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

Systems Engineering Transformation through Model Centric Engineering

Past-Why, Present-What, and Future-How

Presented by:

Dr. Mark R. Blackburn (PI)

With Contributing Sponsors (NAVAIR, ARDEC, DASD(SE))

With Contributing Researchers (RT-48, 118, 141, 157, 168, 170, 176)

July 31, 2017

Opening Thoughts and Perspectives

Introductions after Opening Thoughts

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SE Transformation

- “You have a choice: you can either create your own future, or you can become the victim of a future that someone else creates for you. By seizing the transformation opportunities, you are seizing the opportunity to create your own future.”
- VADM Arthur K. Cebrowski

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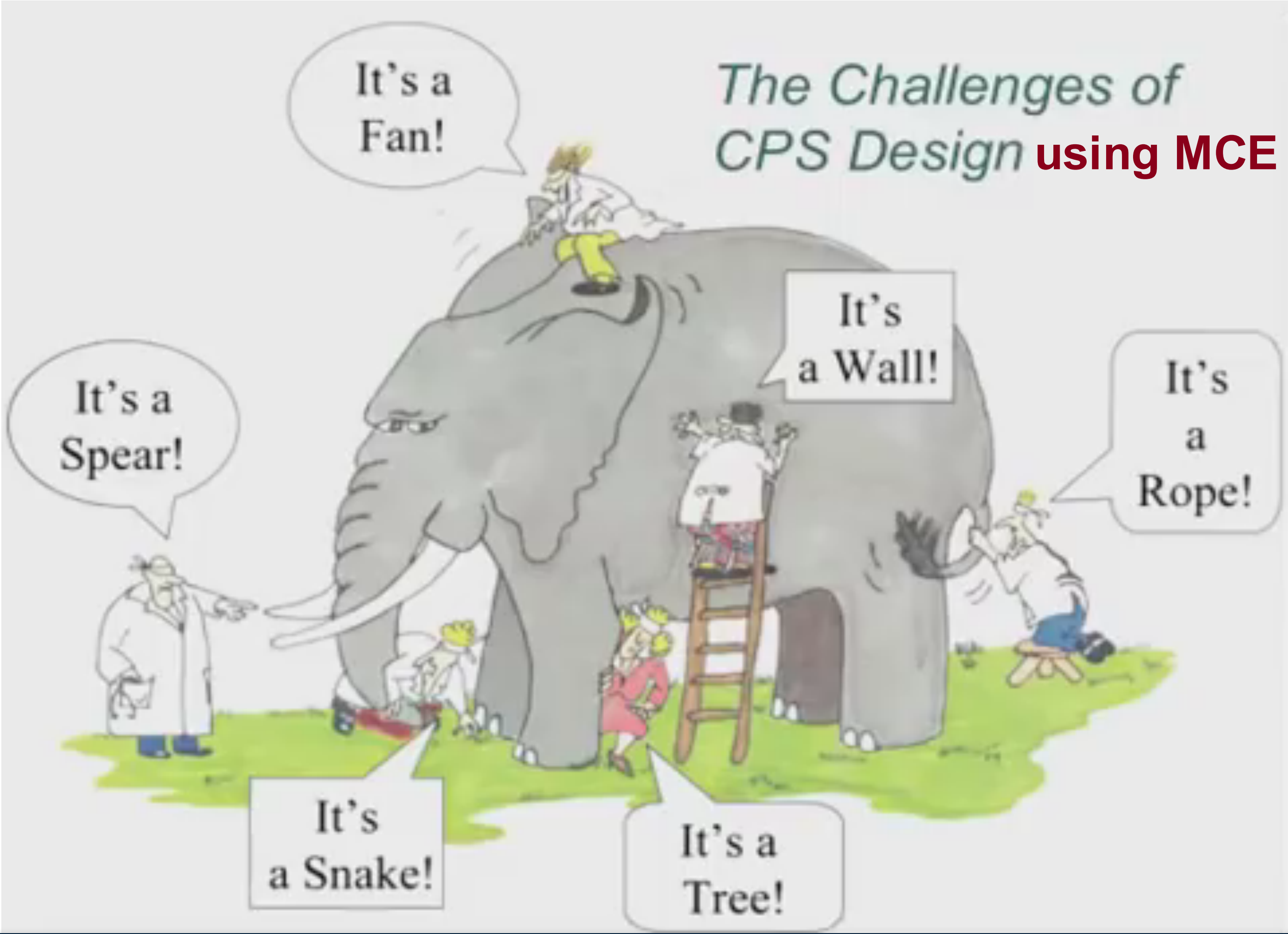
Why this Session?
It can be difficult to understand Big Picture!



Multi-Mission, Multi-physics, Multi-Discipline, Multi-vendor, etc.

Professor Ed Lee, Cyber-Physical Systems (CPS) - A Rehash or A New Intellectual Challenge?

Objectives

- Dr. Dinesh Verma
  - Executive Director for Systems Engineering Research Center
- "Provide Big Picture – Mental Model"
  - Use historical context of research investigating "***the most advance and holistic approaches and technologies supporting state-of-the-art in Model Centric Engineering***" aka Digital Engineering
  - Summarize expanse of research thrusts
  - Discuss alignment with sponsors' evolving needs, transformation, and goals of digital engineering initiative
  - Provide awareness of collaborations with other initiatives, industry, government, academia & open communities
- Format: open discussion

Notation Key – Upper Left on Some Slides

Deep Dive

Example/Definition

Discussion

Research Tasks and Collaborator Network

RT-48
- Mark Blackburn (PI), Stevens
- Rob Cloutier (Co-PI) - Stevens
- Eirik Hole - Stevens
- Gary Witus – Wayne State

RT-118
- Mark Blackburn (PI), Stevens
- Rob Cloutier - Stevens
- Eirik Hole - Stevens
- Gary Witus – Wayne State

RT-141
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Gary Witus – Wayne State

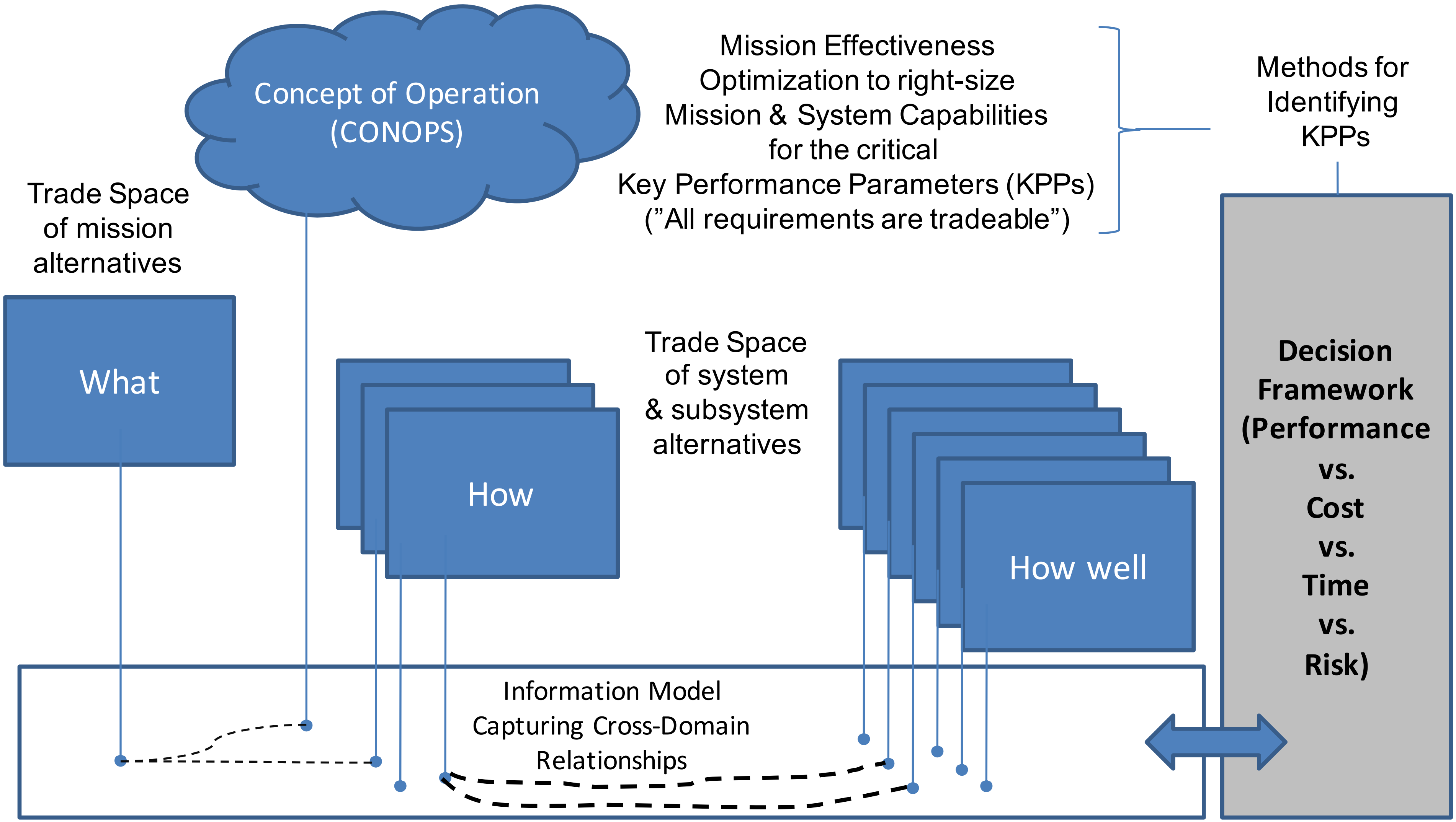
RT-157
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Roger Blake - Stevens
- Mark Austin – Univ. Maryland
- Leonard Petnga – Univ. of Maryland

RT-170
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Deva Henry - Stevens
- Paul Grogan - Stevens
- Steven Hoffenson - Stevens
- Mark Austin – Univ. of Maryland
- Leonard Petnga – Univ. of Maryland
- Russell Peak – Georgia Tech
- Stephen Edwards – Georgia Tech

RT-168
- Mark Blackburn (PI), Stevens
- Dinesh Verma (Co-PI) - Stevens
- Roger Blake - Stevens
- Mary Bone – Stevens
- Brian Chell - Stevens
- Andrew Dawson - Stevens
- John Dzielski, Stevens
- Paul Grogan - Stevens
- Deva Henry - Stevens
- Steven Hoffenson - Stevens
- Eirik Hole - Stevens
- Roger Jones – Stevens
- Benjamine Kruse - Stevens
- Jeff McDonald - Stevens
- Kishore Pochiraju – Stevens
- Chris Snyder - Stevens
- Gregg Vesonder - Stevens
- Lu Xiao - Stevens
- Robin Dillon-Merrill – Georgetown Univ.
- Todd Richmond – Univ. of Southern California
- Edgar Evangelista – Univ. of Southern California

RT-176
- Kristin Giammaro (PI) – NPS
- Ron Carlson (Co-PI), NPS
- Mark Blackburn (Co-PI), Stevens
- Mikhail Auguston, NPS
- Rama Gehris, NPS
- Marianna Jones, NPS
- Chris Wolfgeher, NPS
- Gary Parker, NPS

Perspectives on Characterizing Challenges of Research Space



Reasoning about completeness and consistency of information across domains

Key Performance Parameter (KPP)

- Performance attributes of a system considered critical to the development of an effective military capability.
- Example:
  - —Predator shall have an endurance of 40 hours
  - —Possibly with other constraint:
    - o And carry 340kg of multiple payloads including video cameras, laser designators, communications
  - —Meet some availability and cost objectives

http://www.airforce-technology.com/features/featurethe-top-10-longest-range-unmanned-aerial-vehicles-uavs/featurethe-top-10-longest-range-unmanned-aerial-vehicles-uavs-5.html

Example: Cross Domain Relationships Needed for System Trades, Analysis and Design

- Scenario Refueling UAV
- Valve – Cross-domain **Object**
- Mechanical **Domain**
  - Valve connects to Pipe
- Electrical **Domain**
  - Switch opens/closes Value
  - Maybe software
- Operator **Domain**
  - Pilot remotely send message to control value
- Communication **Domain**
  - Message sent through network
- Fire control **Domain**
  - Independent detection to shut off valve
- Safety **Domain**

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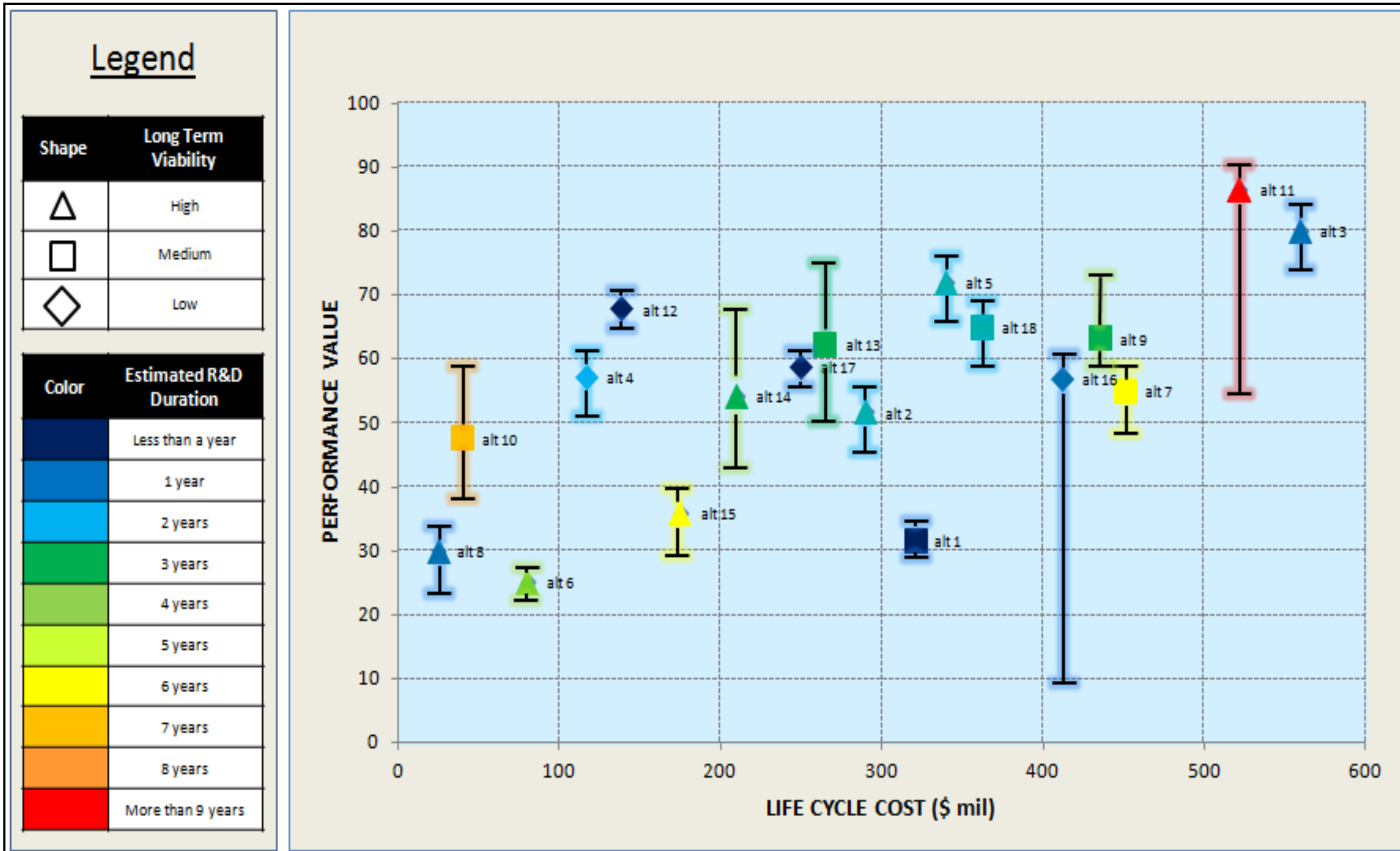
Formalizing, Automating & Visualization for Decision Process: Dr. Matthew Cilli (ARDEC)

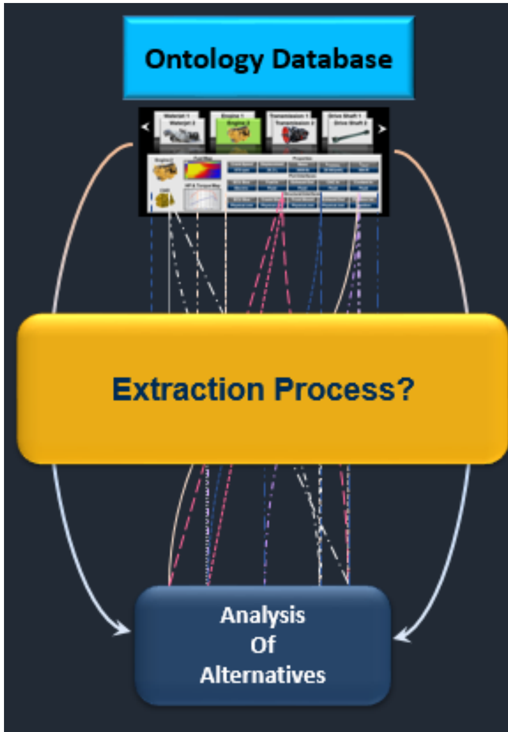


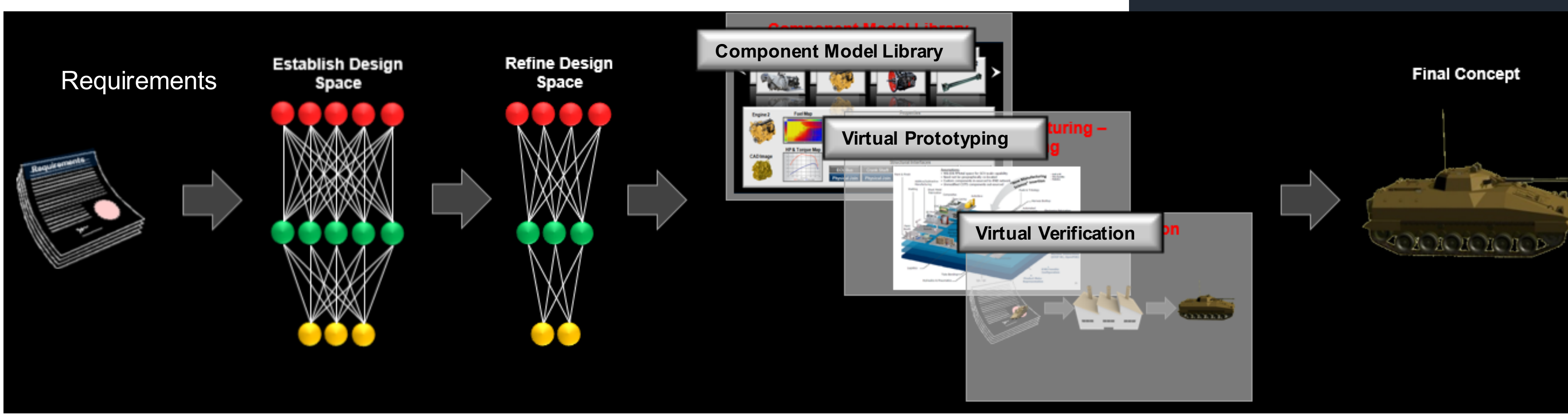
Cilli, M. Seeking Improved Defense Product Development Success Rates Through Innovations to Trade-Off Analysis Methods, Dissertation, Stevens Institute of Technology, Nov. 2015.

Trade Space Automation using Semantic Web Technologies: Dr. George Ball (Raytheon)

- Automating process of extracting the functional decomposition and relationships of a system from a domain ontology, and importing that information to a design space using semantic technologies

- Virtually design, manufacture, and verify complex defense systems





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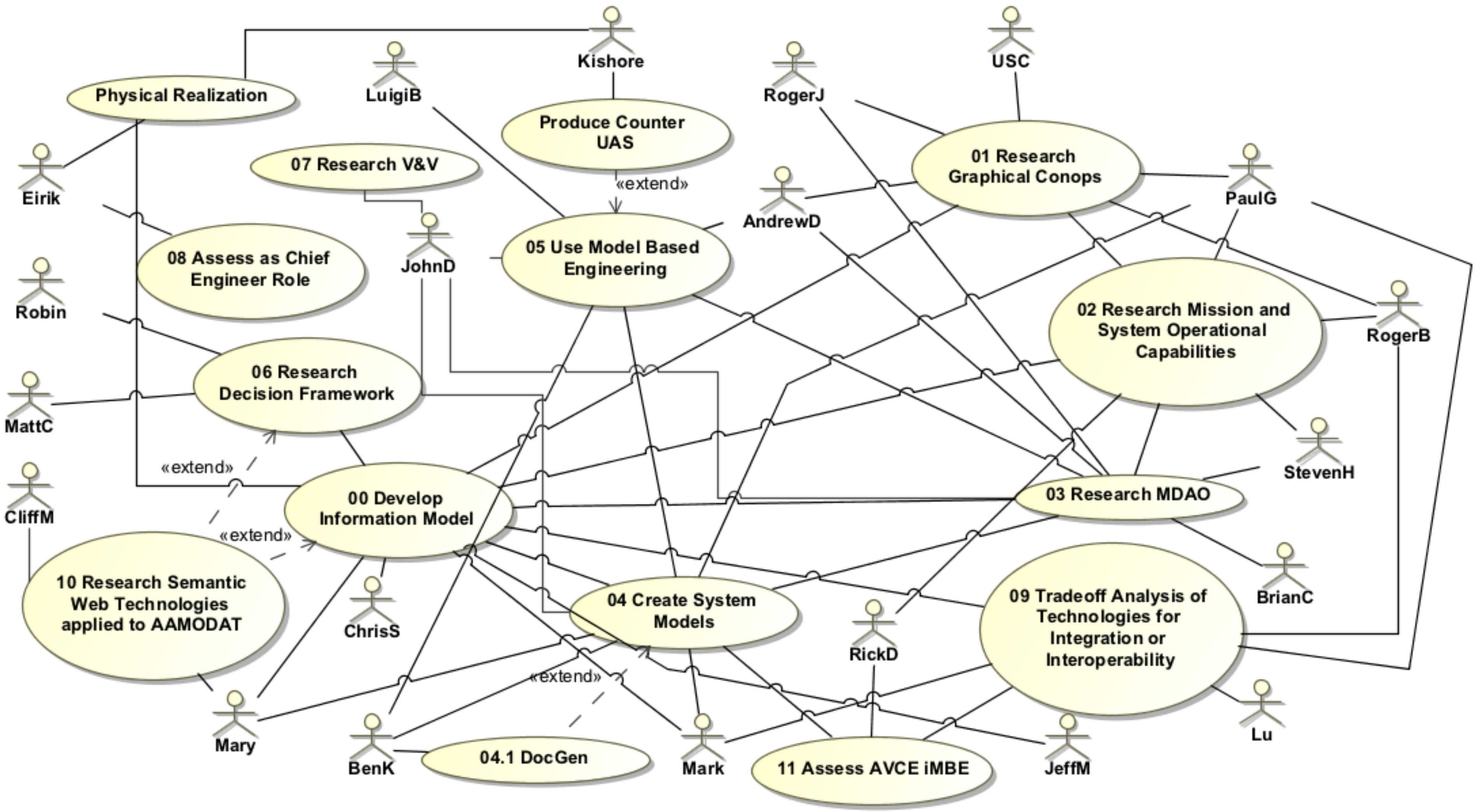
Agenda

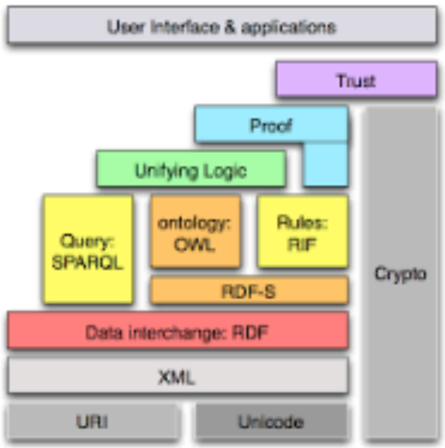
	July 31, 2017 @ Stevens	
8:15	Introductions – Why Here and Goals for the Day	SERC/Stevens
8:30	Past - Why and Present - What	Dr. Mark Blackburn
10:15	Break	
10:30	Future - How - Digital Engineering Transformations (Deep Dive a Few Research Topics)	Dr. Mark Blackburn
11:30	Discussion	
12:00 (Noon)	Lunch	
12:30	Integrated Systems Engineering Decision Management (ISEDM) Process Enabled by Digital Engineering Technologies	Dr. Matthew Cilli
13:00	Semantic Technologies and Ontologies Research to enable Trade Space Analytics for Engineered Resilient Systems	Dr. George Ball
13:30	Break	
13:45	Breakout Sessions • Breakout 1: Risk for Digital Engineering Transformation • Breakout 2: Priorities for Digital Engineering Transformation	Dr. Mary Bone Dr. Peter Korfiatis
15:15	Break out Briefs	ARDEC
15:45	Forward Planning and Actions	All
16:00	Adjourn	

RT-168 Use Case Perspective and Team



Deep Dive Topics

Semantic Web Technologies



Enforces **Modeling Methods**

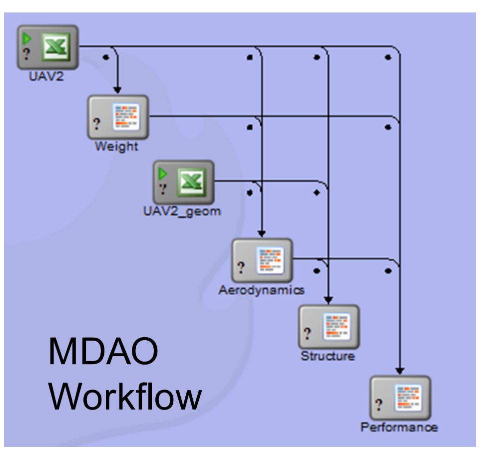
Underlying technologies for reasoning about completeness and consistency **Across Domains** in modeling tool agnostic way

Modeling Methodologies

Guides proper usage to ensure **Model Integrity** (trust in model results) for decision making

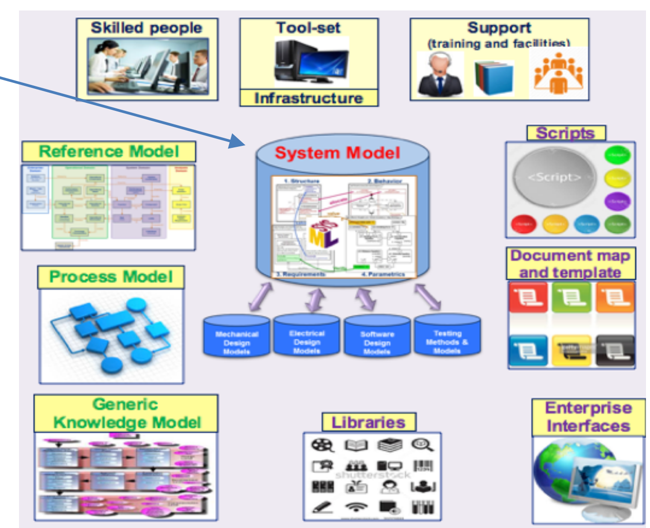
Digital System Model:
Single Source of Truth
(authoritative source of truth)

Multidisciplinary Design, Analysis and Optimization MDAO



Provides optimization analysis **Across Domains** to support KPP and alternatives trades at mission, system, & subsystem levels

Integrated Modeling Environment



Why?
Historical perspectives –
How we got here and why

How Do We Know it Works?

