineering analysis and review sessions

Holistic Model-centric Engineering can Enable, But will Require New Types of Coordination

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

Conclusions

- 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.

Acknowledgment

- 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, 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 30 discussions with organizations from Industry, Government, and Academia, and we want to thank all of those stakeholders (over 180 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.

Thank You

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Acronyms

CONOPS	Concept of Operations
CDR	Critical Design Review
DARPA	Defense Advanced Research Project Agency
DoD	Department of Defense
HPC	High Performance Computing
IMCE	Integrated Model-Centric Engineering
IMCSE	Interactive Model-centric Systems Engineering
IoT	Internet of Things
MBSE	Model-based System Engineering
MBE	Model-Based Engineering
MCE	Model-Centric Engineering
MCSE	Model-Centric System Engineering
MDE	Model-Driven Engineering
NAVAIR	Naval Air Systems Command
OV	Operational View
P&FQ	Performance and Flight Quality
PDR	Preliminary Design Review
PLM	Product Lifecycle Management
SLOC	Software Lines Of Code
SE	Systems Engineering
SERC	System Engineering Research Center
SETR	Systems Engineering Technical Review
SFR	System Functional Review
SRR	System Requirements Review
SoS	System of Systems
SV	System View
V&V	Verification and Validation

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