Image credit: http://theaviationist.com/2015/01/16/f-35-weapons-suite/

Feasibility Study Objectives – Circa 2013

NAVAIR 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)?

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

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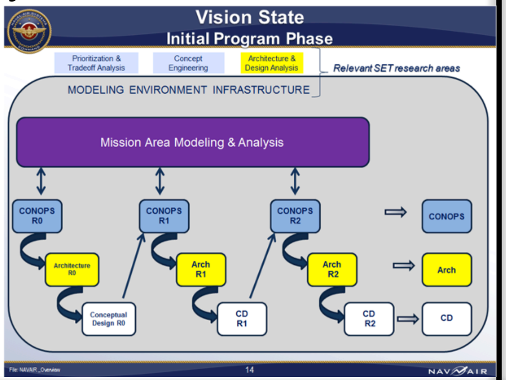
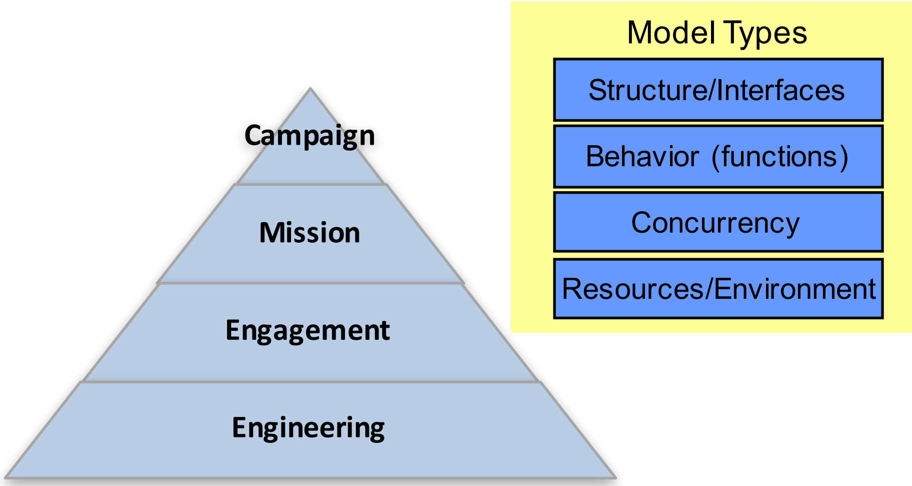
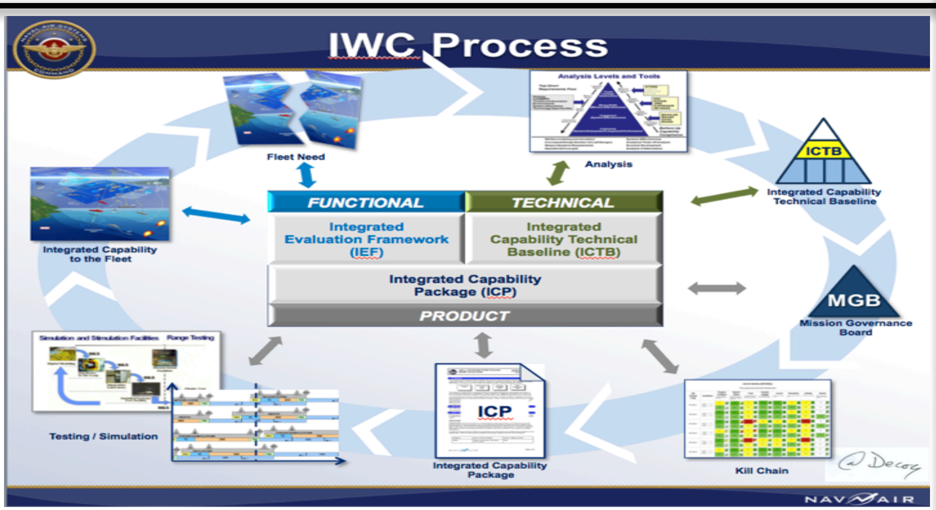
1) Global scan and classification of holistic state-of-the-art MBSE

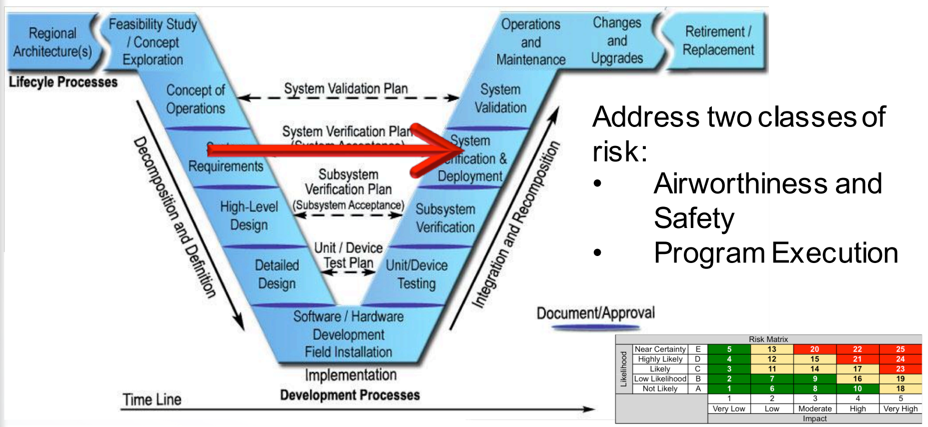
- Use discussion framework to survey government, industry and academia
- Quantify, link and trace realized modeling capabilities to Vision (task 3)



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







Address two classes of risk:

- Airworthiness and Safety
- Program Execution

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

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

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- 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 now also use the words **Digital Engineering**

Scope of Data Collection for Task 1 Traced to Evidence (not exhaustive)

	Instances where discussed (not exhaustive)												Characteristics						From Kickoff Briefing					
Discussion Topics (not exhaustive)	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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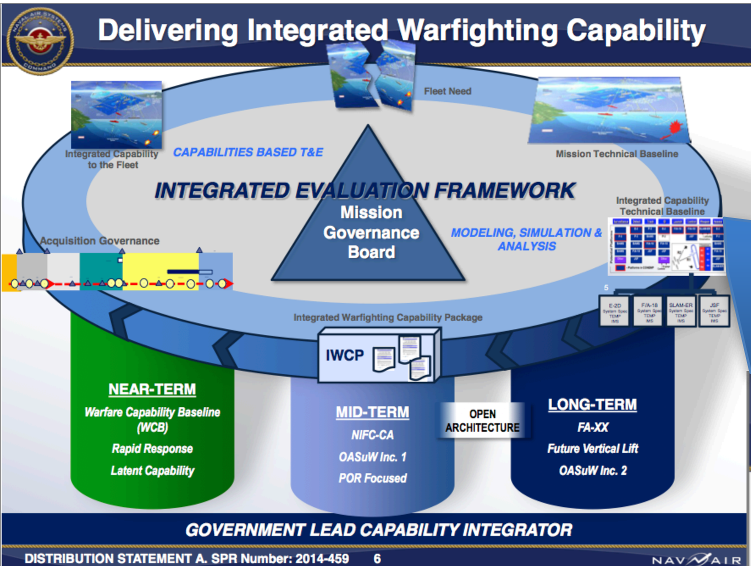
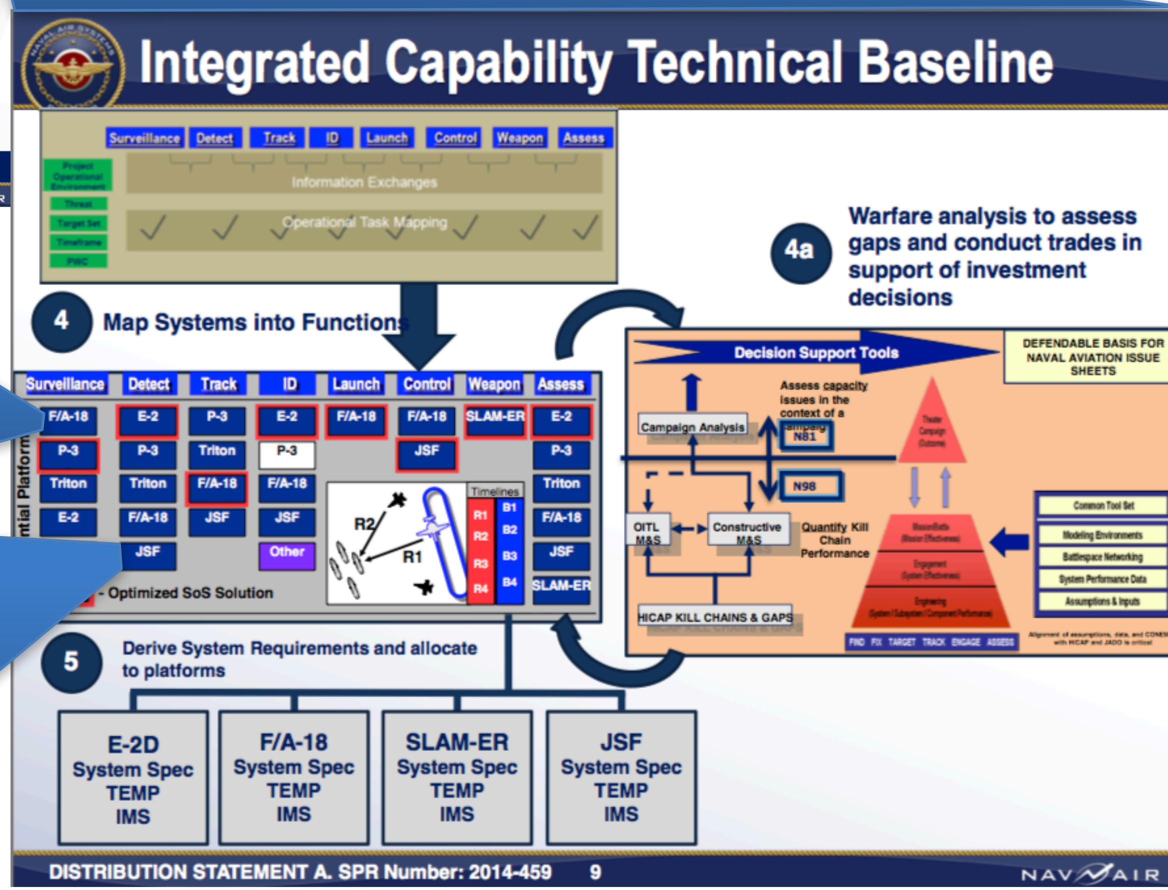
Cross Domain Model Integration

Continuous refinement of models through cross-domain & multidisciplinary analysis supporting continuous virtual V&V from CONOPS to manufacturing (and training systems)

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

Tracing Mission Effectiveness Analysis to System Capabilities of Evolving Platforms





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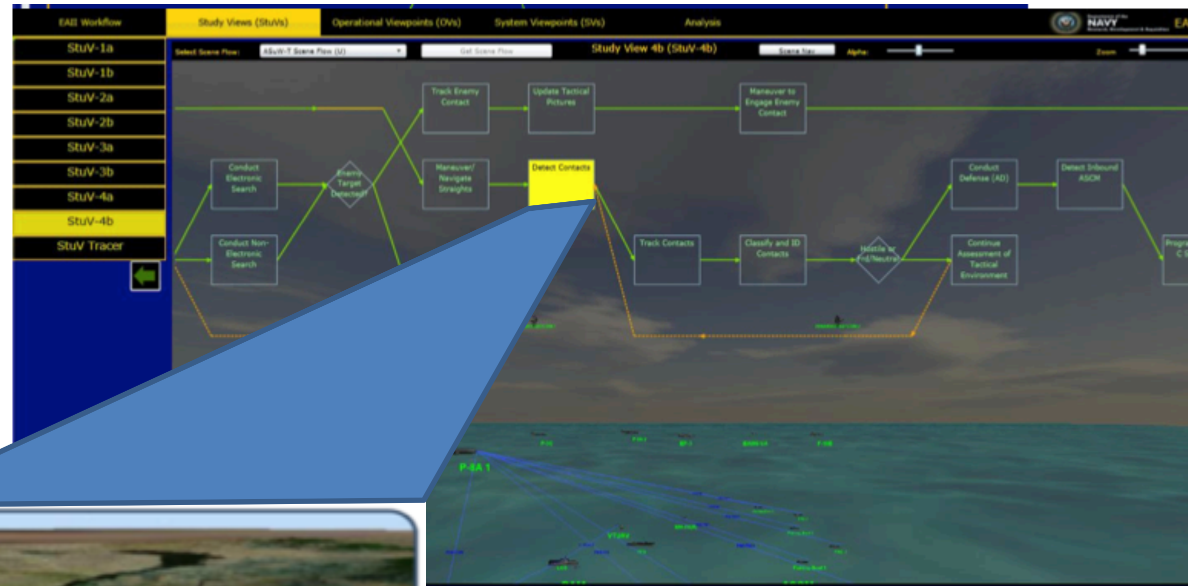
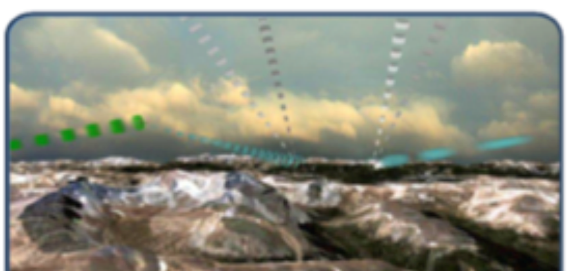
Dynamic CONOPS Integrated with Mission Simulations to Better Understand Needed System Capabilities

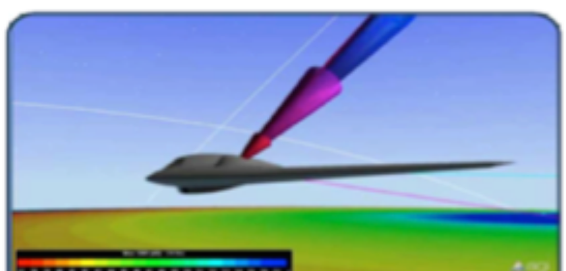
Simulated-based
Study Views Method
Structures and Formalizes Mission and Operational Analysis




Vehicle Motion Models
Model vehicle position and attitude

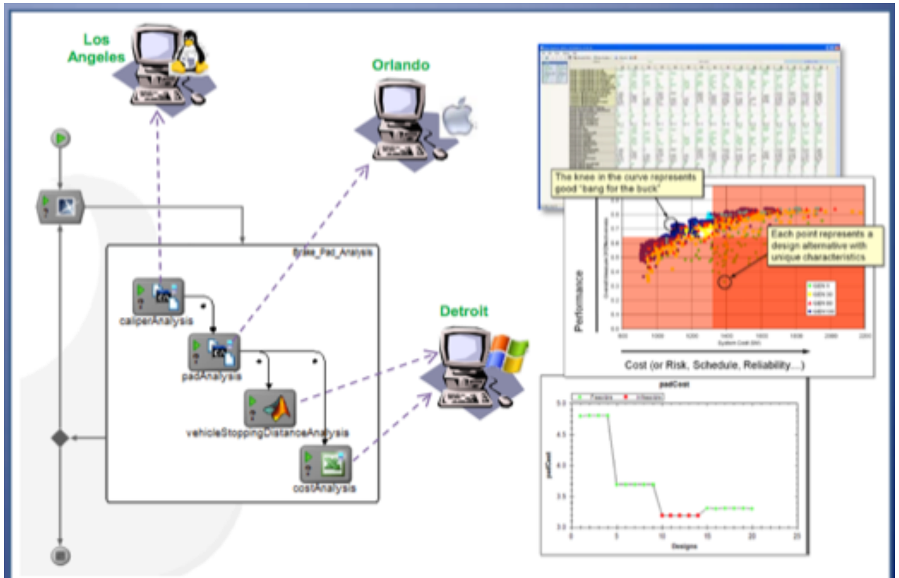

Sensor Models
Model sensor geometry & pointing


Environment Models
Model terrain, atmosphere & space


Comms & Radar Models
Model RF propagation & interference

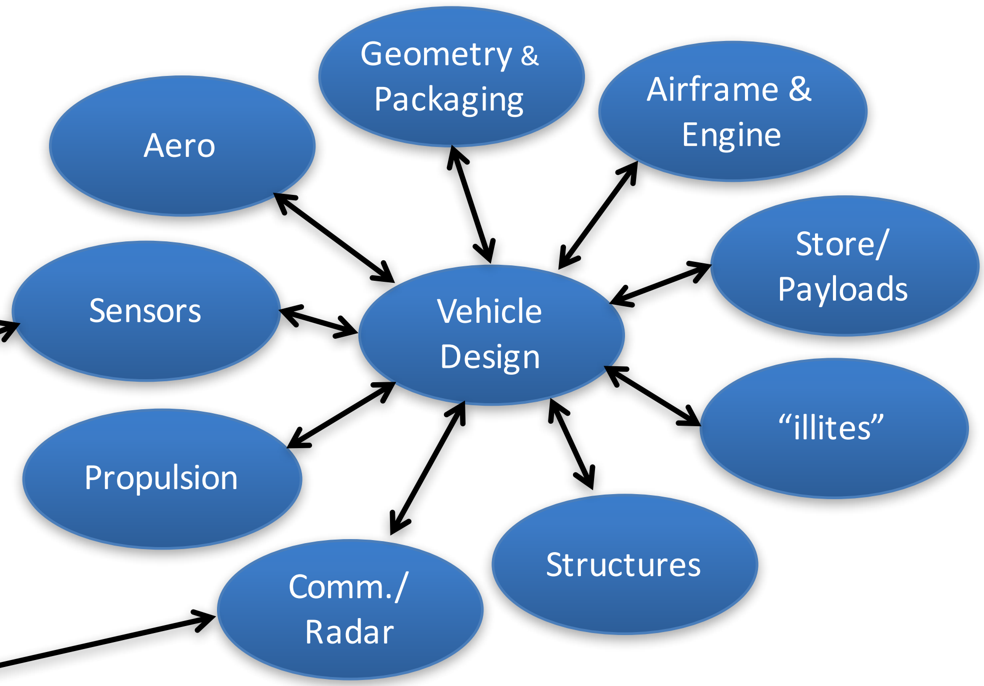
Integrates with libraries of system and environmental models (e.g., AGI System Tool Kit)

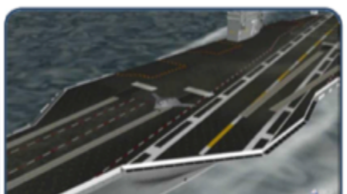
Multidisciplinary Design, Analysis and Optimization Supports Tradespace Analysis Across Disciplines



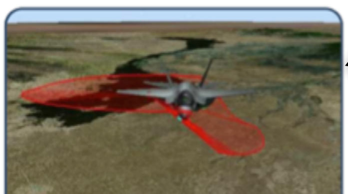
Multidisciplinary Distributed Analysis, Optimization, Design Space Exploration

MDAO Implements Workflows with Solvers to Evaluate Trades Systematically Driven by Design of Experiments

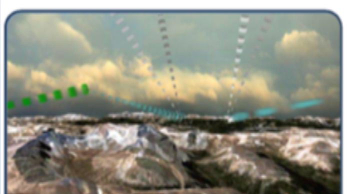




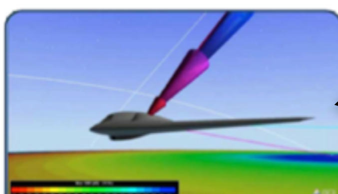
Vehicle Motion Models
Model vehicle position and attitude



Sensor Models
Model sensor geometry & pointing



Environment Models
Model terrain, atmosphere & space

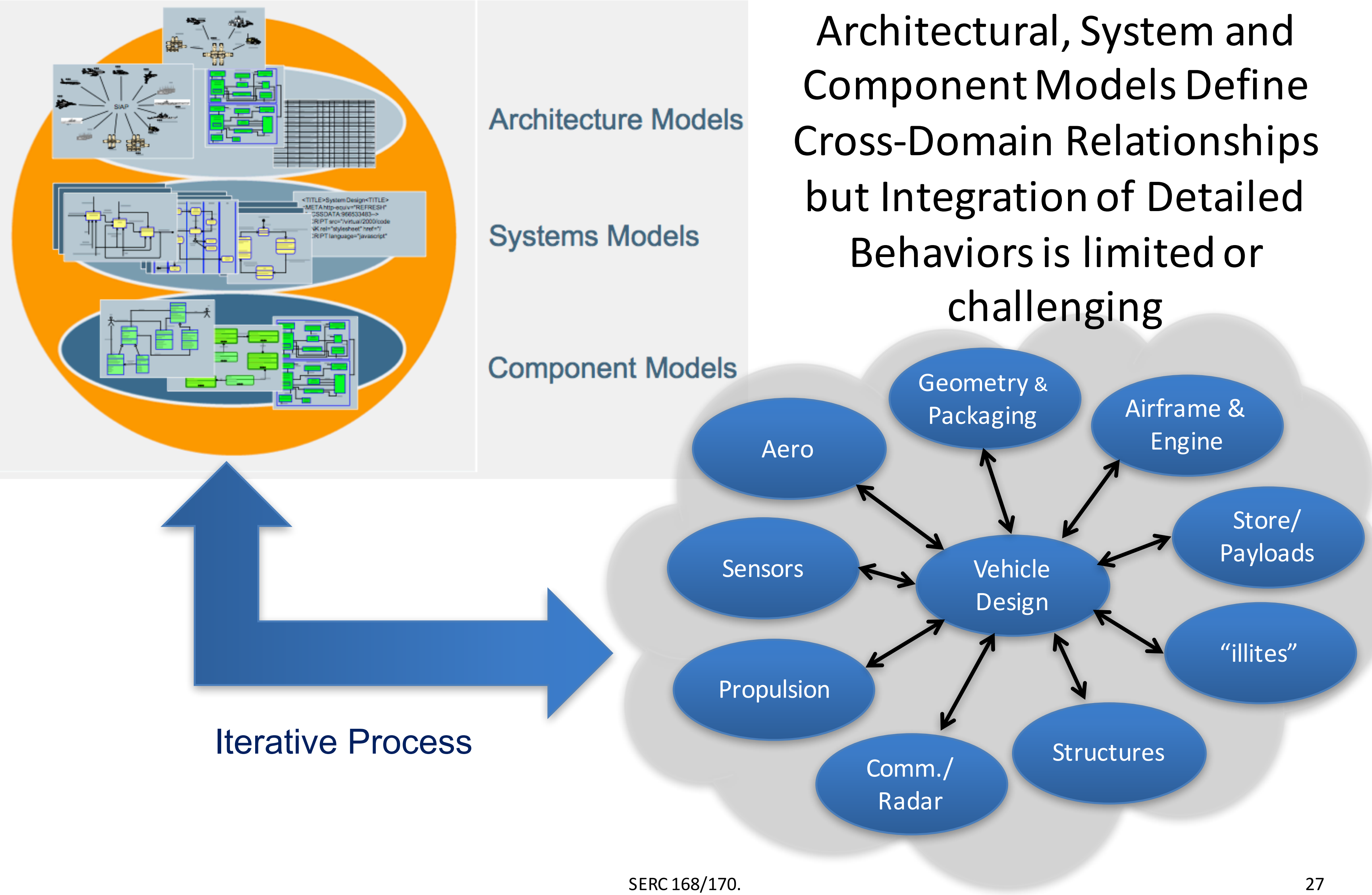


Comms & Radar Models
Model RF propagation & interference

Detailed Design from Associated Disciplines Across Domains

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

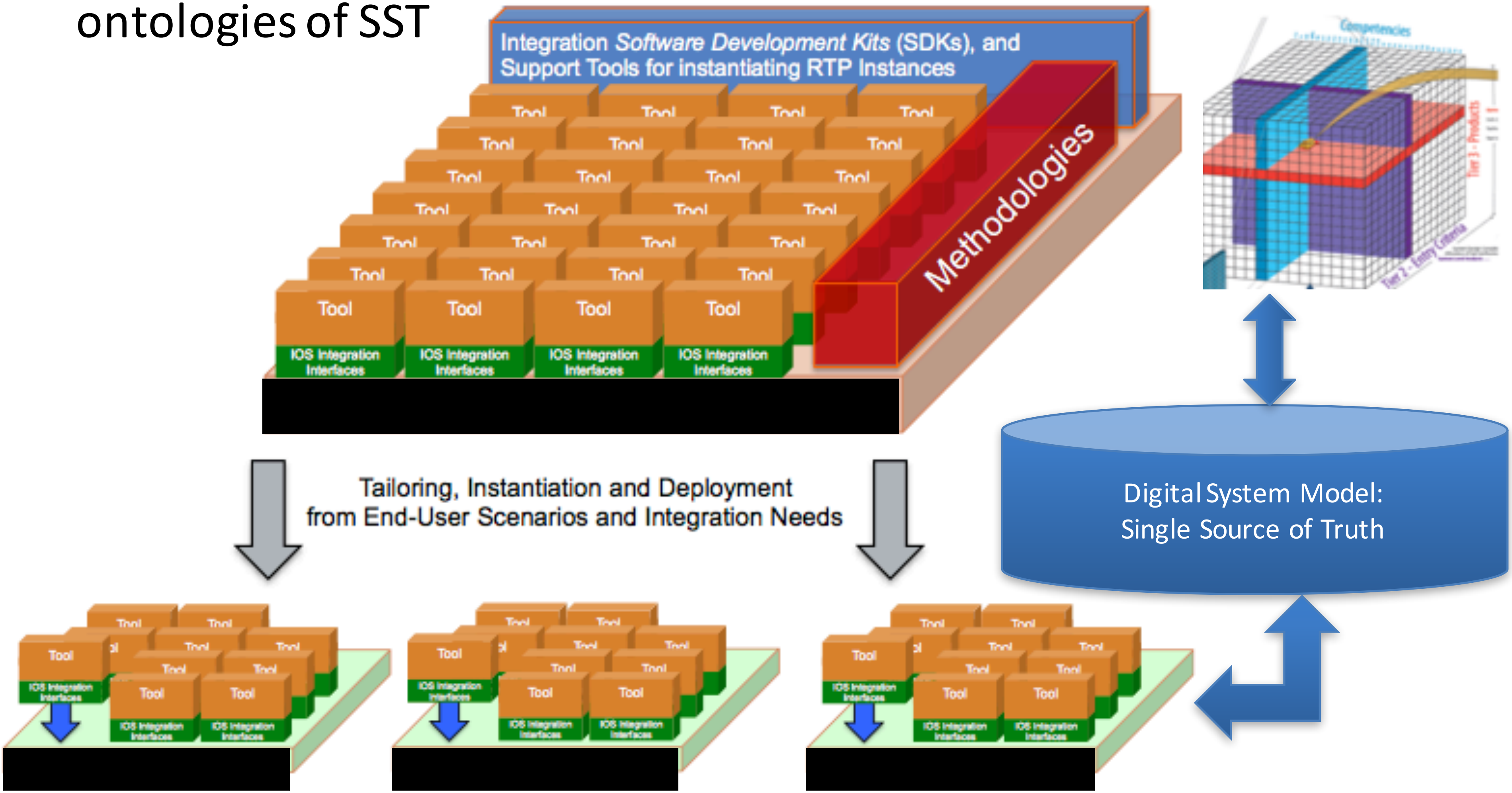
Architectural, System and Component Models Define Cross-Domain Relationships but Integration of Detailed Behaviors is limited or challenging



SERC 168/170.

Methodologies are Critical Because Commercial Tools are Method Agnostic

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



Workflow Reflects Tool Interfaces

Prodas → CFD Muzzle Analysis

		Flow to the RIGHT -->		-->	-->		Flow to the RIGHT -->
TOOLS	Prodas	CASRED	CFD Muzzle Analysis	Terminal/ Systems Effects	IWARS	System/ Operational Effects	External Ballistics Effects
Prodas	Prodas		X	x		X	
CASRED		CASRED			X		
CFD Muzzle Analysis			CFD Muzzle Analysis			X	
Terminal/ Systems Effects		X		Terminal/ Systems Effects			X
IWARS			X		IWARS		
System/ Operational Effects		X				System/ Operational Effects	
External Ballistics Effects			X	X	X		External Ballistics Effects
	Flow to the <--- LEFT		<---	<---		Flow to the <--- LEFT	

CASRED ← Terminal/Systems Effects

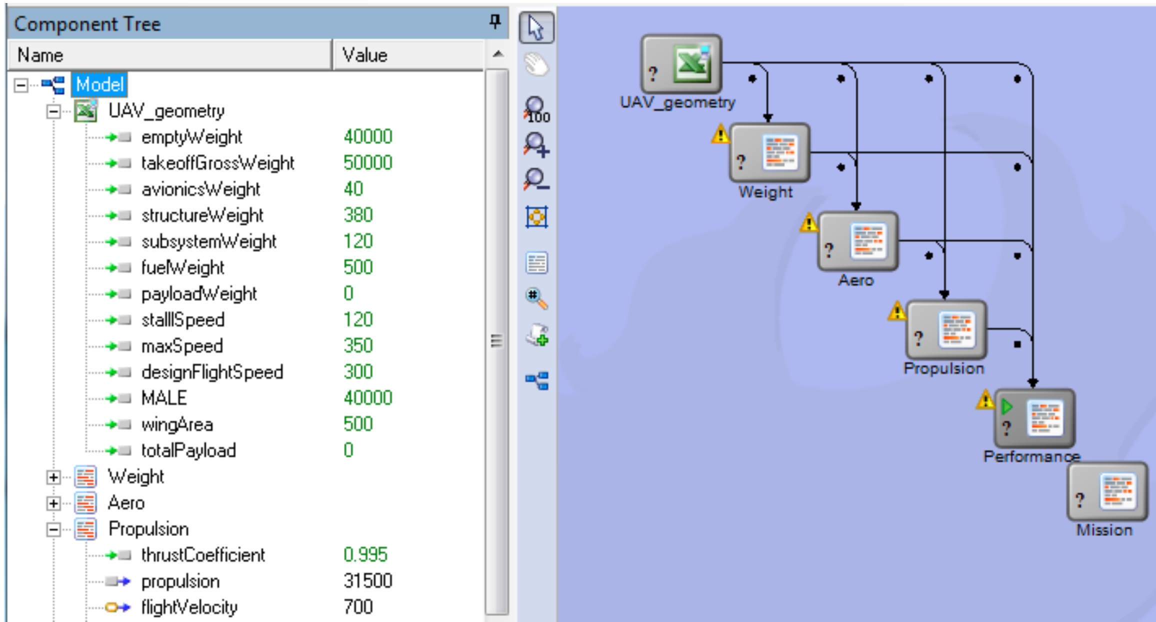
All Major Contractors Have These MDAO Environments

Real-Time Customer Interaction in Major Trades Facilitated by MDAO Environment

Presented at NDIA Event

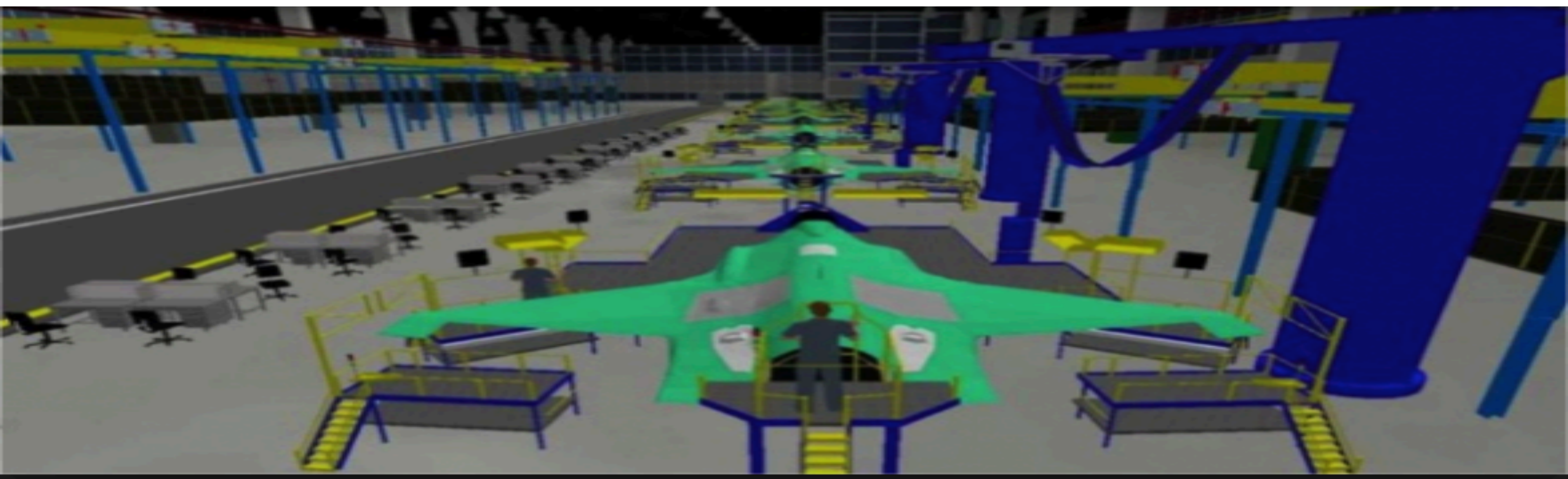
Status Requested Against Framework Research

- 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



Organizations are Modeling and Simulating Manufacturing Before Tooling

- Set-based design selection allows trade space to remain open longer, and increasingly factor in better manufacturability options



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

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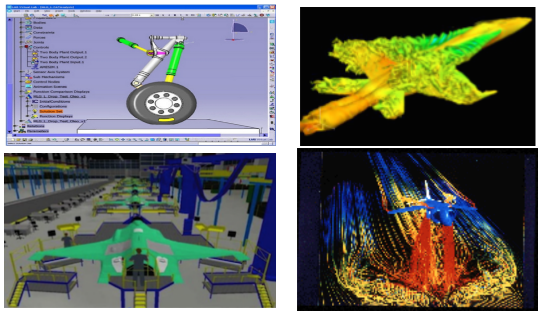


Rich Modeling Interfaces

Appropriate Views for Stakeholders

"Web" Interface integrated with Rich Visualizations

Multidiscipline Design, Analysis and Optimization (MDAO)

Computer Augmentation & Training

Continuous Workflow Orchestration

DocGen

Secure Plugin

Single Source of Truth:

Tool Agnostic, Semantically Precise Cross Domain Integration & Interoperability enabled by HPC

PLM

Performance

Integrity

Cost & Schedule

"Illities"

Knowledge

…

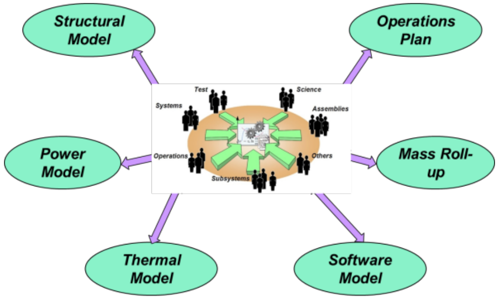
Systems, Surrogates & Platforms

Critical Technical Feasibility Items

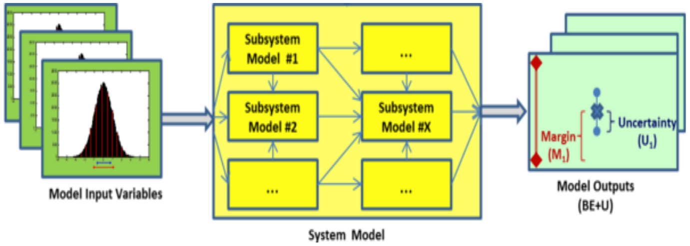
I. Cross-domain and multi-physics model integration

II. Technologies to establish & quantify model integrity

III. High Performance Computing[1] (HPC)



Cross-Domain Model Integration



Model Integrity

HPC

1) In the context of our discussions, this generally relates to Super Computing

Deep Characterization of Research

- **Provide cross-domain model integration (possibly through interoperability) to enable cross-domain analyses – understanding the impacts of a design decision(s) in one discipline on other disciplines, and also on different levels of systems and mission operations**.
- Also, such "cross-domain integration" needs to allow for "**model integrity**" (can we trust the analysis "predictions"), which leads to defining the appropriate methods – use the tools in the way that they provide trusted predictions.
- Hypothesis: **Semantic Web Technologies** provides a means for doing this and with the reasoning capabilities (going beyond just ontologies) allows us to demonstrate the "art of the possible" in **Enabling Computation of Systems Engineering**.

What?

Aligning the research gaps and challenges for a Systems Engineering Transformation

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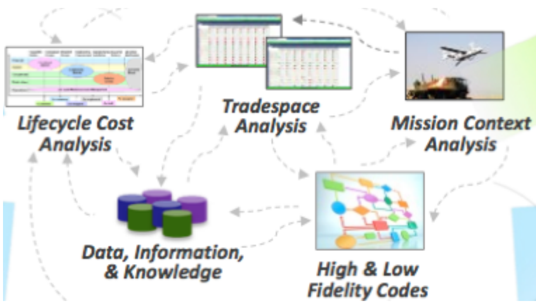
Present: NAVAIR: SE Transformation Phase II

"Doing Everything with Models – 25% Reduction in Cycle-time"

1) Model Cross-Domain Integration

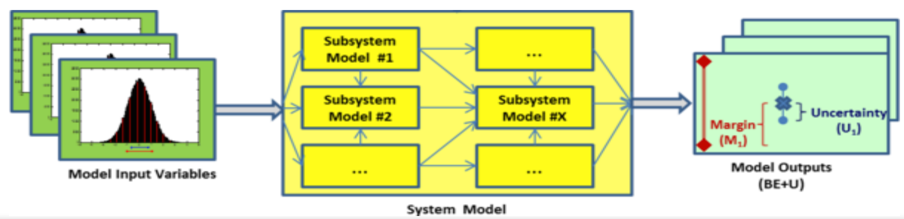
Targeted discussions with Government, Industry & Academia on developing and operating in modeling framework enabling cross-domain model integration & Single Source of Truth (SST) methodology

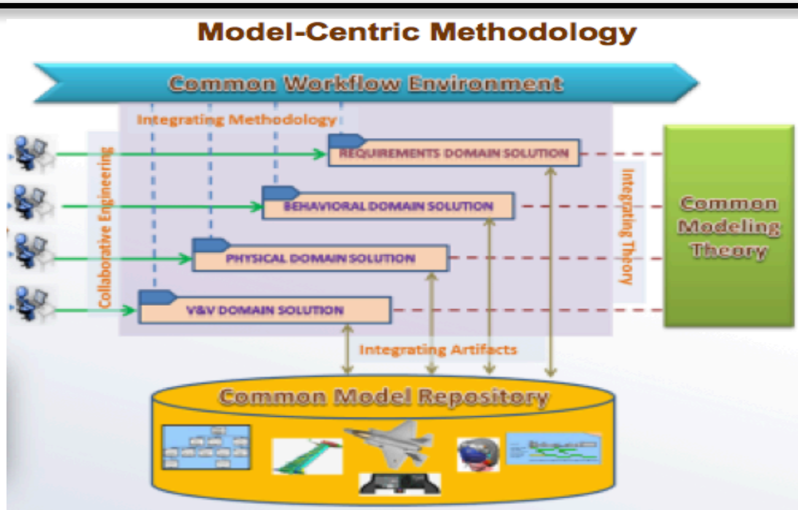


2) Model Integrity

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

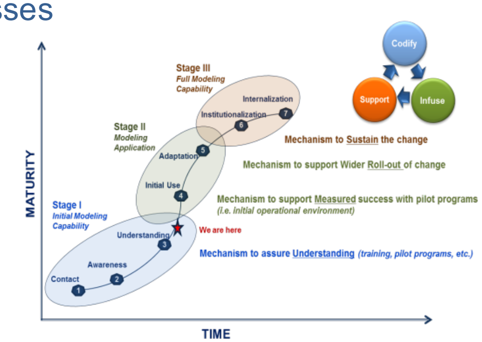




3) Modeling Methodology Implementation at NAVAIR

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



4) SE Transformation Roadmap

Systems Engineering Transformation Initiated at NAVAIR

- 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

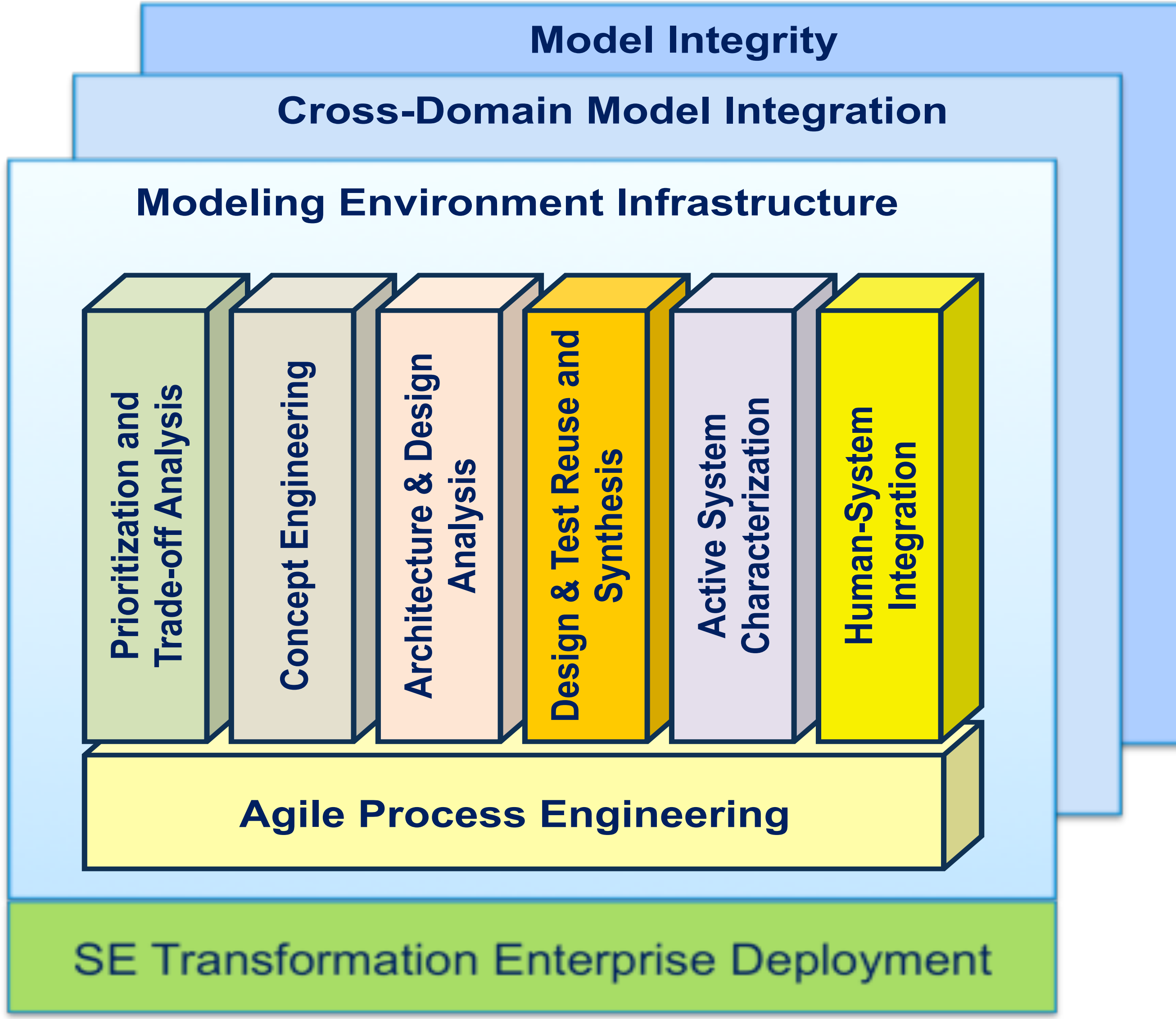
March 2016: Change of Command has Accelerated the Systems Engineering Transformation and Broadened the Scope

SE Transformation (SET) Expanded Research Areas

Expanded Research Interest Areas (Much joint effort with NAVAIR and SERC teams)

Modeling Methodology at NAVAIR

SET Roadmap



Model-Centric Engineering Can Enable New Types of Coordination & SET Demands It

- In a "Digital Engineering" environment, government and industry need to work in a different way, but workforce, infrastructure and methods need to advance

Framework for New Operational Paradigm Between Government and Industry

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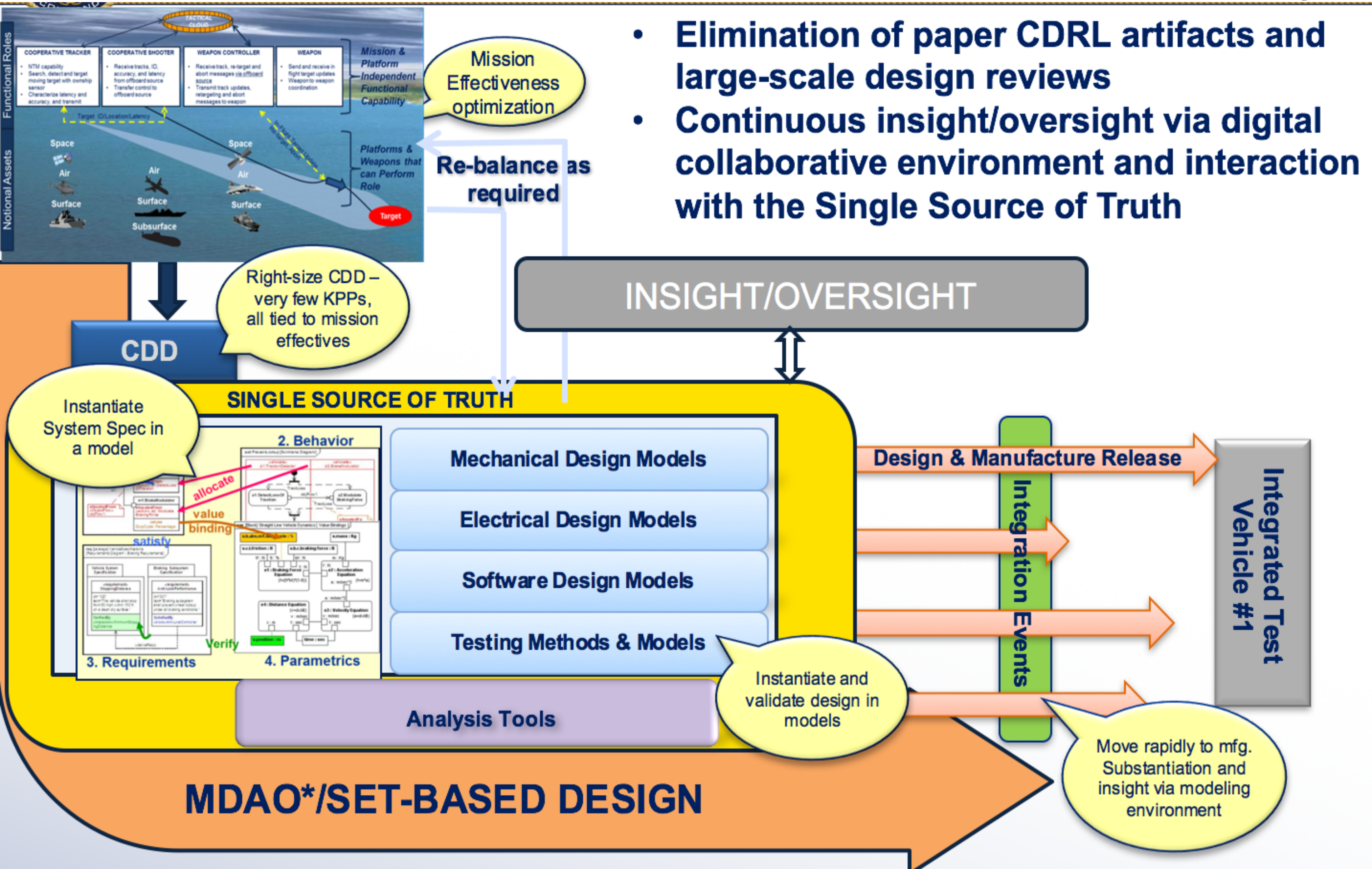
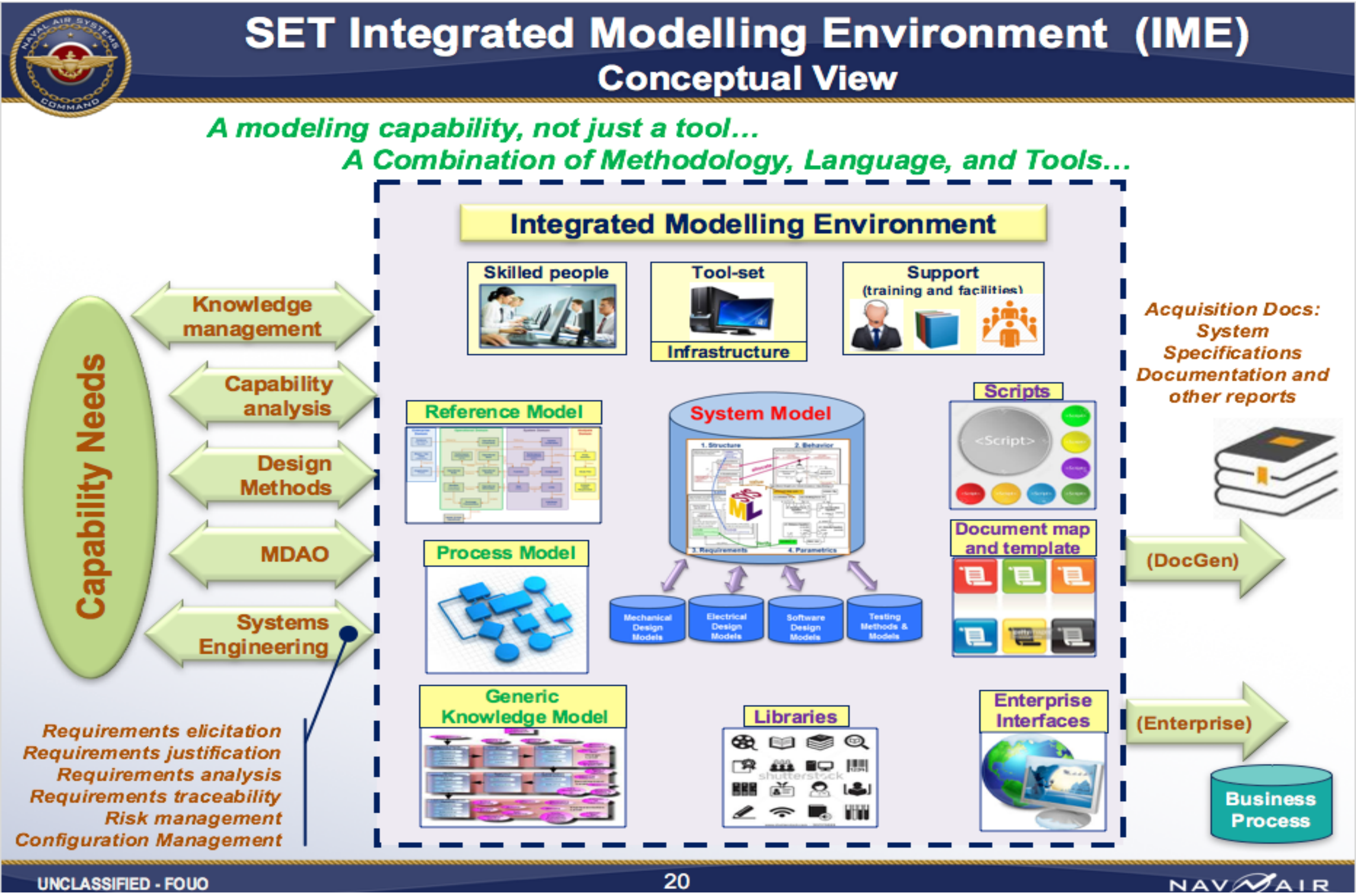
- Elimination of paper CDRL artifacts and large-scale design reviews
- Continuous insight/oversight via digital collaborative environment and interaction with the Single Source of Truth



* *Multi-Disciplinary Analysis & Optimization*

Increased Focus on "Right" Infrastructure for Workforce and Industry Collaboration



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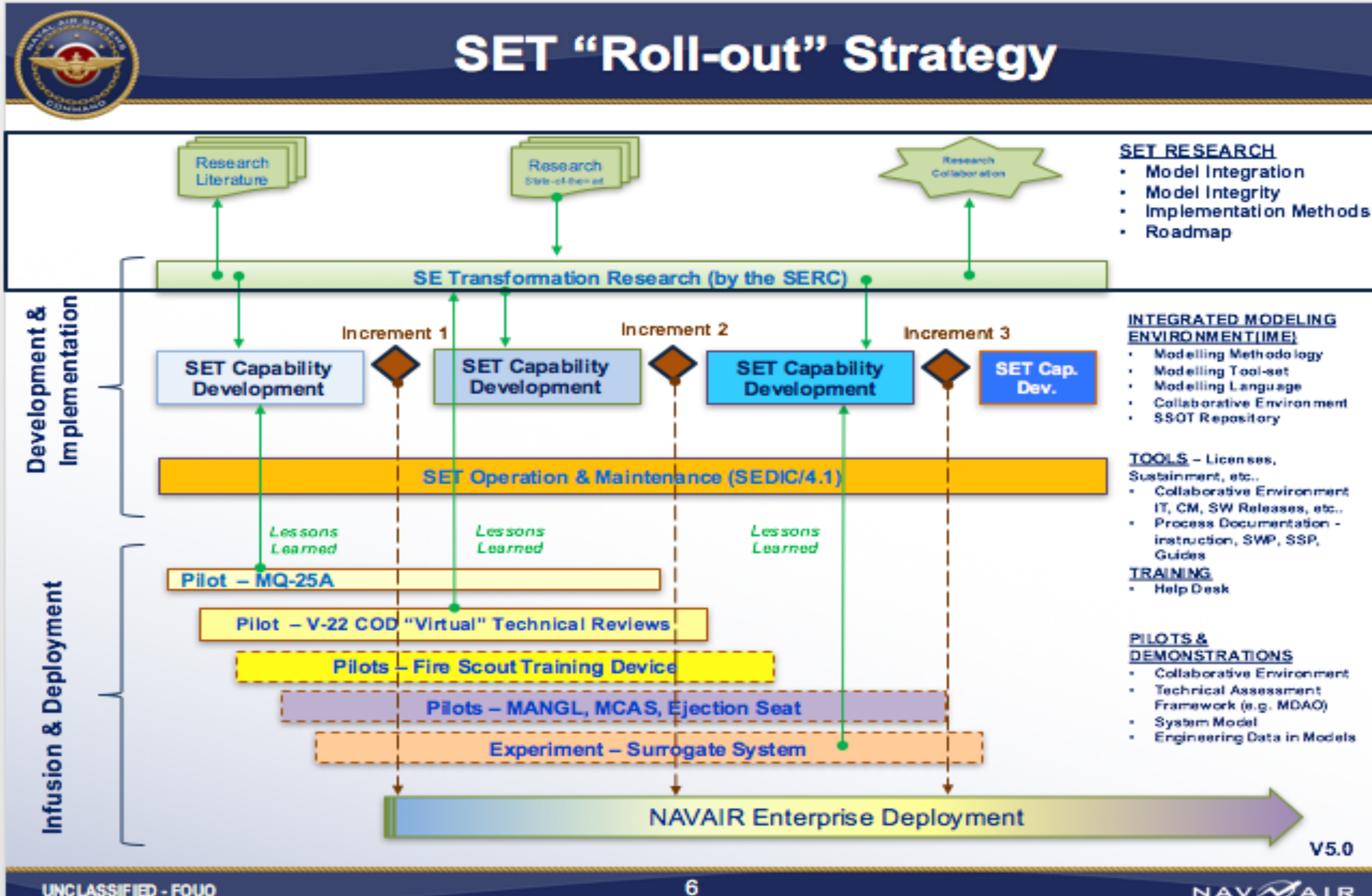
SE Transformation “Role-out” Strategy



Present: ARDEC: Systems Engineering Transformation through Model-Centric Engineering (MCE)

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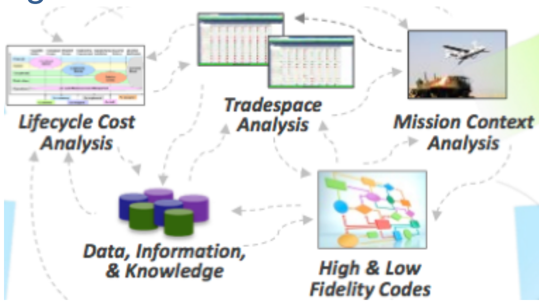
1) MCE Framework

Modeling framework enabling mission/system problem and design-space, multi-model and cross-domain model integration with enabling methodologies



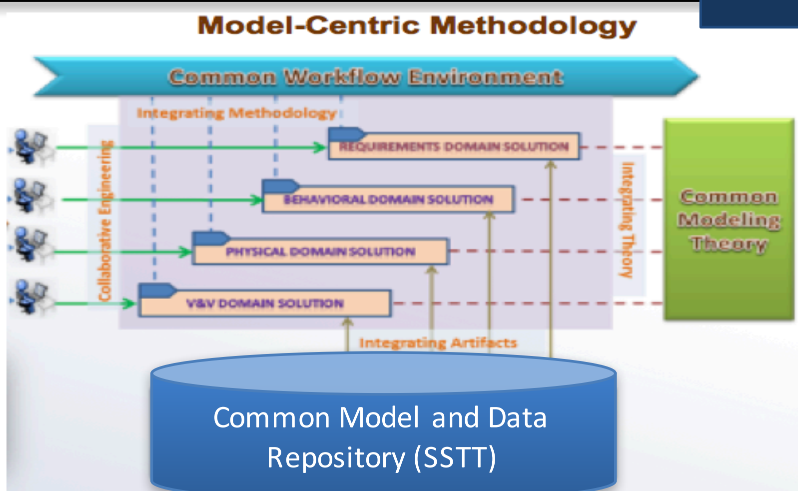
2) Formalization of Information Model for ARDEC-relevant Domains

Support capturing and sharing of data and information as a conceptual System Model (or Digital System Model), or "Single Source of Truth":

- Domain information models can be informed by Army and ARDEC Taxonomy
- Ensure the domains are evolvable to address continual evolution in technologies

Digital System Model:
Single Source of Truth (SST)

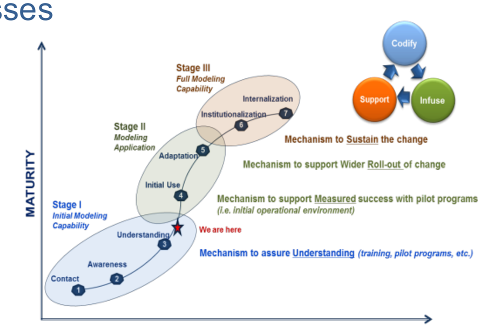
4) Challenge Areas



3) Modeling Methodology Implementation at ARDEC

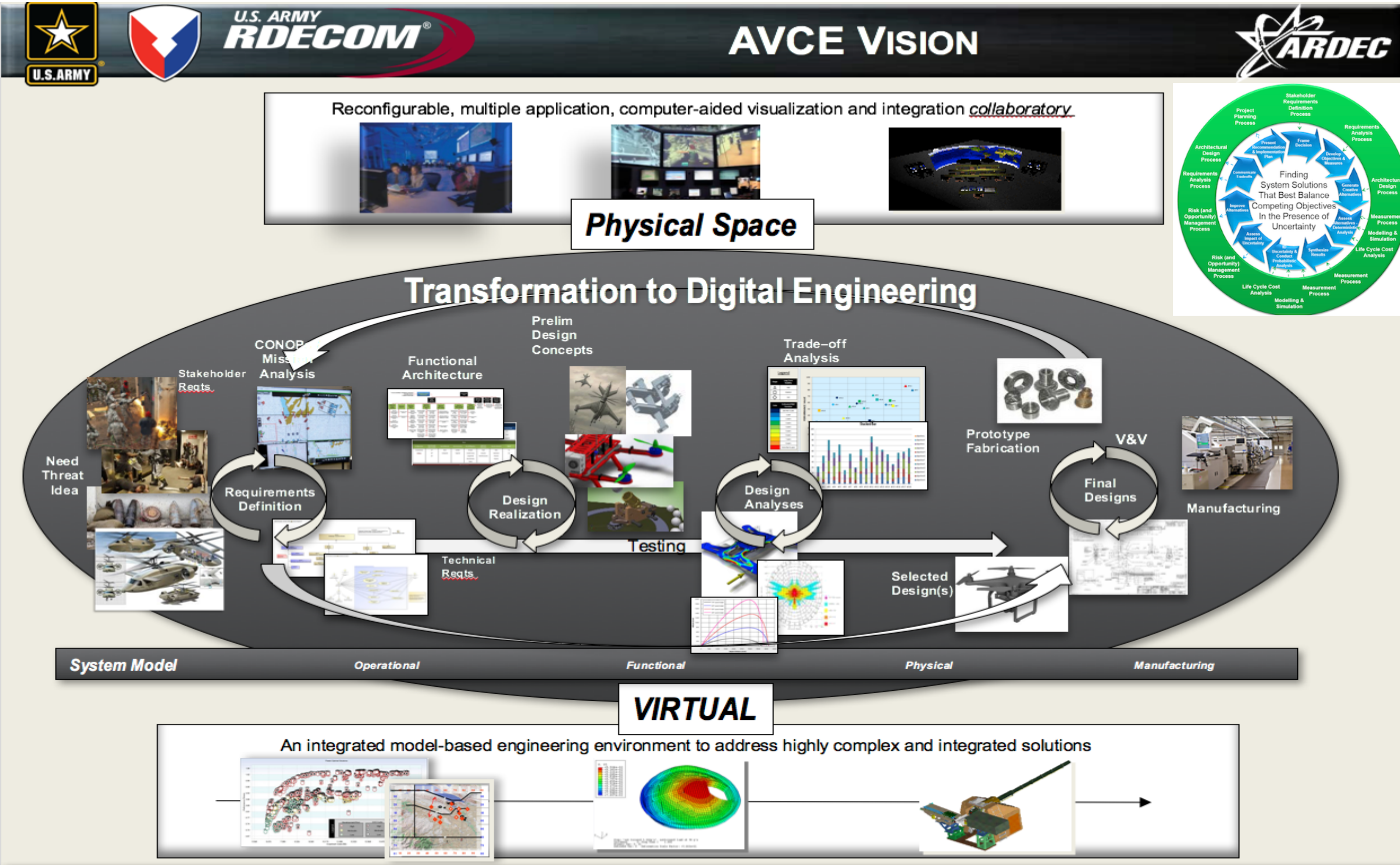
Develop a roadmap to rollout capabilities addressing all five perspectives in parallel:

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

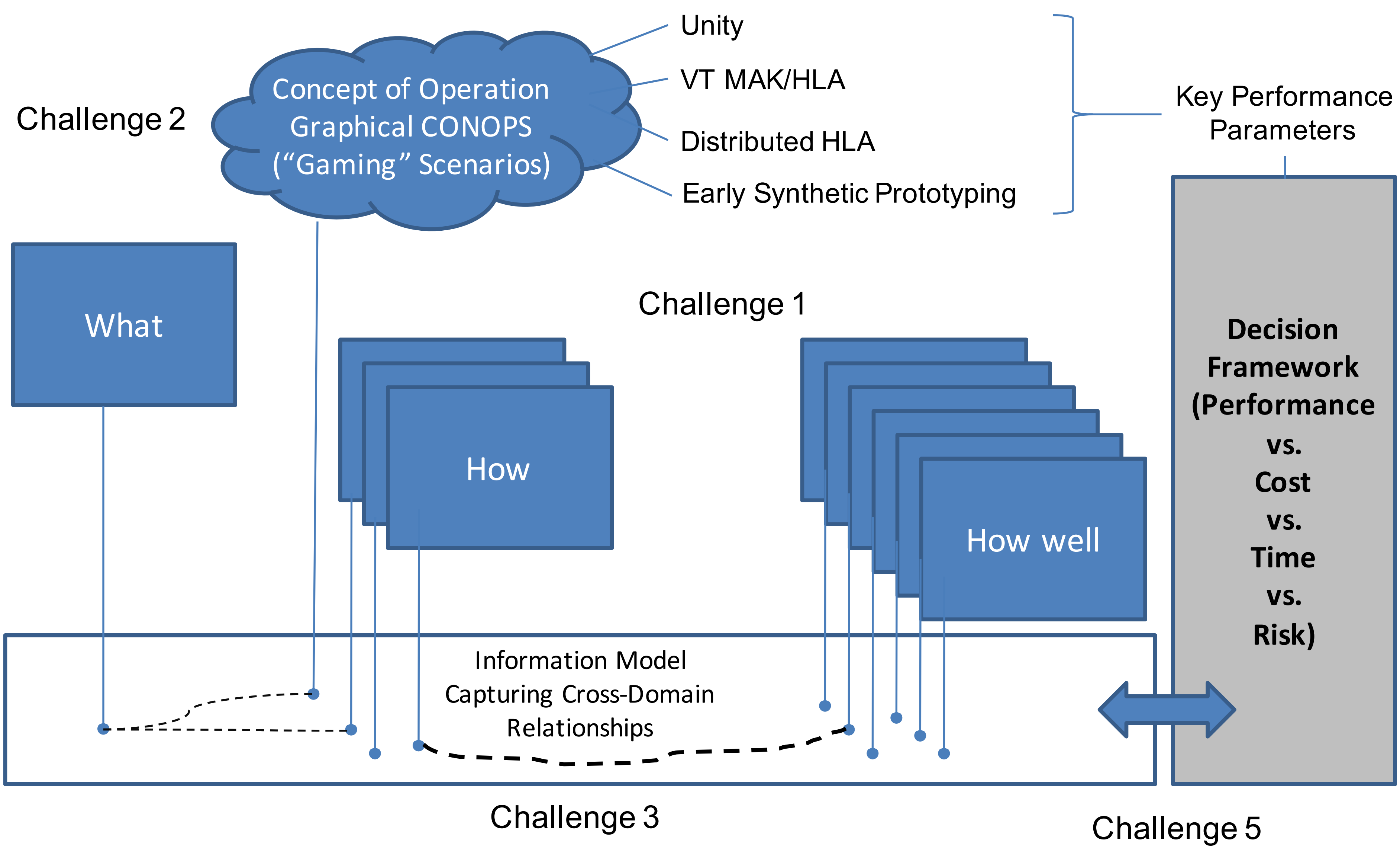


5) SE Transformation Roadmap

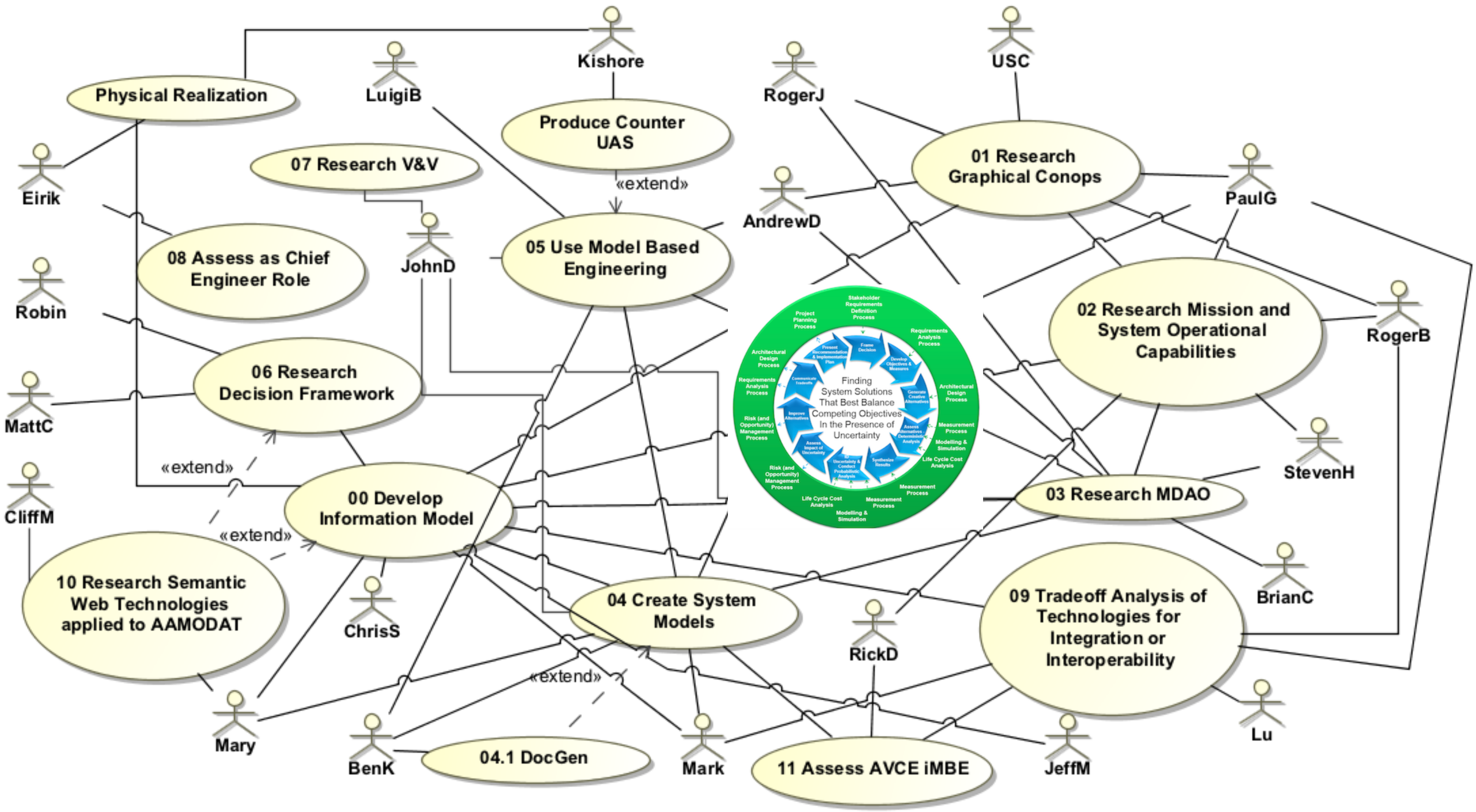
Armaments Virtual Collaborative Environment (AVCE) integrated Model Based Environment (iMBE)



Perspectives on the Challenge Areas



RT-168 Use Case Perspective and Team

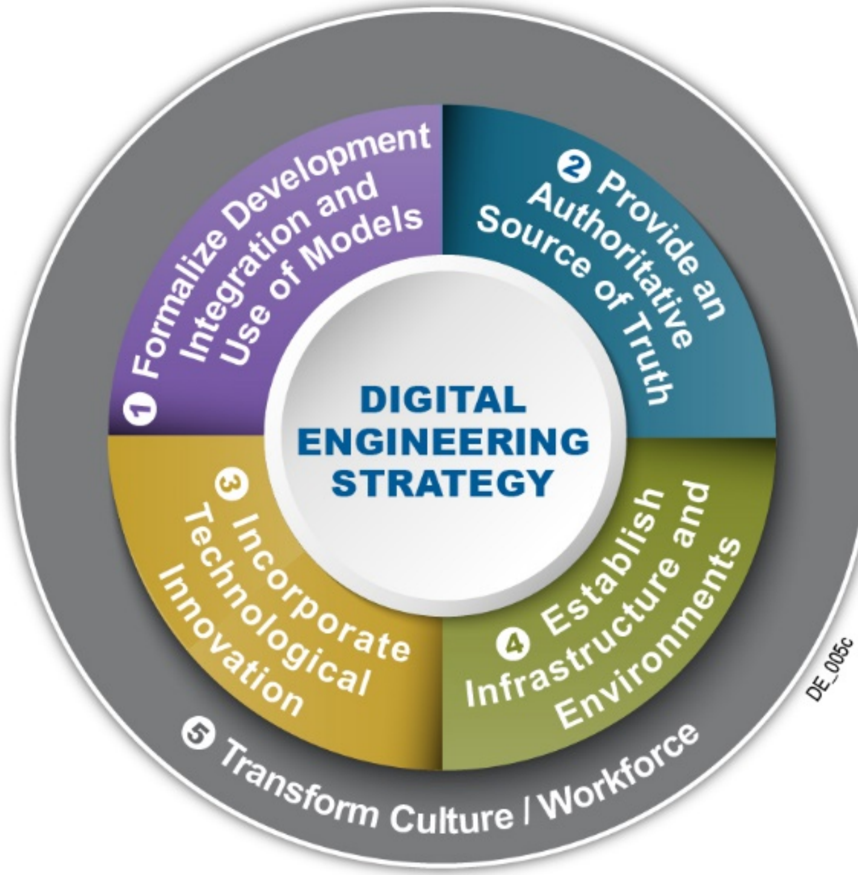


How?

Blending and evolving our research results
with
Digital Engineering (DE) Transformations
across the DoD to be in a
Future State by Computationally Enabled DE

Digital Engineering Strategy

1. Formalize the **development, integration and use of models** to inform enterprise and program decision making
2. Provide an enduring **authoritative source of truth**
3. Incorporate **technological innovation** to link digital models of the actual system with the physical system in the real world
4. Establish supporting **infrastructure and environments** to perform activities, collaborate, and communicate across stakeholders
5. Transform a **culture and workforce** that adopts and supports Digital Engineering across the lifecycle



"to be followed by the Service/Agency HOW….."

Future: SERC Research Supports Digital Engineering (DE) Thrust by DoD

- ***An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support lifecycle activities from concept through disposal***
- *Current DE Goals:*
  - —***G1. Formalize the development, integration and use of models to inform enterprise and program decision making.***
  - —***G2. Provide an enduring authoritative source of truth.***
  - —***G3. Incorporate technological innovation to link digital models of the actual system with the physical system in the real world.***
  - —***G4. Establish a supporting infrastructure and environment to perform activities, collaborate and communicate across stakeholders.***
  - —***G5. Transform a culture and workforce that adopts and supports Digital Engineering (DE) across the lifecycle.***
- NAVAIR and ARDEC are participating in DE Working Group and collaborating through SERC on synergistic and complementary research

Mapping Future Research Areas to Goals of Digital Engineering Transformation Strategy

Future Research Areas	**G1.** Formalize the development, integration and use of models to inform enterprise and program decision making.	**G2**. Provide an enduring authoritative source of truth.	**G3**. Incorporate technological innovation to link digital models of the actual system with the physical system in the real world.	**G4**. Establish a supporting infrastructure and environment to perform activities, collaborate and communicate across stakeholders.	**G5**. Transform a culture and workforce that adopts and supports DE across the lifecycle.
Cross-discipline integration of models to address the heterogeneity of the various tools and environments using semantic technology	X	X	X	X	X
High Performance Computing (HPC) advancements such as; 1) supporting organizing and analyzing "Big Data" and 2) being able to program in parallel to take advantage of HPC capabilities, are needed to support the DE effort	X	X	X	X	
Model integrity to ensure trust in the model predictions by understanding and quantifying margins and uncertainty	X	X	X	X	X
Modeling methodologies that can embed demonstrated best practices and provide computational technologies for real-time training within digital engineering environments	X		X	X	X
Model composability to understand the possibilities, constraints and rulesets for composition of multiple models	X		X		
Human-model task allocation to understand what activities are best performed by human decision makers and what can effectively be automated or augmented with model intelligence					X
Workforce development to understand what is needed to educate model developers, users and decision makers to work in a DE environment					X
MCE acquisition to understand the needed changes to acquisition and security when developing in the new DE environment	X	X		X	X

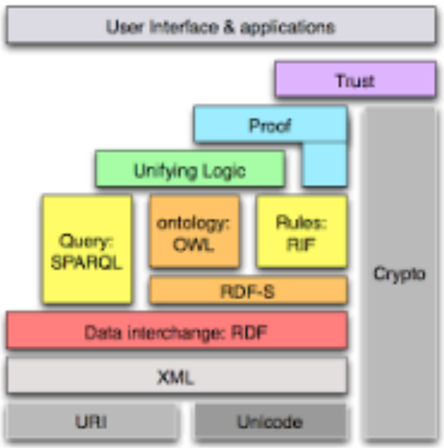
Breakout Areas

Risks	Priorities

Deep Dive Research Topics

Review: Deep Dive Topics

Semantic Web Technologies



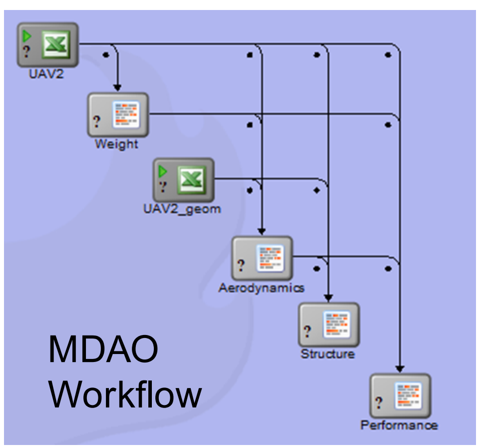
Enforces **Modeling Methods**

Underlying technologies for reasoning about completeness and consistency **Across Domains** in modeling tool agnostic way

Modeling Methodologies

Guides proper usage to ensure **Model Integrity** (trust in model results) for decision making

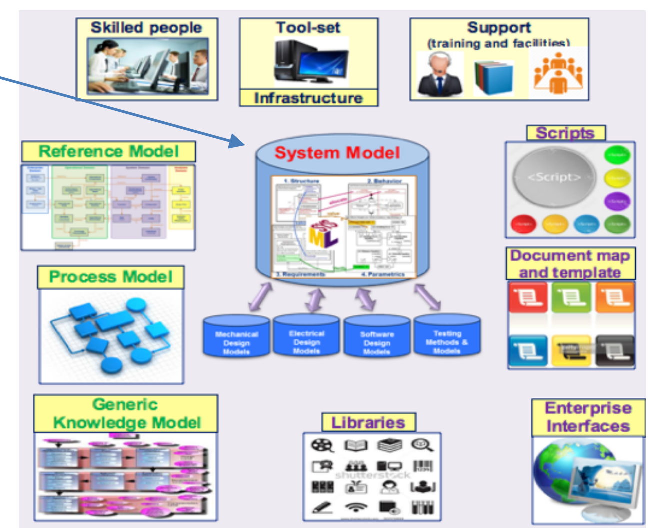
Multidisciplinary Design, Analysis and Optimization MDAO



Digital System Model:
Single Source of Truth
(authoritative source of truth)

Provides optimization analysis **Across Domains** to support KPP and alternatives trades at mission, system, & subsystem levels

Integrated Modeling Environment



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Semantic Web Technologies >
Integrated Modeling Environment >
Modeling Method Alternatives >
MDAO (Time Permitting)

INCOSE MBSE Roadmap

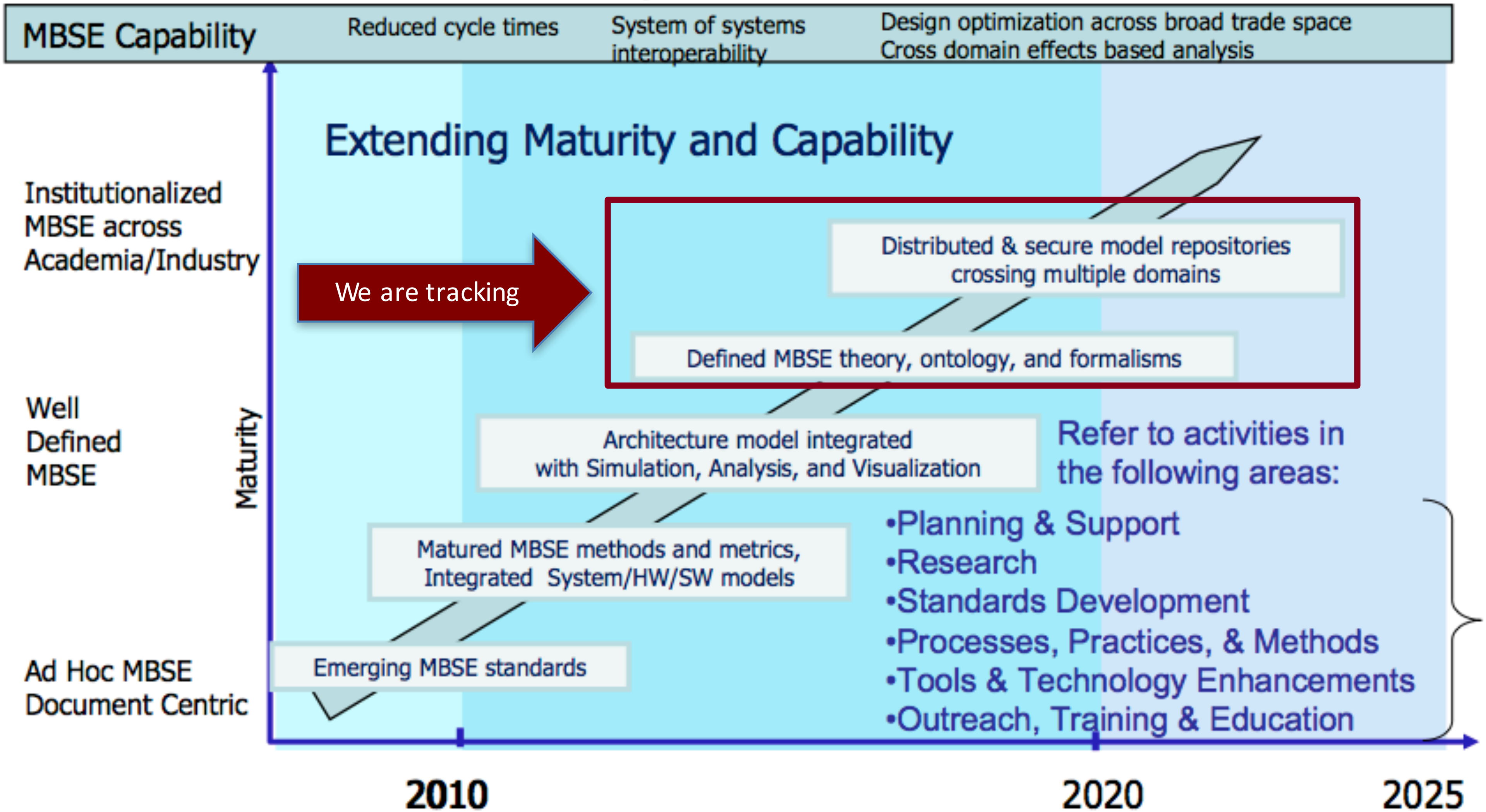
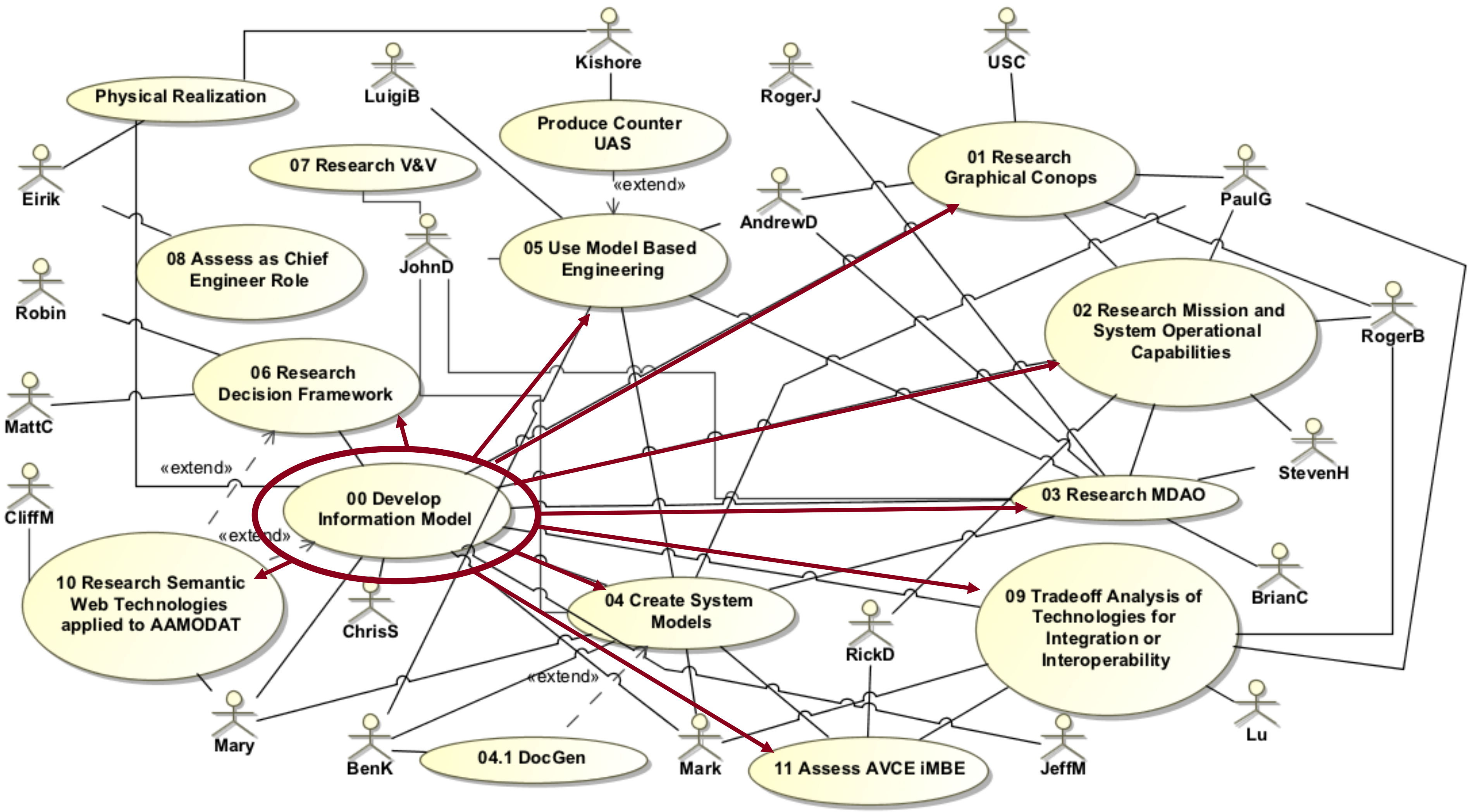
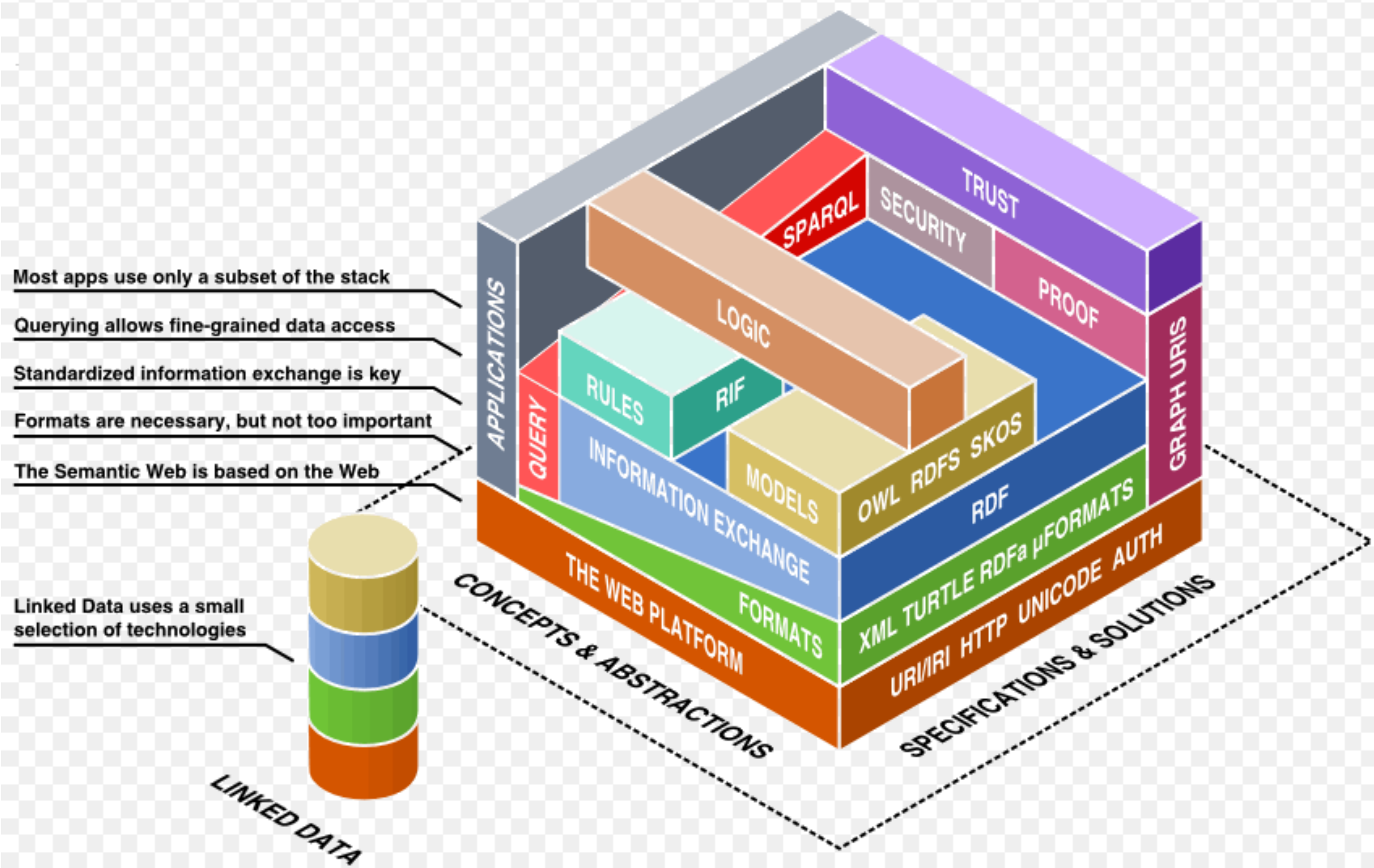


Figure 2-4: INCOSE MBSE Roadmap

RT-168 Use Case Perspective and Team



Semantic Web Technologies is More than Ontologies



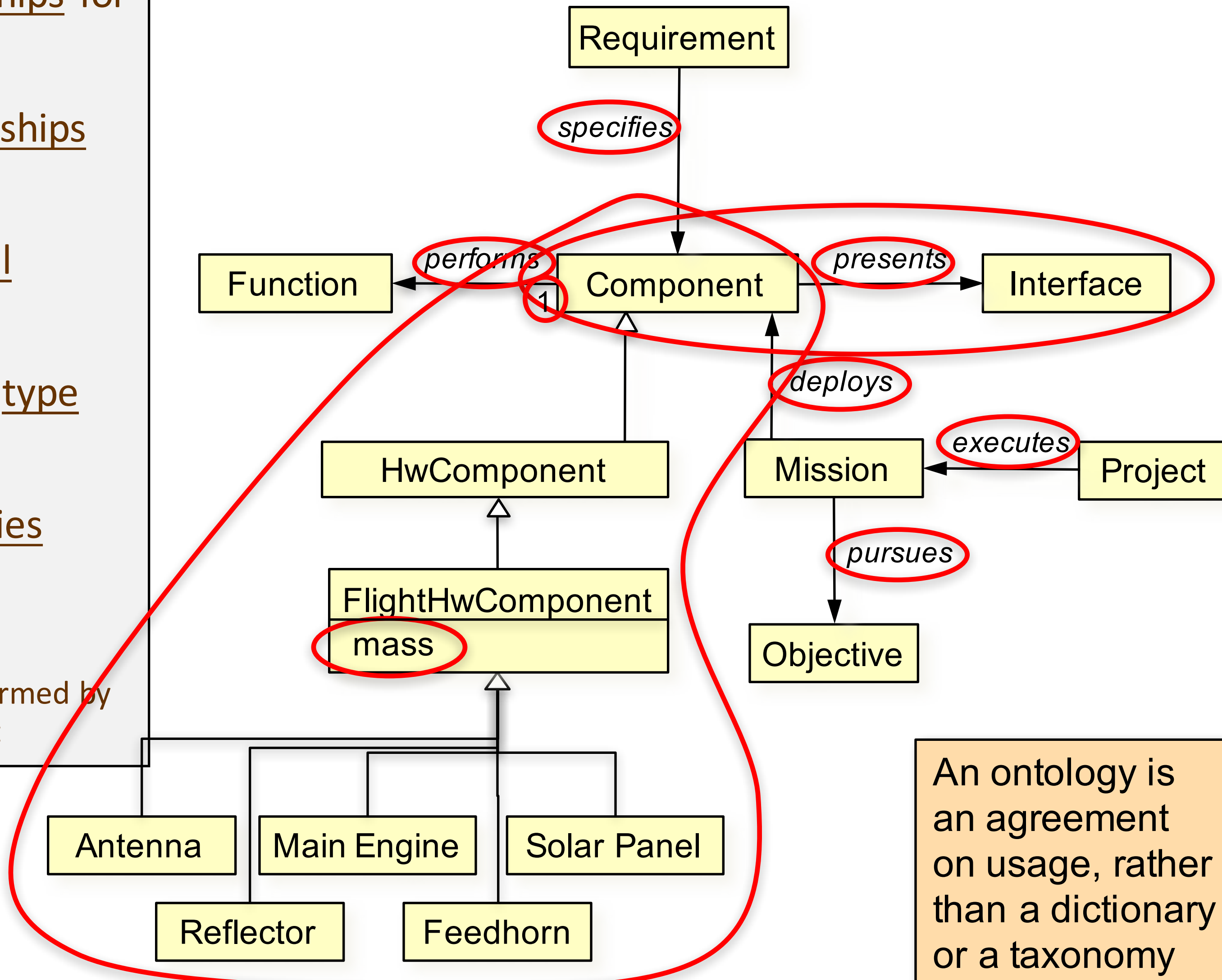
https://adl.gitbooks.io/companion-specification-for-xapi-vocabularies/content/semantic_web_technology,_linked_data,_and_rdf/ SERC 168/170.

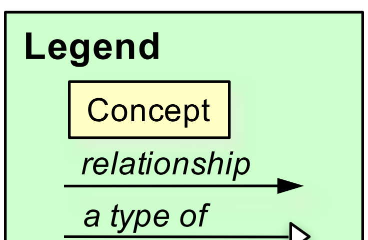
Excellent Videos on Semantic Technologies for Systems Engineering

- Two videos by Steve Jenkins:
  - Model-Centric Engineering, Part 2: Introduction to System Modeling
  - Model-Centric Engineering, Part 3: Foundational Concepts for Building System Models
  - https://nescacademy.nasa.gov/category/3/sub/17
- Part 2 is more about Why
- Part 3 is more about What and How
- Ontologies and SWT being open-sourced and investigated by the Semantic Technologies for Systems Engineering (ST4SE) Initiative
- Using some excerpts from the material

What is an Ontology?

- An ontology describes concepts and relationships for a domain of interest
- Concepts have relationships to each other
- Ontologies specify legal sentences
- Some concepts form a type hierarchy
- Concepts have properties
  - *e.g.,* mass
- Ontologies have rules
  - *e.g.*, a function is performed by exactly one component





An ontology is an agreement on usage, rather than a dictionary or a taxonomy

Partial Map of Foundation Ontology Concepts

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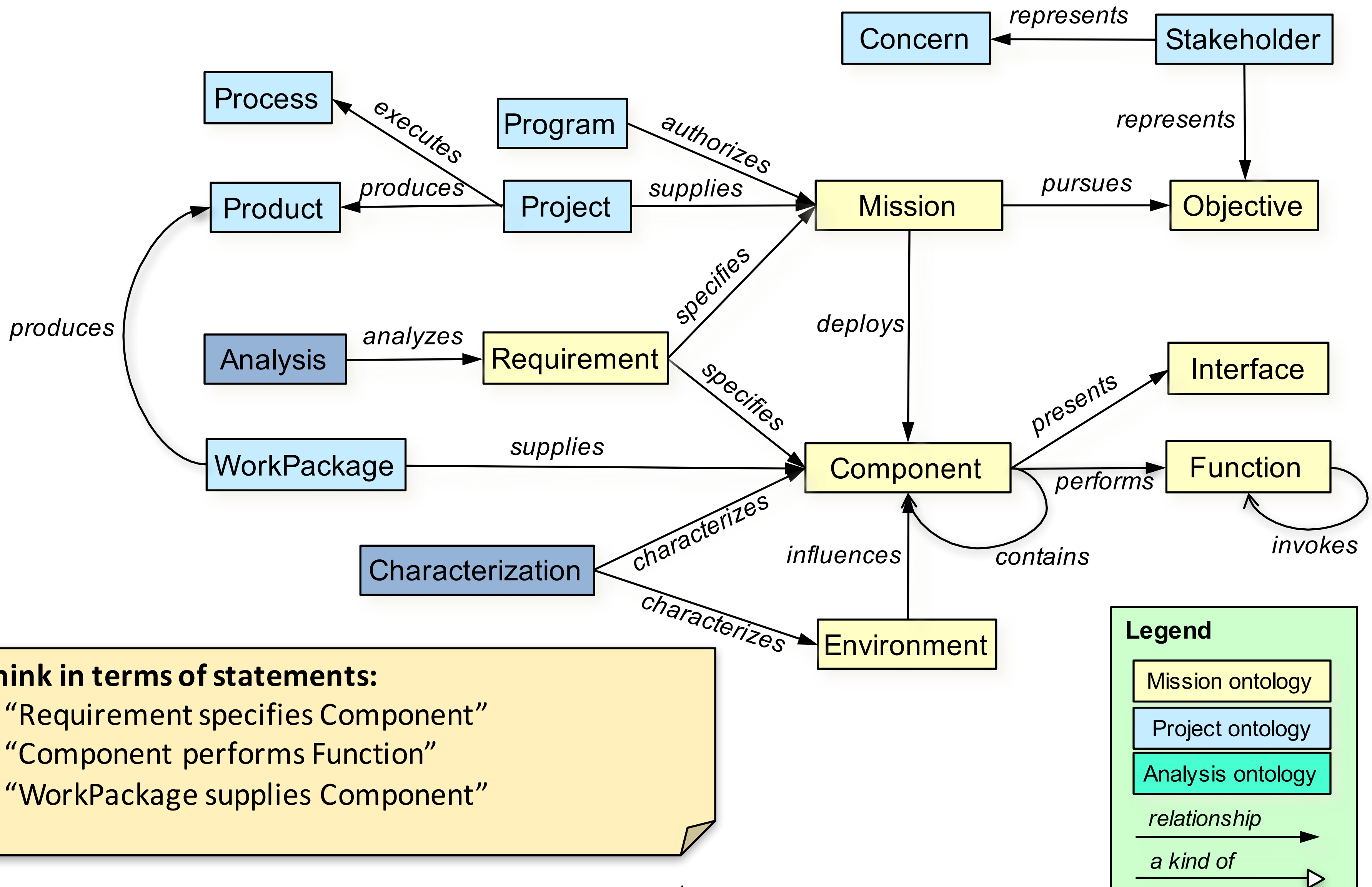
(animated)



Think in terms of statements:

- "Requirement specifies Component"
- "Component performs Function"
- "WorkPackage supplies Component"

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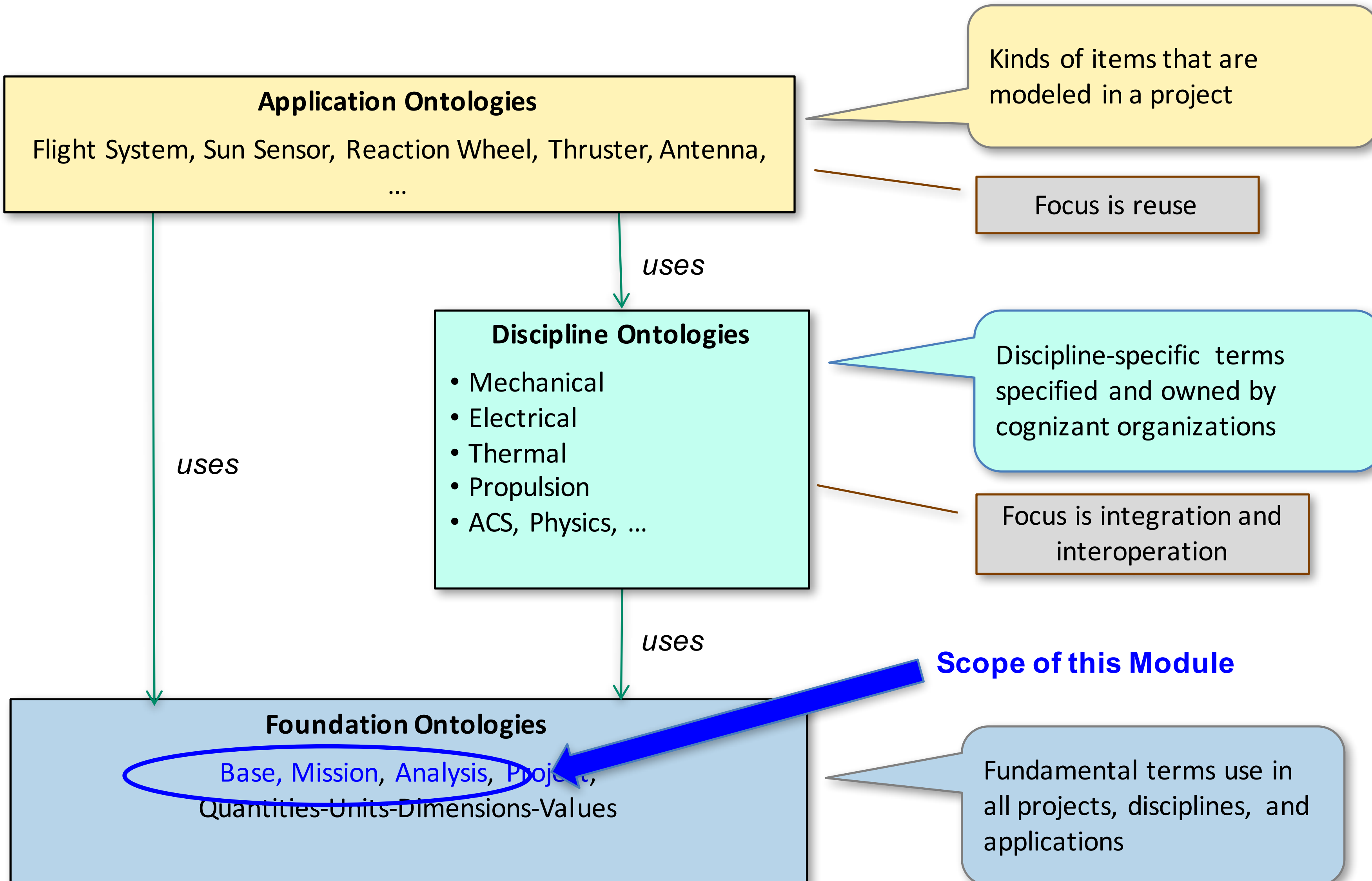
Systems Engineering Ontologies

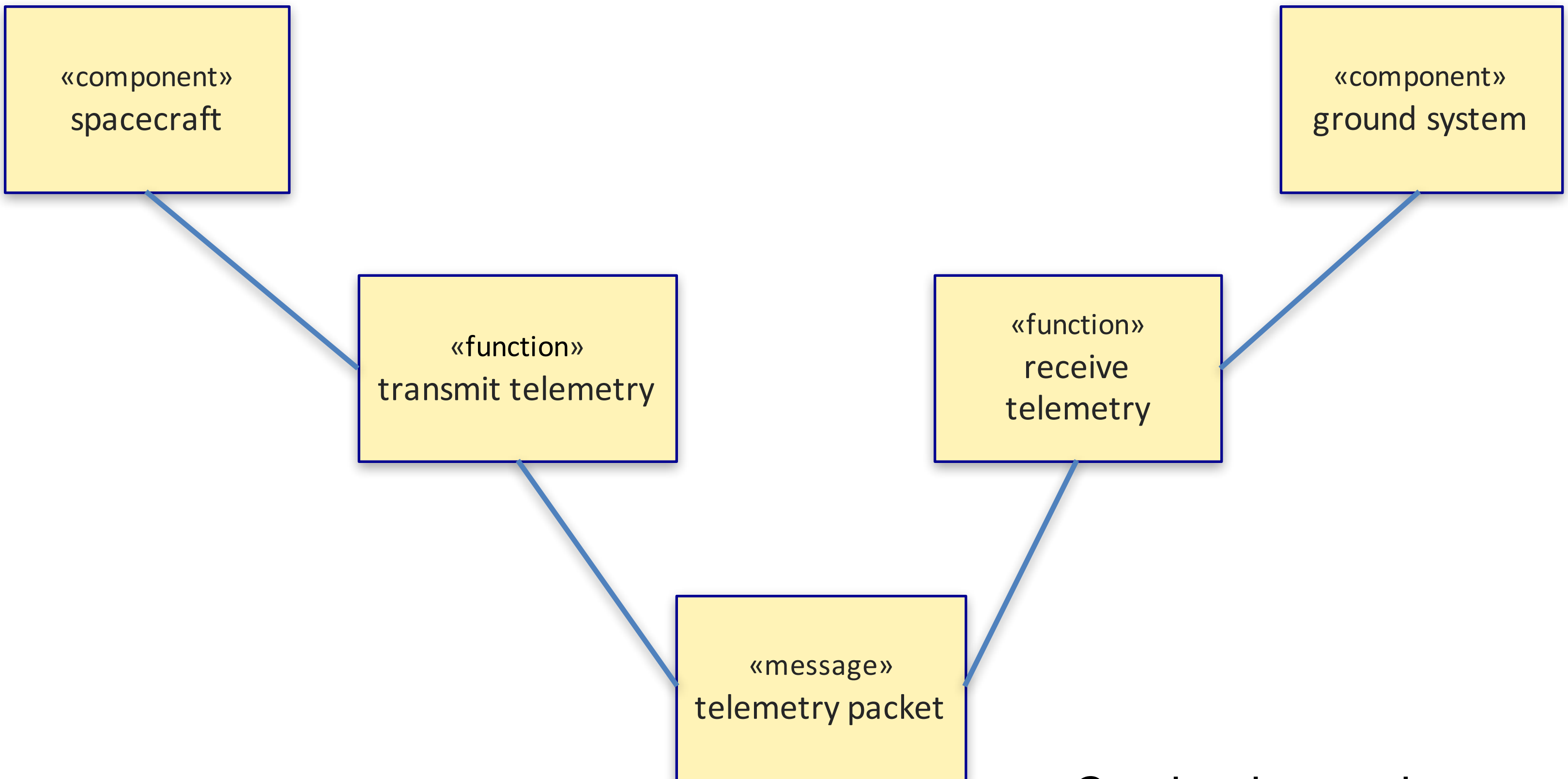


Semantic Web Technologies >
Integrated Modeling Environment >
Modeling Method Alternatives >
MDAO (Time Permitting)

Modeling Methods Alternatives

- Traditional: process guidelines – human review models
  - Time consuming and not comprehensive considering evolving complexity
- Template-based generation process; e.g., View and Viewpoint mechanism supported by OpenMBEE Model Development Kit (MDK)/DocGen
  - Alternative use for concept – see NAVAIR Surrogate Pilot
- Add checks inside tools – increasingly supported concept, but will be tool-specific, and usually requires "coding"
- Semantic Web Technology concept – see NASA/JPL approach
  - Computationally enable Systems Engineering
  - Could be unified across Systems Engineering community
  - Following scenarios from: Jenkins, Model-Centric Engineering, Part 2: Introduction to System Modeling

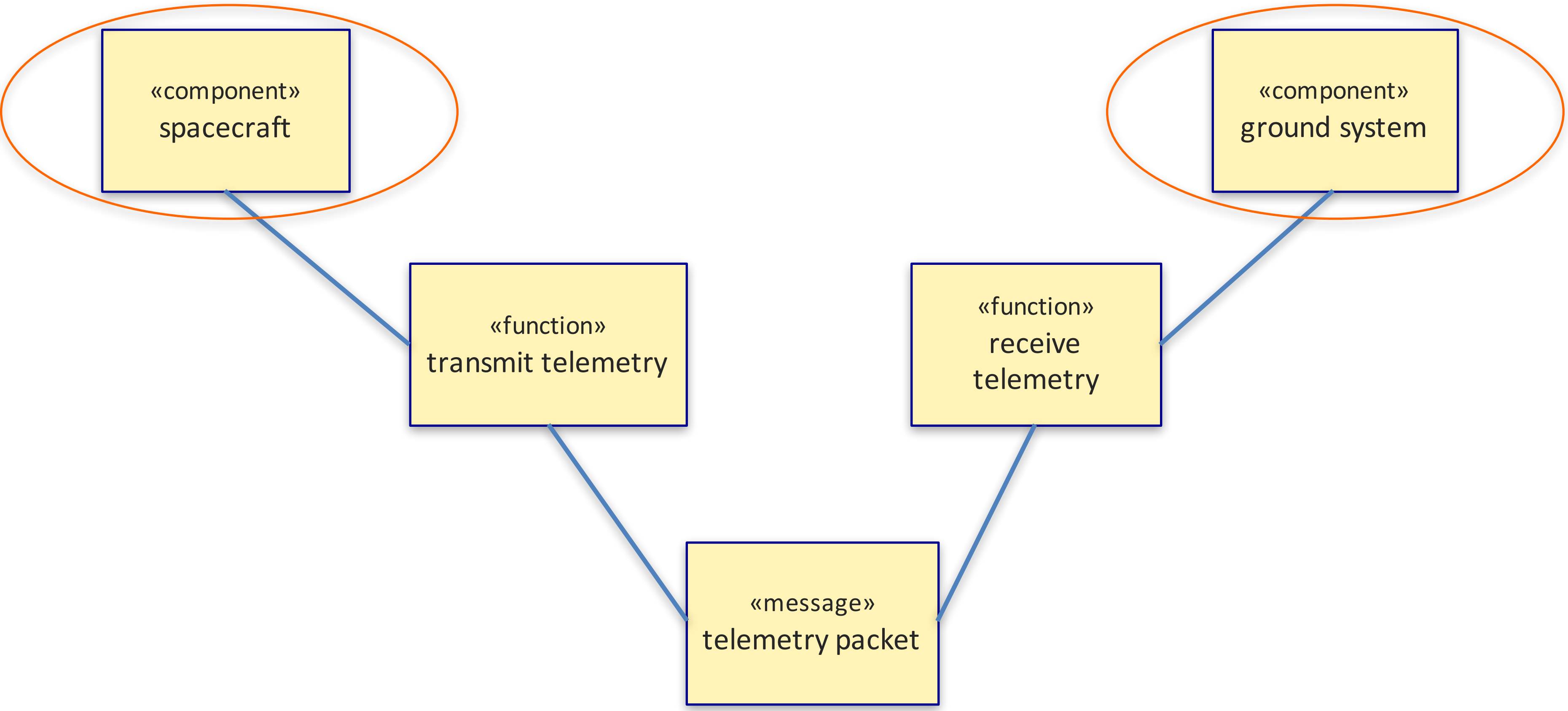
Model With Typed Elements



Can be done using Profiles and Stereotypes with most SysML-based tools

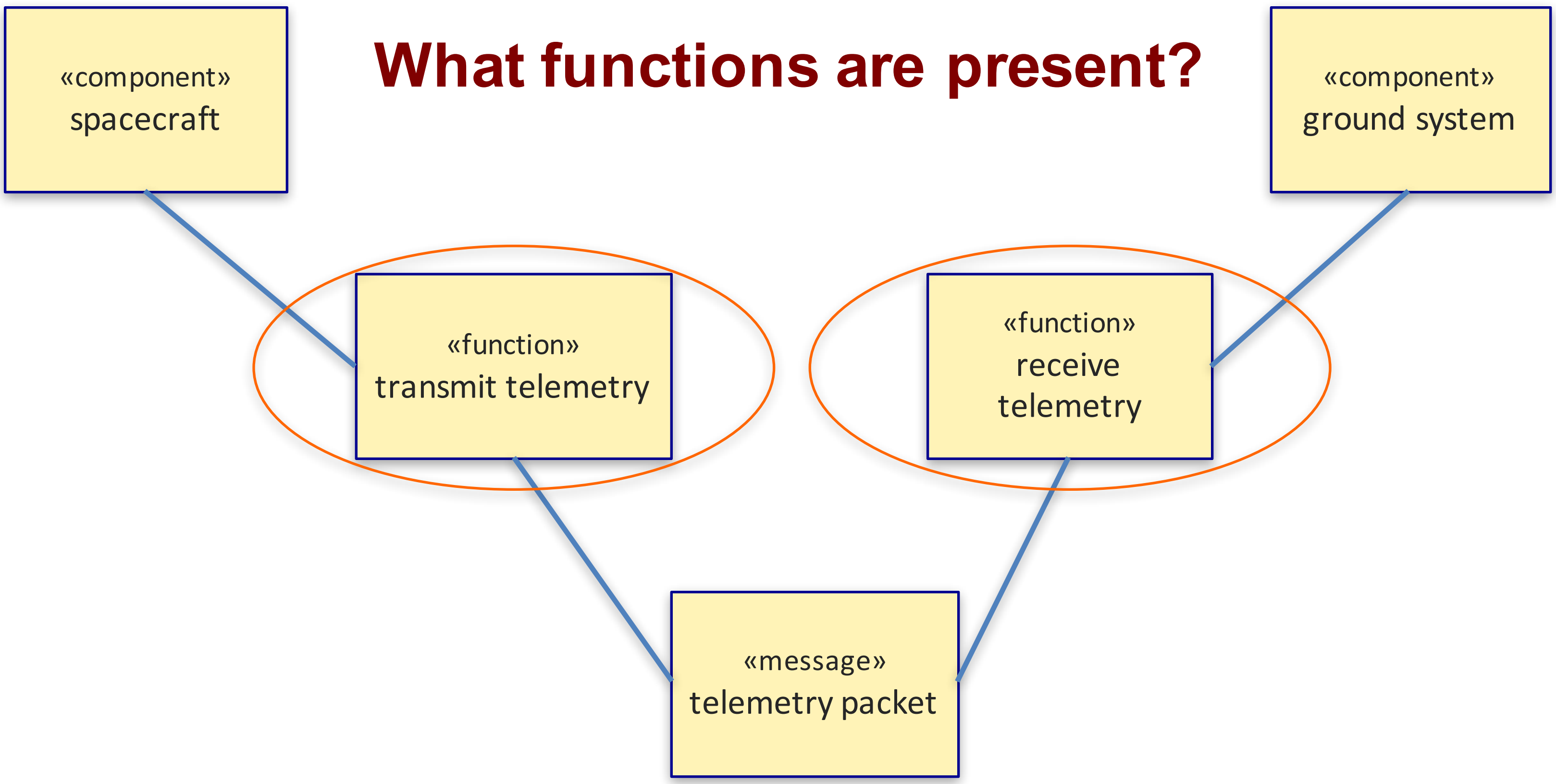
Answering Questions

What components are present?



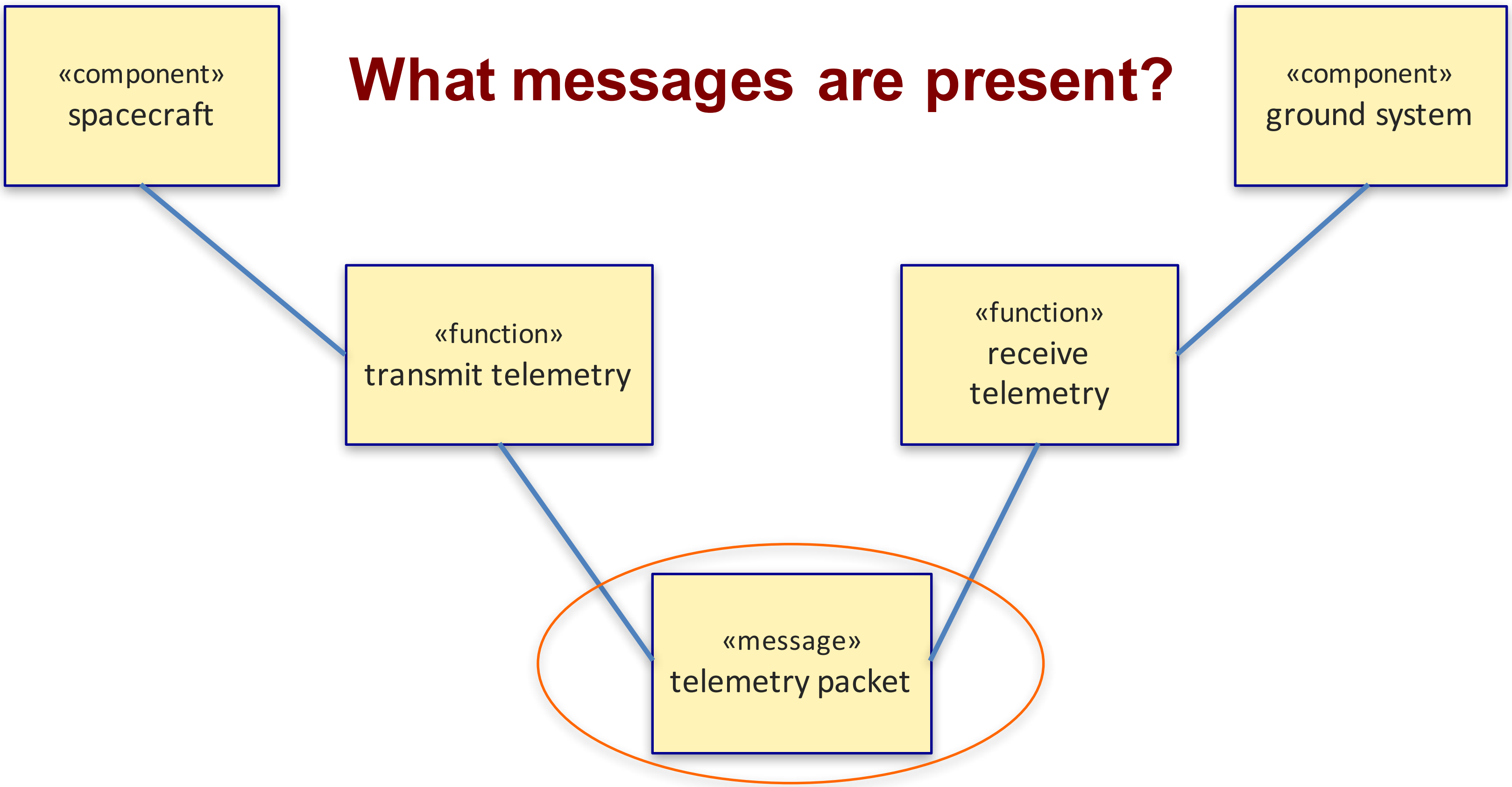
Answering Questions

What functions are present?

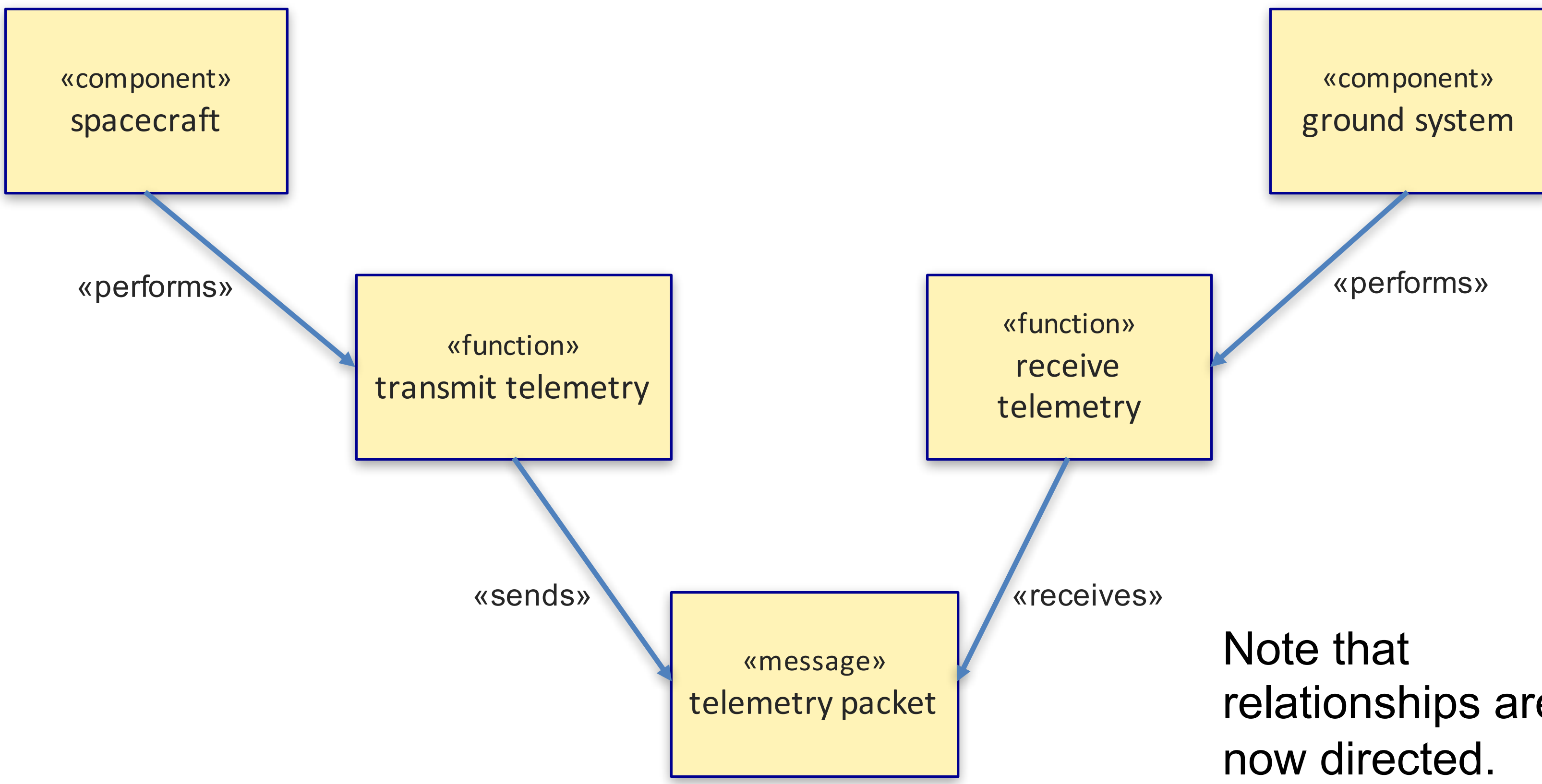


Answering Questions

What messages are present?

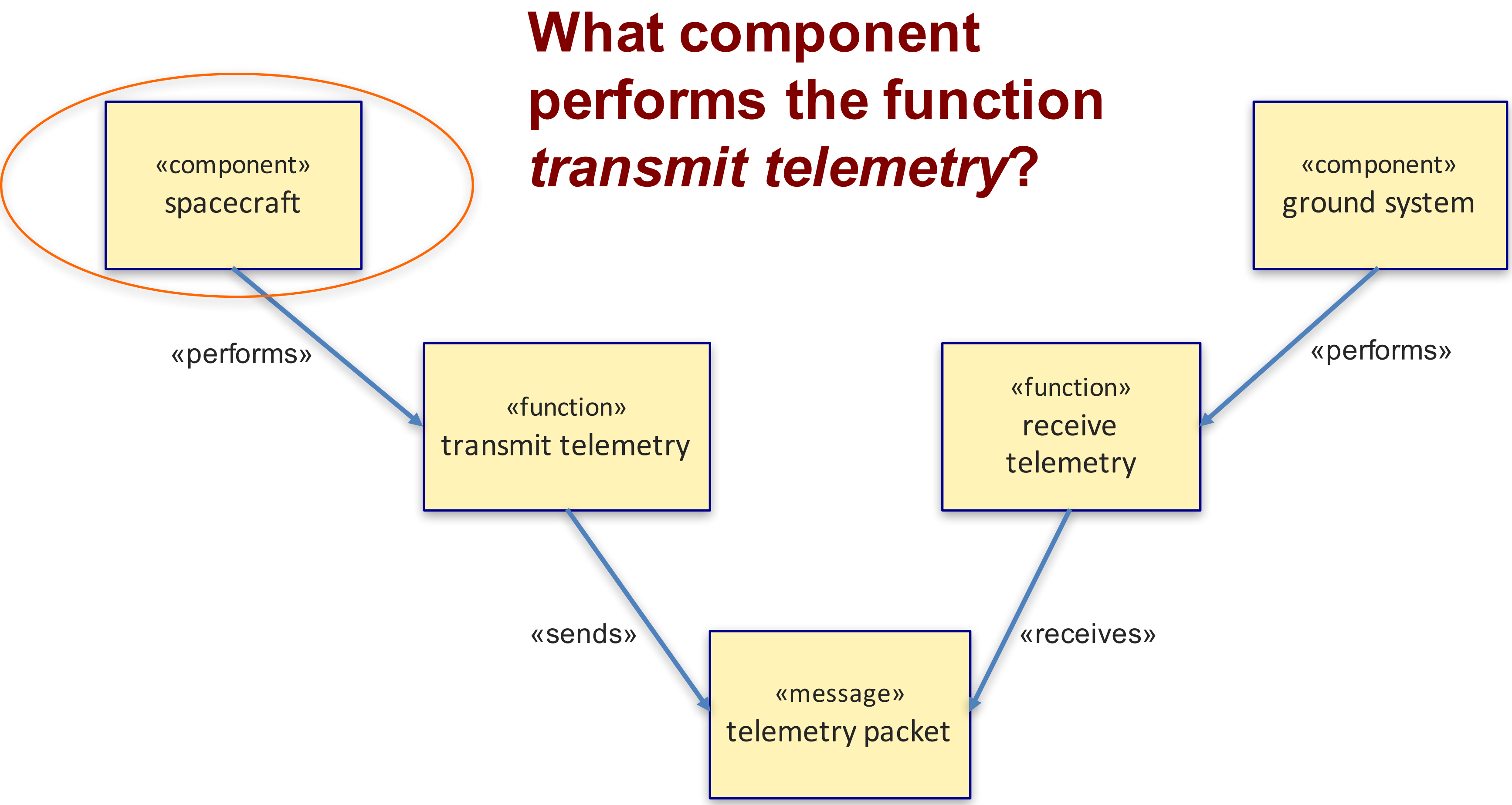


Add Typed Relationships



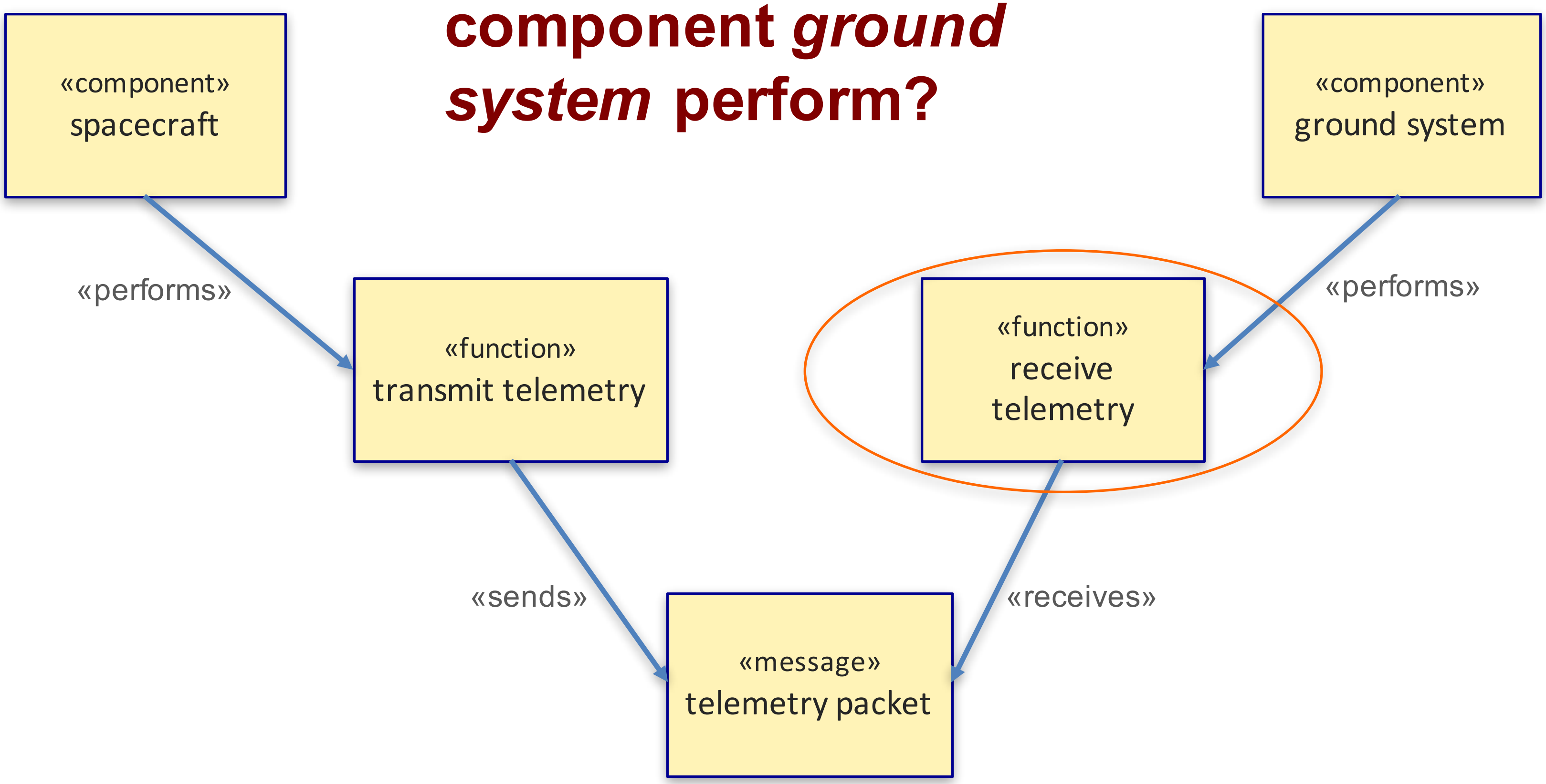
Note that relationships are now directed.

More Questions and Answers



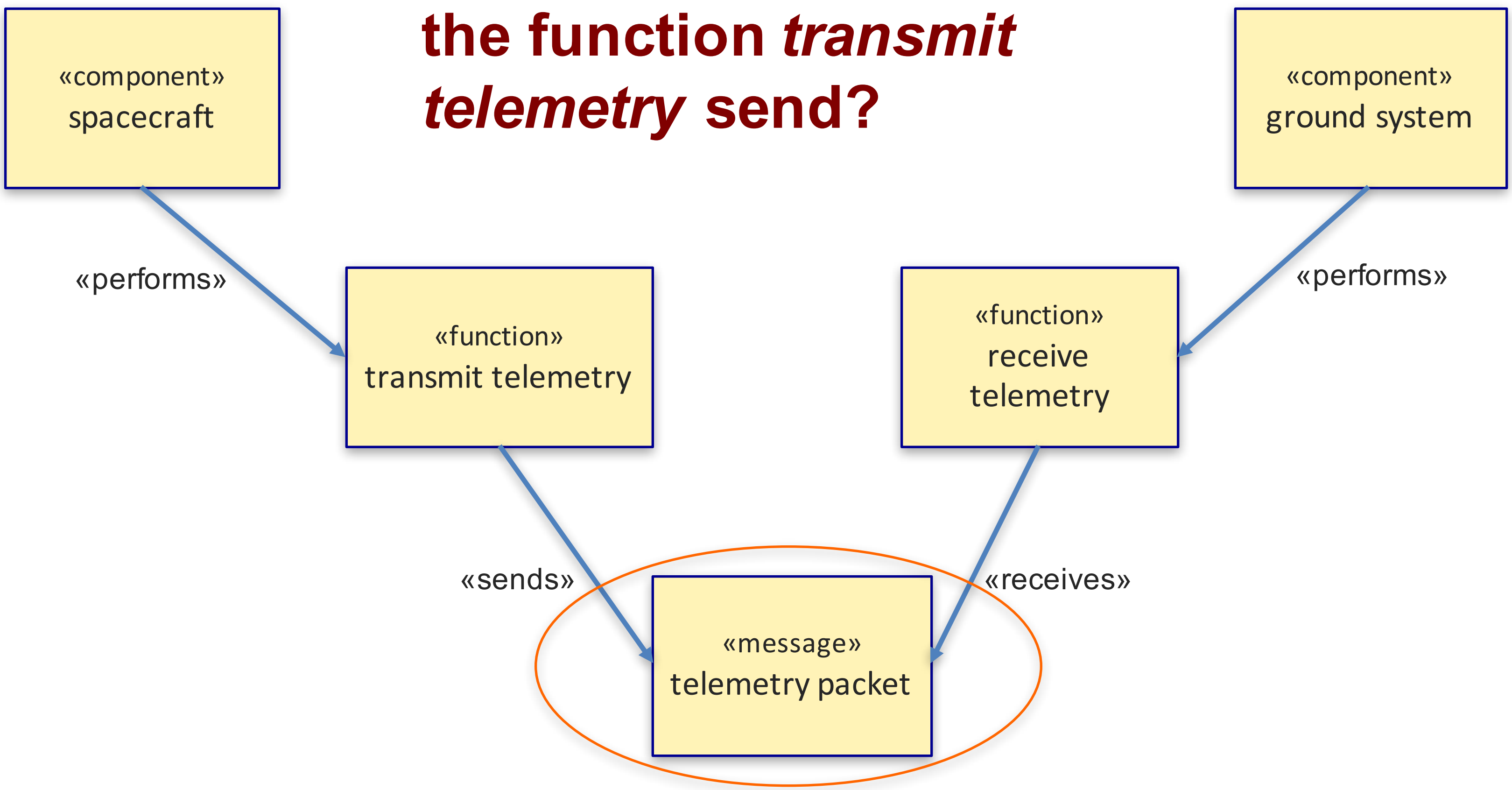
More Questions and Answers

What functions does the component *ground system* perform?



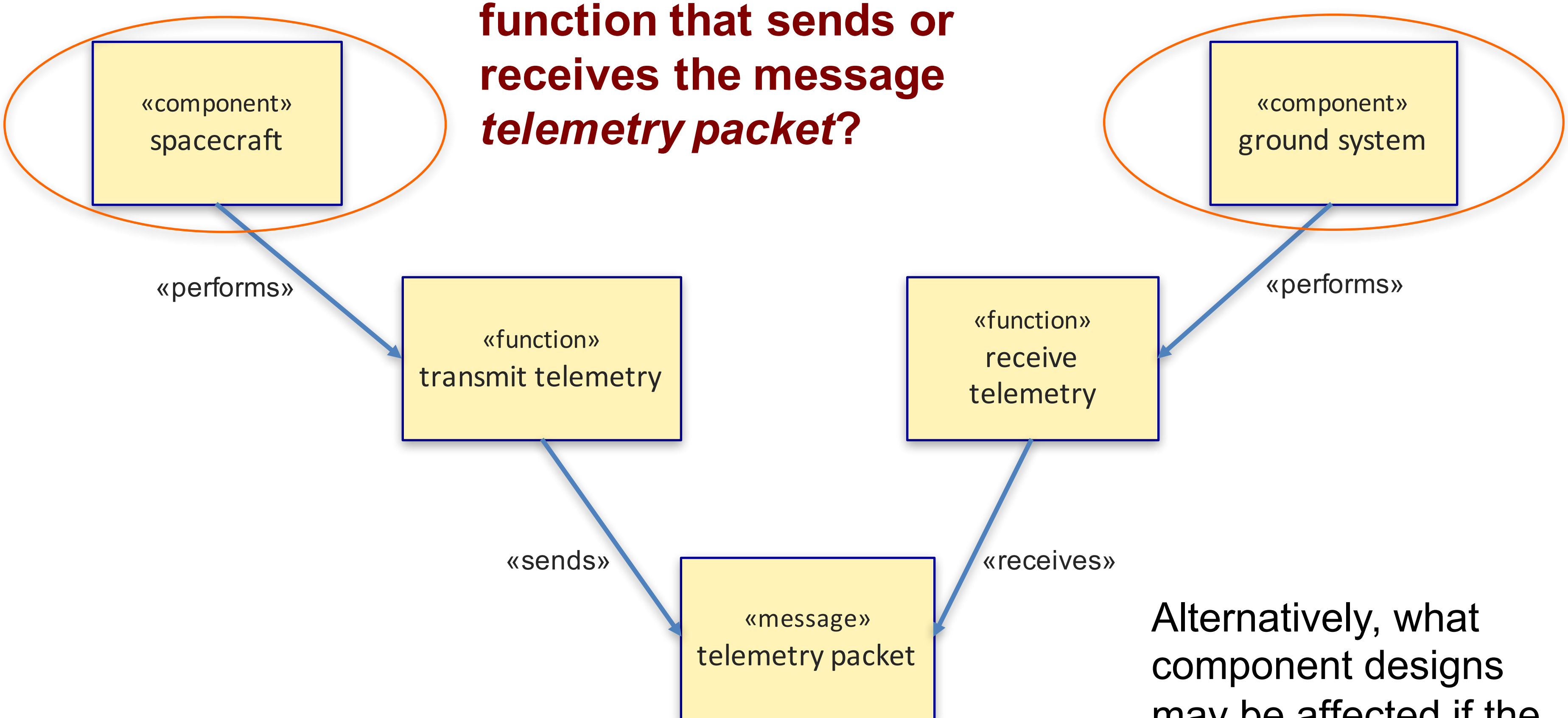
More Questions and Answers

What messages does the function *transmit telemetry* send?



More Questions and Answers

What components perform a function that sends or receives the message *telemetry packet*?



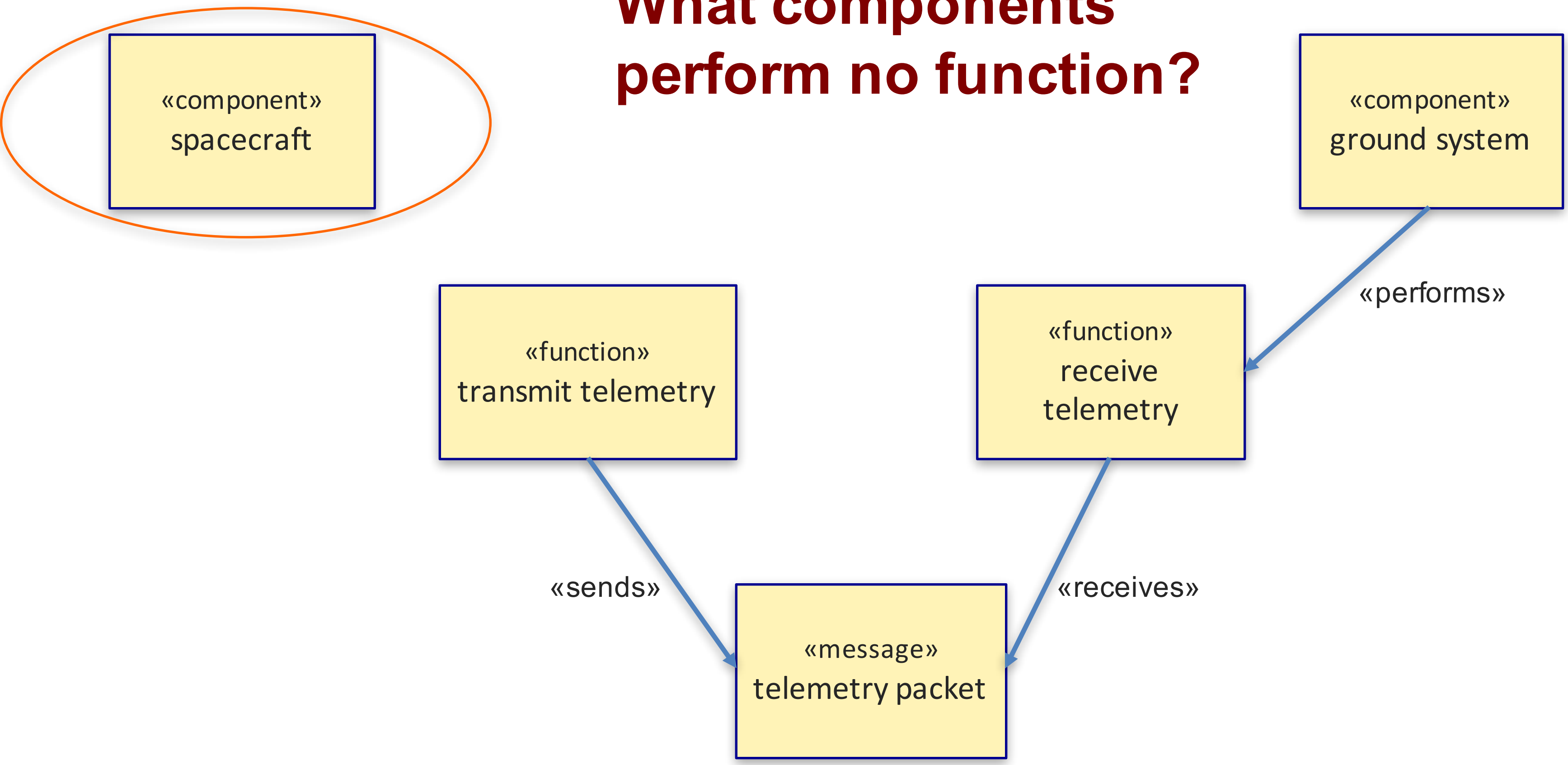
Alternatively, what component designs may be affected if the definition of *telemetry packet* changes?

Reasoning About Models

- We can use models to answer questions
- The questions may be about the system itself
  - What is it?
  - How does it work?
  - Is the performance adequate?
  - What happens if something breaks?
- The questions may be about the model
  - Is it complete?
  - Is it consistent?
  - Does it support required analyses?
- The questions may be about the design artifacts
  - Are all required documents present?
  - Does each document contain all required content?
- We call answering these kinds of questions *reasoning*
  - It doesn't necessarily mean exotic, artificial intelligence

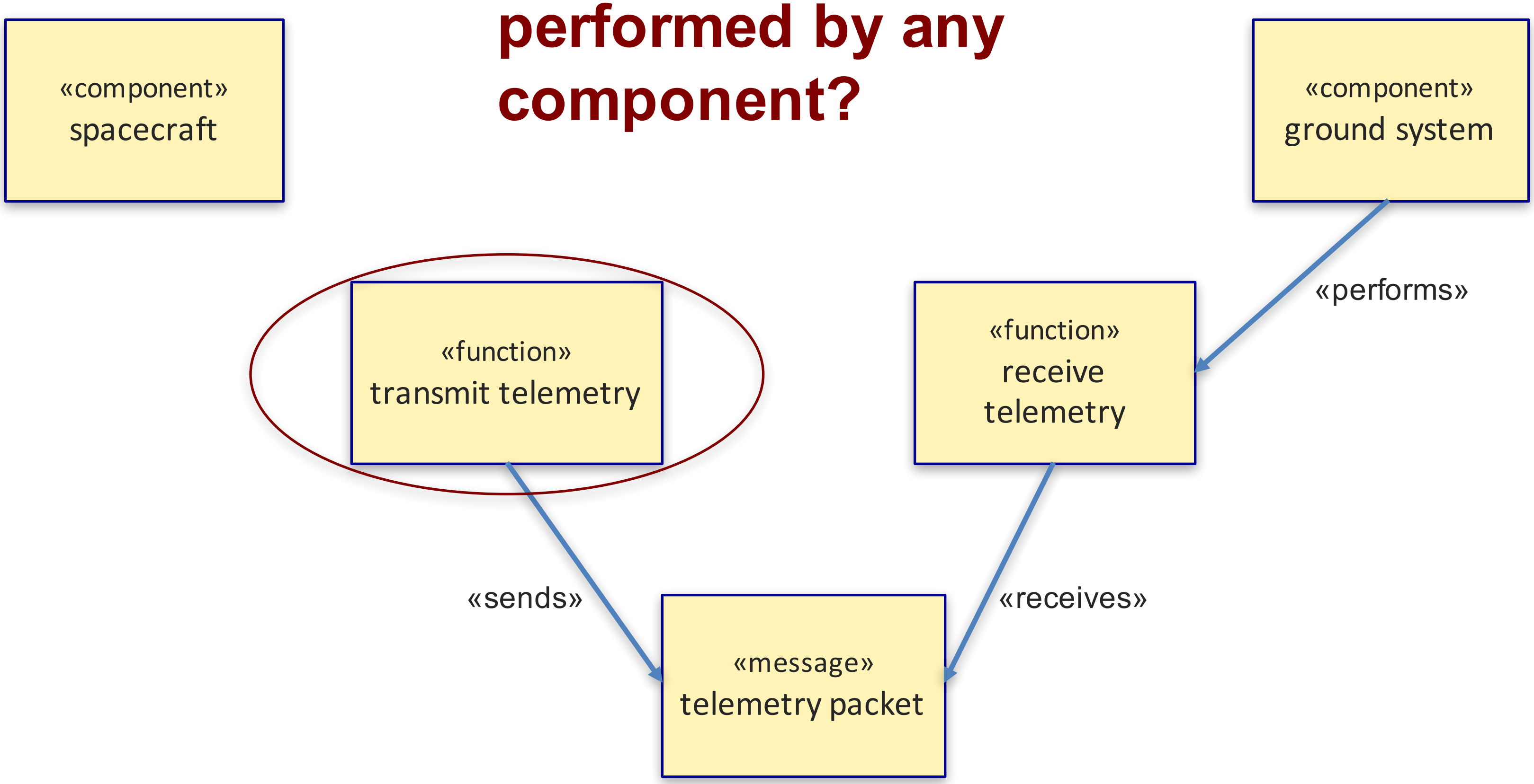
Reasoning About Completeness

What components perform no function?



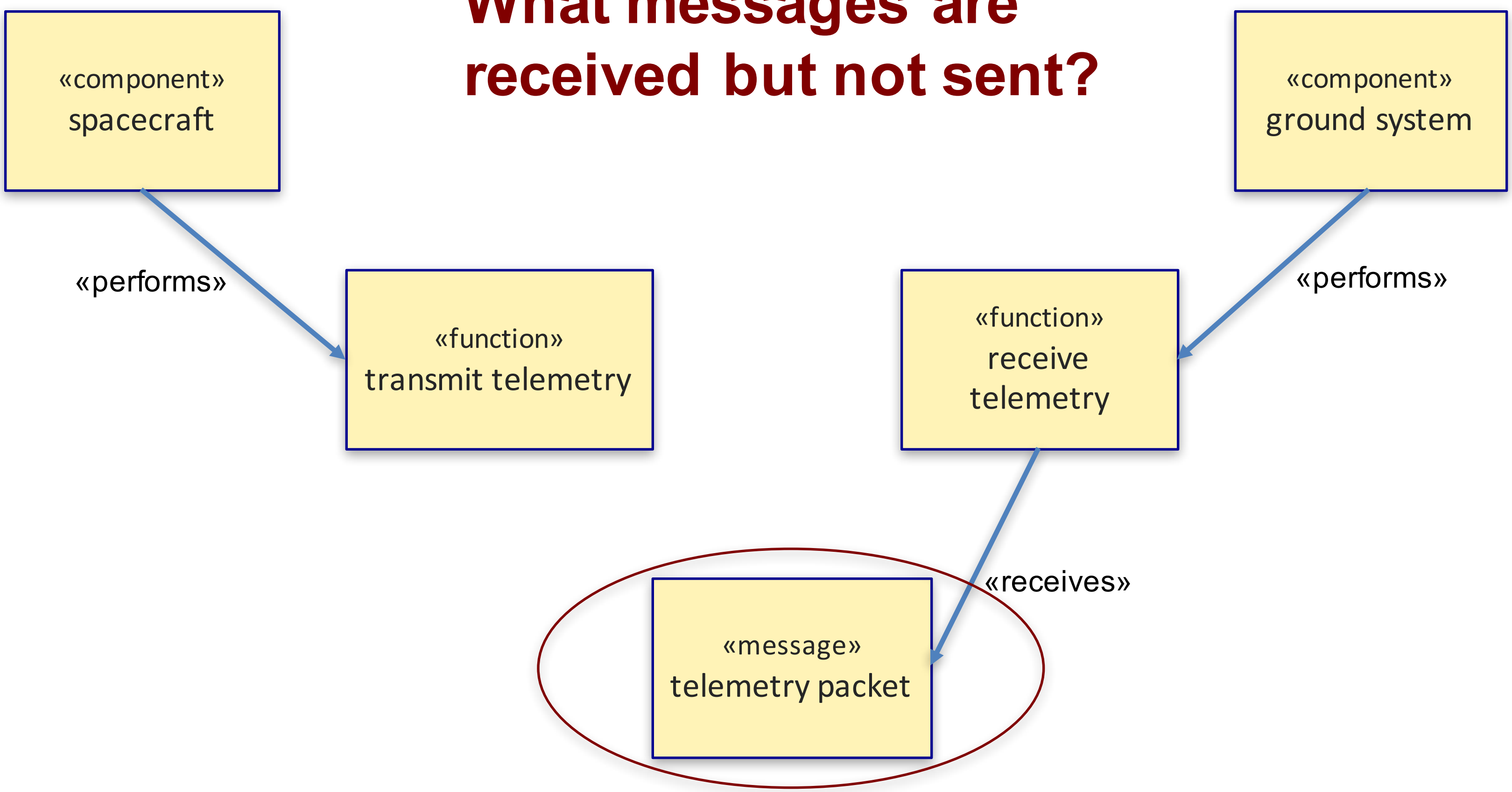
Reasoning About Completeness

What functions are not performed by any component?

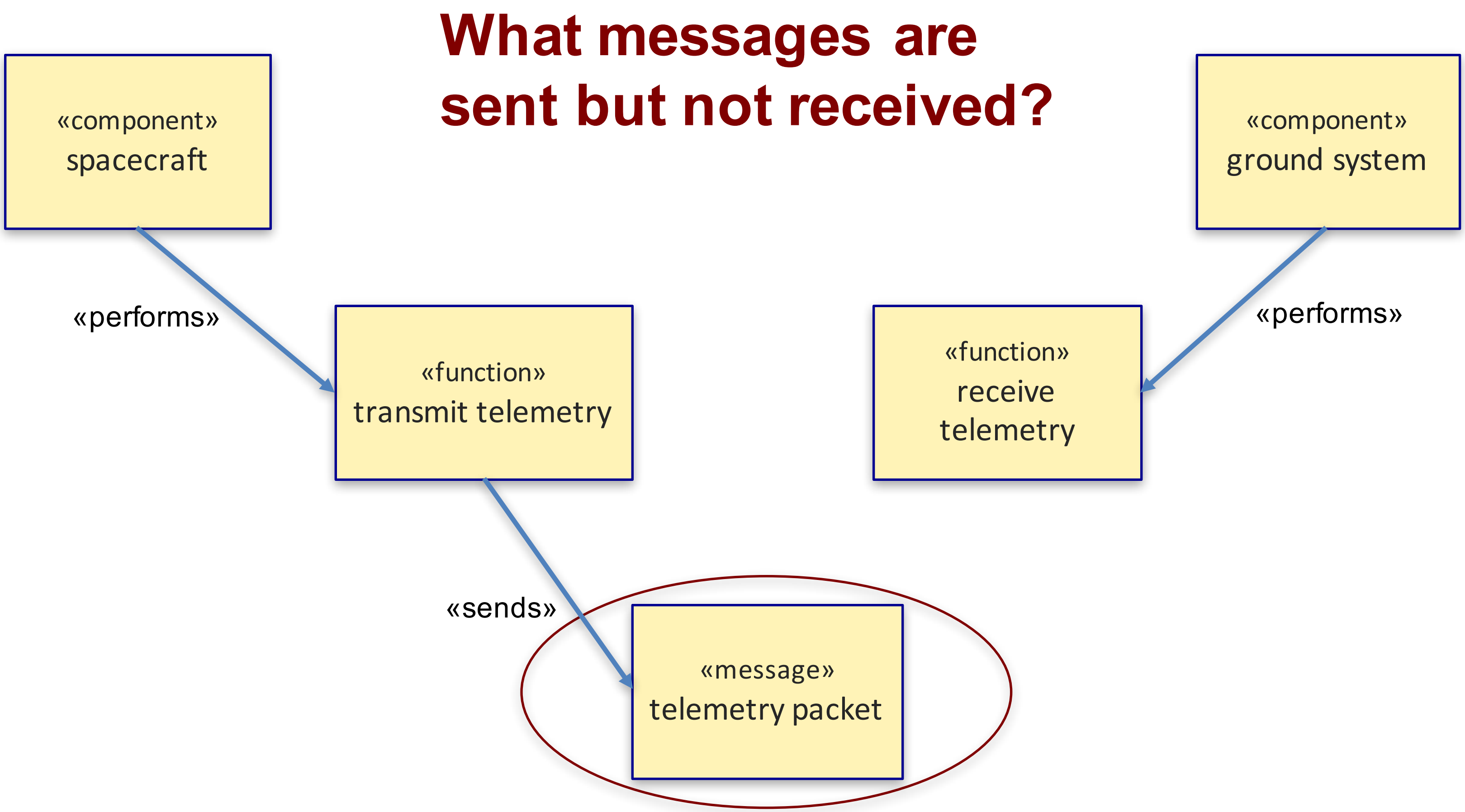


Reasoning About Completeness

What messages are received but not sent?

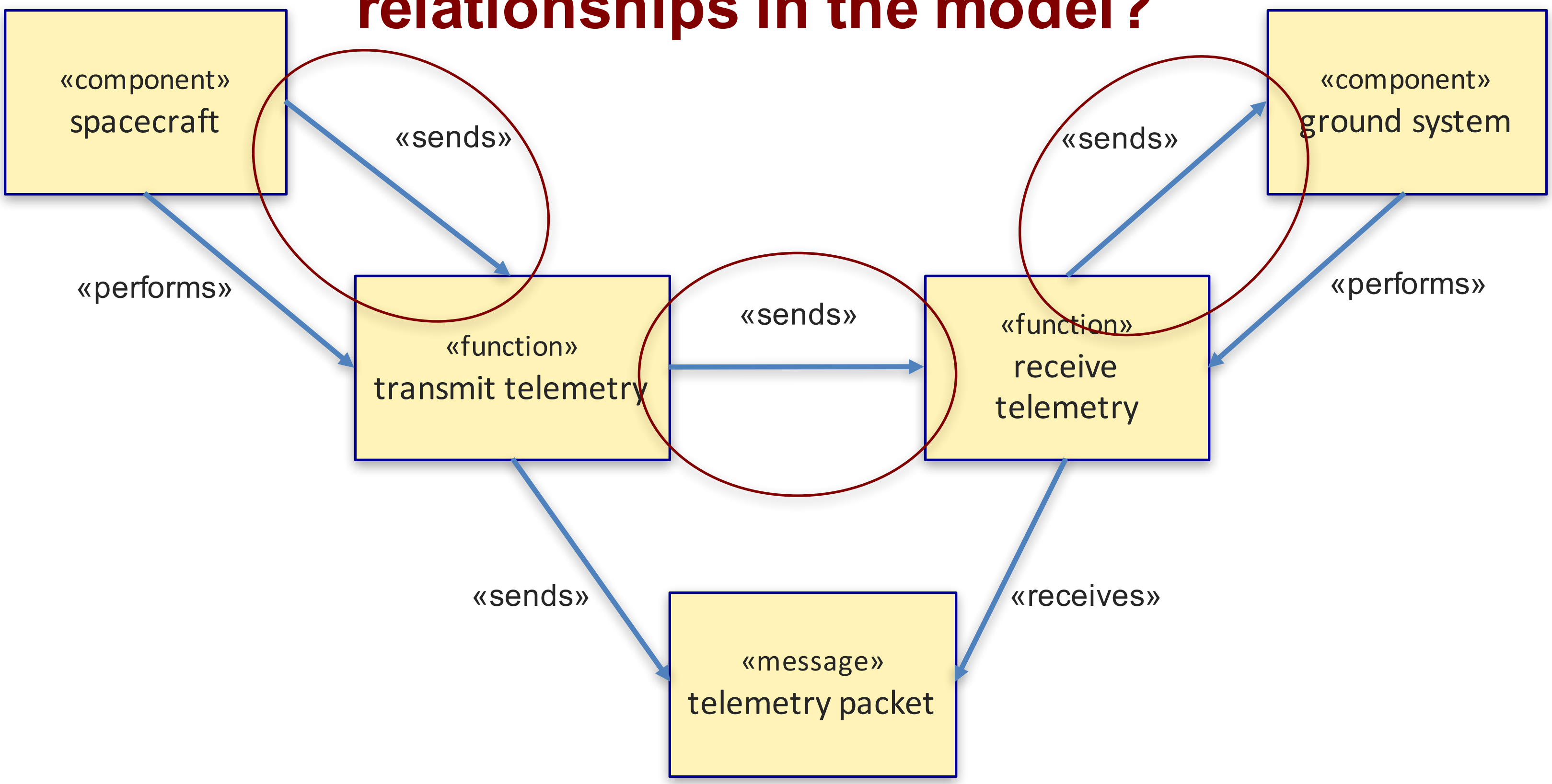


Reasoning About Completeness

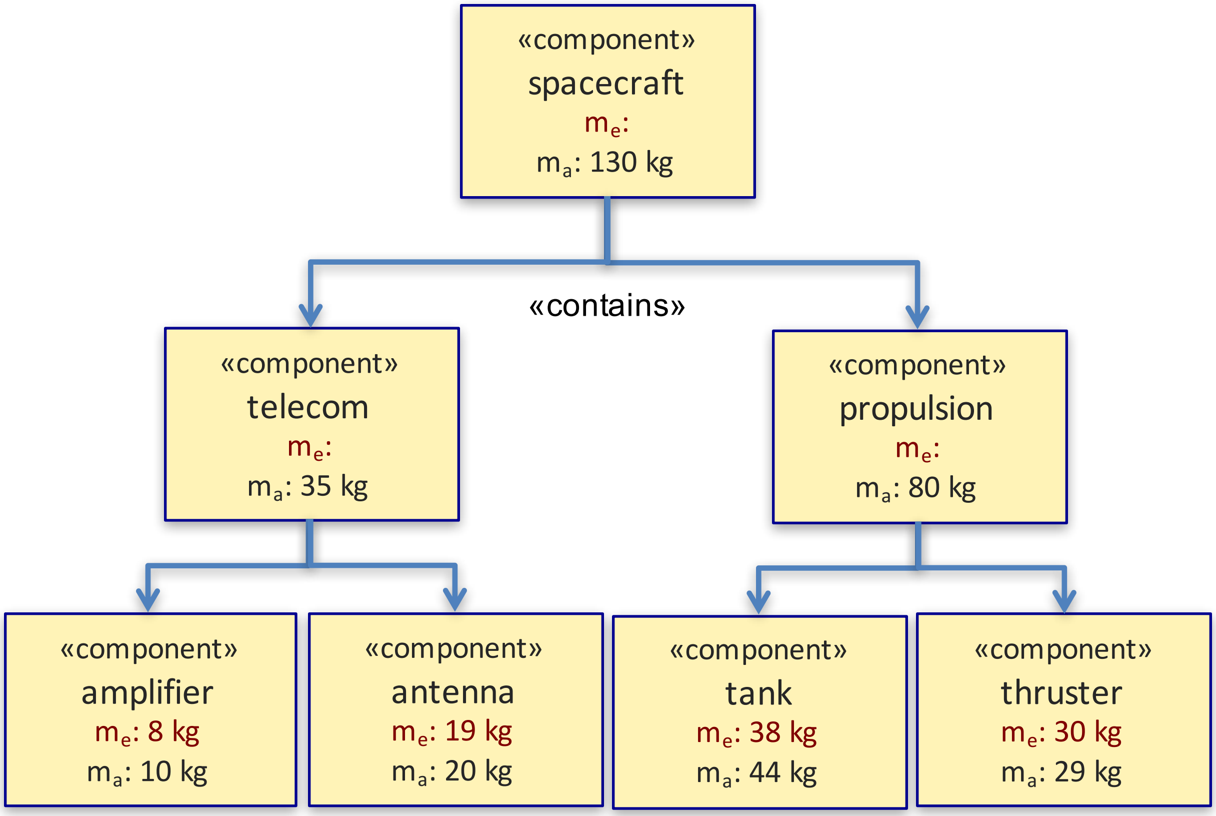


Reasoning About Consistency

Are there illegal or meaningless relationships in the model?



Reasoning About Design

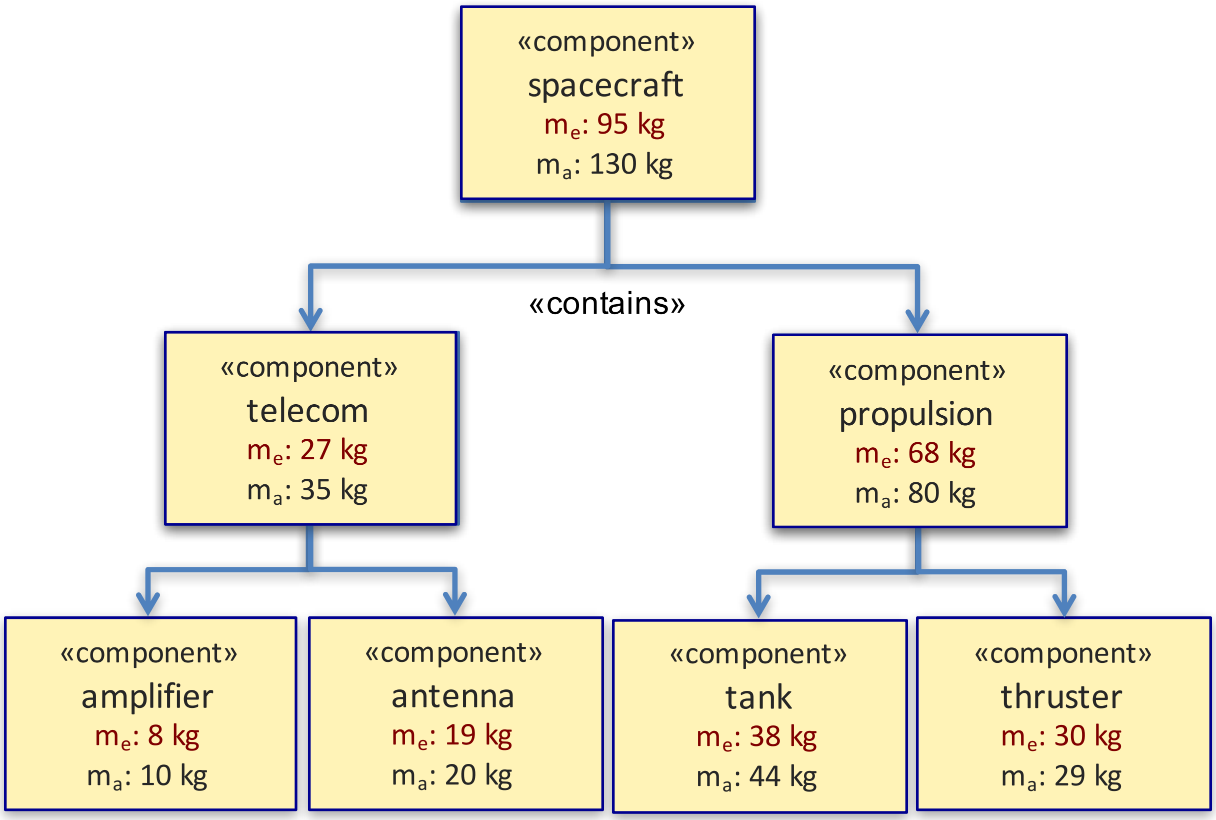


Each component has:

- allocated mass (m_a)
- estimated mass (m_e)

m_e: estimated mass
m_a: allocated mass

Reasoning About Design



Each component has:
- allocated mass (m_a)
- estimated mass (m_e)

Rule: Estimated mass m_e of any component with parts is the sum of m_e of its parts

m_e: estimated mass
m_a: allocated mass

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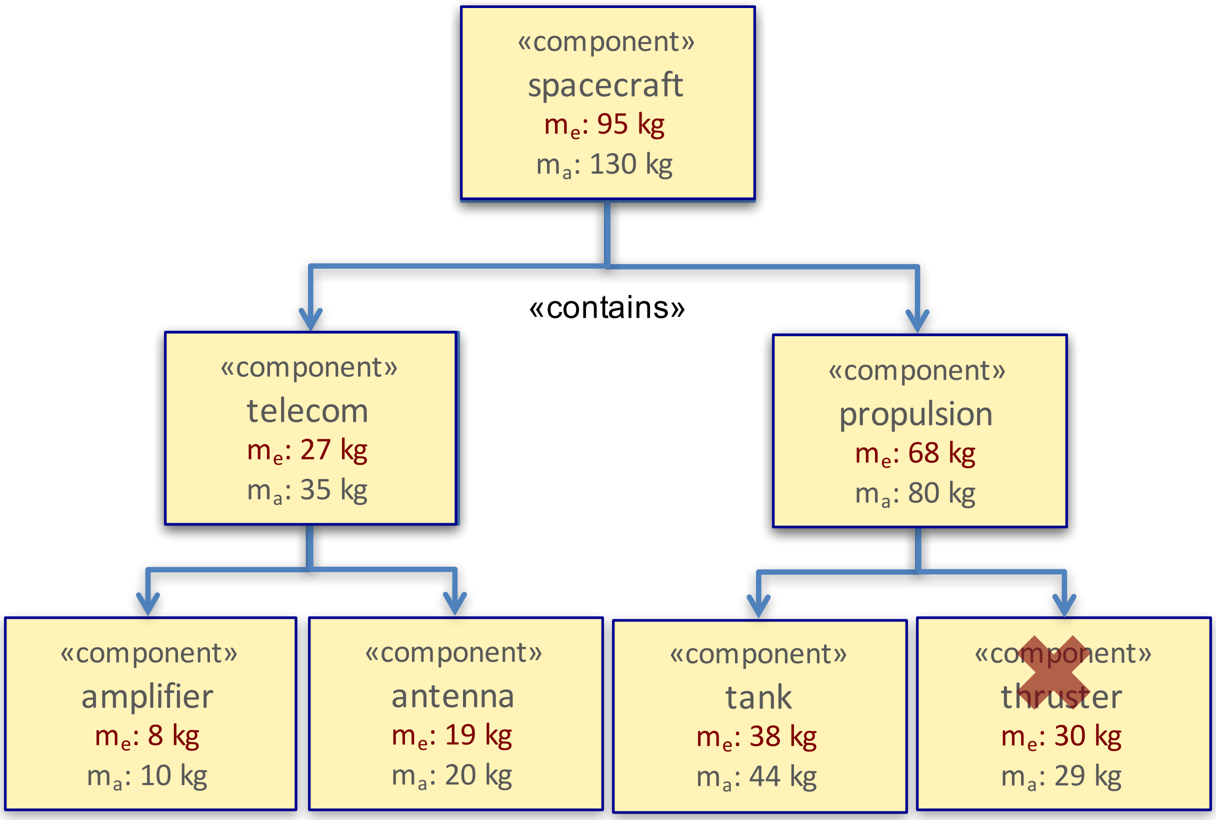
Reasoning About Design



Each component has:
- allocated mass (m_a)
- estimated mass (m_e)

Rule: CBE mass m_e of any component with parts is the sum of m_e of its parts

Policy: m_e < m_a for every component

m_e: estimated mass
m_a: allocated mass

How: Representing Ontologies using OWL and SysML

- OWL is a language for expressing ontologies using a logical formalism
- SysML is a graphical modeling language for representing systems engineering concepts

Component has *performs* relationship with Function
Hardware specializes Component
FlightHardware specializes Hardware
FlightHardware has *mass* property
StarTracker specializes FlightHardware

OWL

```
<!-- http://imce.jpl.nasa.gov/mission/mission...

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    <rdfs:subClassOf rdf:resource="&base;Container"/>
    <rdfs:subClassOf rdf:resource="&base;IdentifiedElement"/>
    <rdfs:subClassOf rdf:resource="&mission;PerformingElement"/>
    <rdfs:subClassOf>
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    <rdfs:subClassOf>
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    <owl:disjointWith rdf:resource="&mission;Environment"/>
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        &lt;classname&gt;Component&lt;/classname&gt;s include launch vehicle, spacecraft, telecommunication subsystem,
    flight software, attitude control software, and mission operations team.&lt;/para&gt;</dc:description>
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```
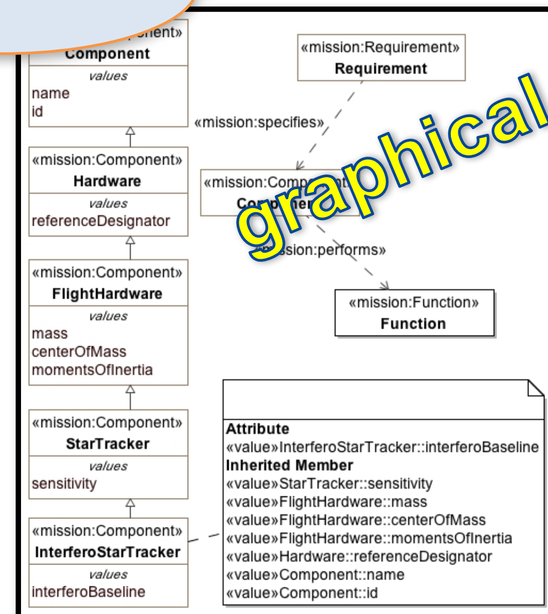

rigorously formal

Logical Automatic Processing

SysML

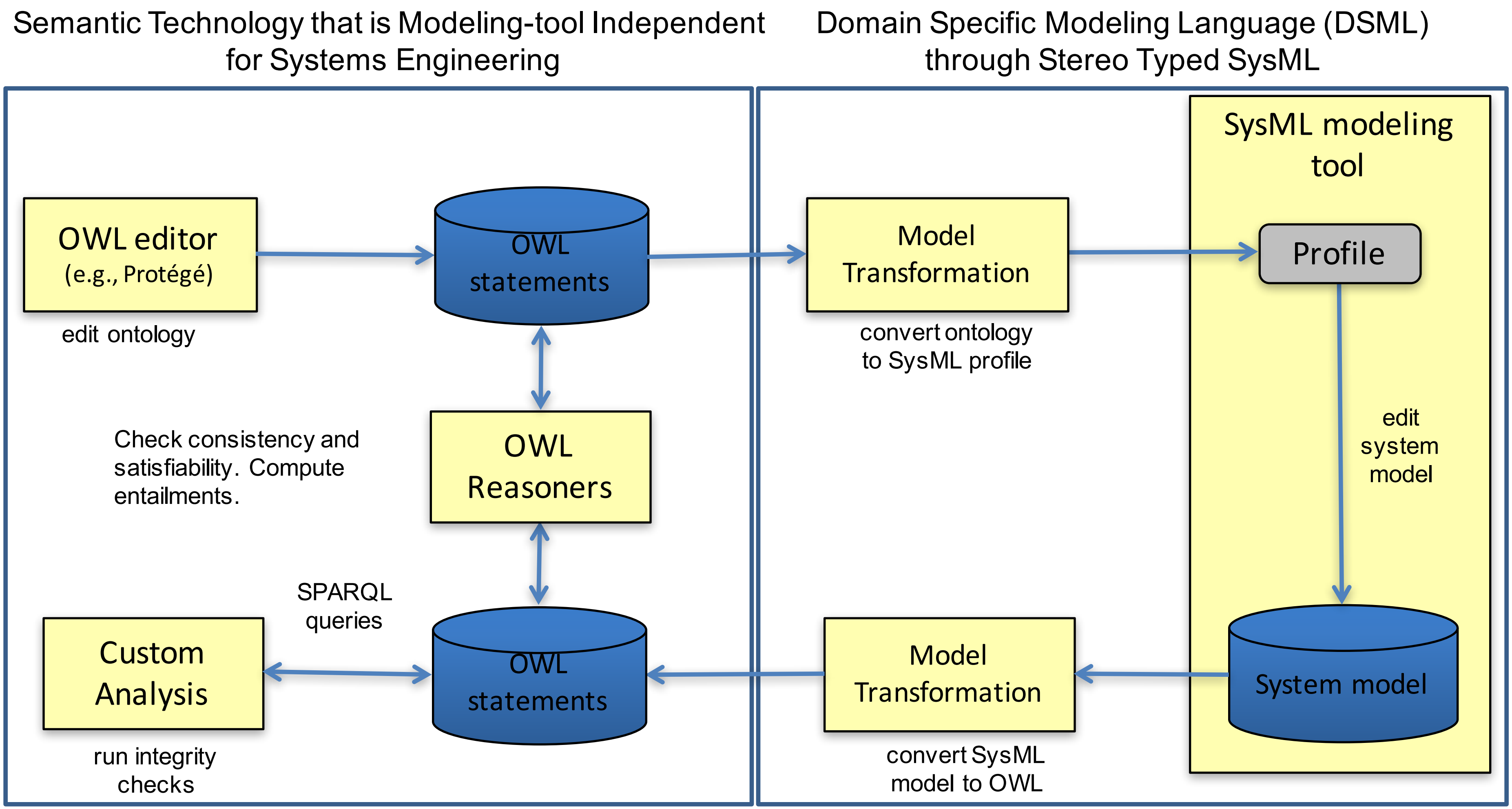


graphical

Ad-hoc Automatic Processing

MBSE approach leverages both OWL and SysML

IMCE Vision for OWL/SysML Integration



This is *one* example of how OWL and SysML tools might be used in MBSE

English → OWL → SysML Profile → Usage

(animated)

1

English: “Component performs Function”

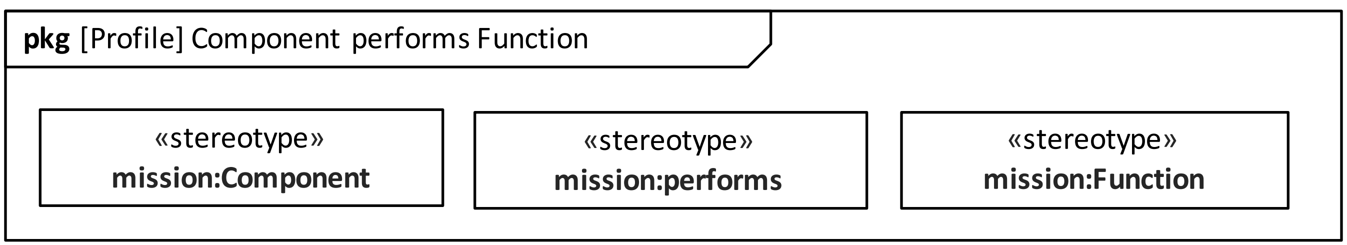
2

OWL (RDF)

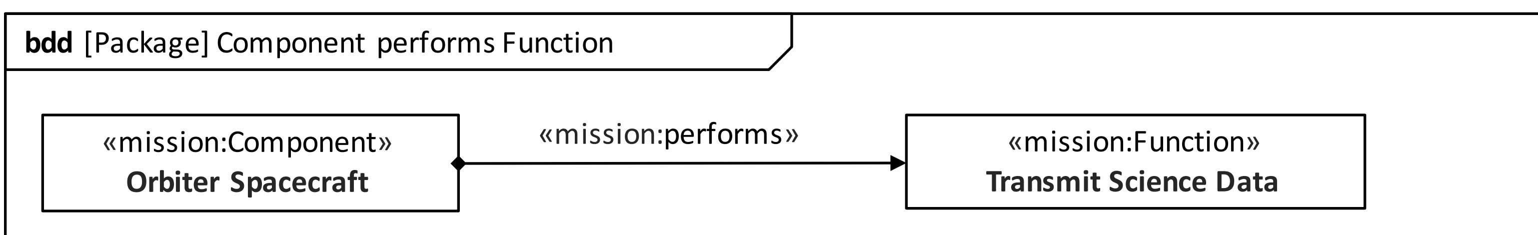
```
<owl:Class rdf:about="&mission;Function">
      <rdfs:subClassOf rdf:resource="&base;IdentifiedElement"/>
      <rdfs:subClassOf rdf:resource="&mission;SpecifiedElement"/>
</owl:Class>
<owl:Class rdf:about="&mission;Component">
      <rdfs:subClassOf rdf:resource="&base;ContainedElement"/>
      <rdfs:subClassOf rdf:resource="&base;Container"/>
      <rdfs:subClassOf rdf:resource="&base;IdentifiedElement"/>
      <rdfs:subClassOf rdf:resource="&mission;PerformingElement"/>
</rdfs:subClassOf>
</owl:Class>
```

```
<owl:ObjectProperty rdf:about="&mission;performs">
      <rdf:type rdf:resource="&owl;AsymmetricProperty"/>
      <rdf:type rdf:resource="&owl;InverseFunctionalProperty"/>
      <rdf:type rdf:resource="&owl;IrreflexiveProperty"/>
      <rdfs:range rdf:resource="&mission;Function"/>
      <rdfs:domain rdf:resource="&mission;PerformingElement"/>
</owl:ObjectProperty>
```

3 SysML profile

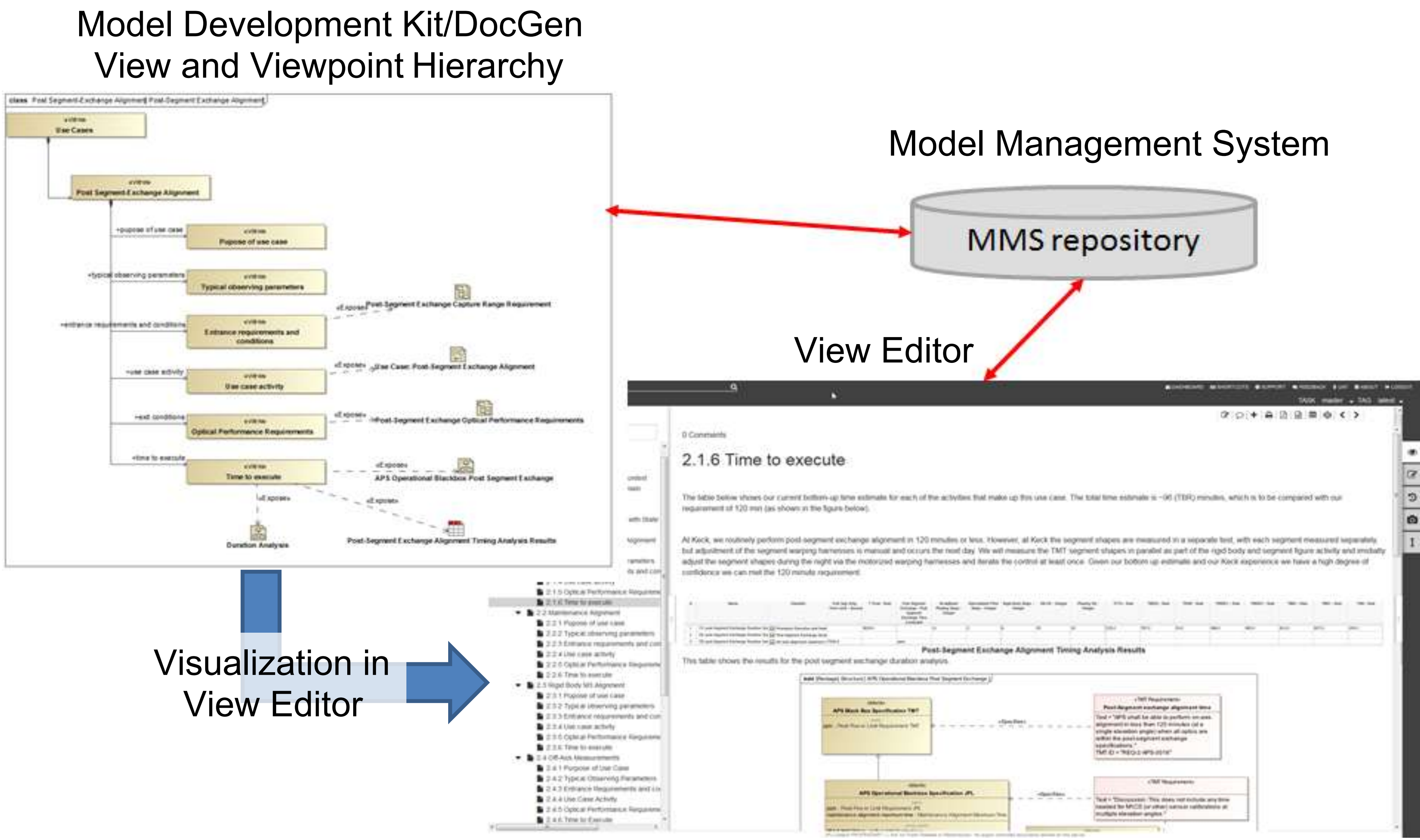


4 Usage

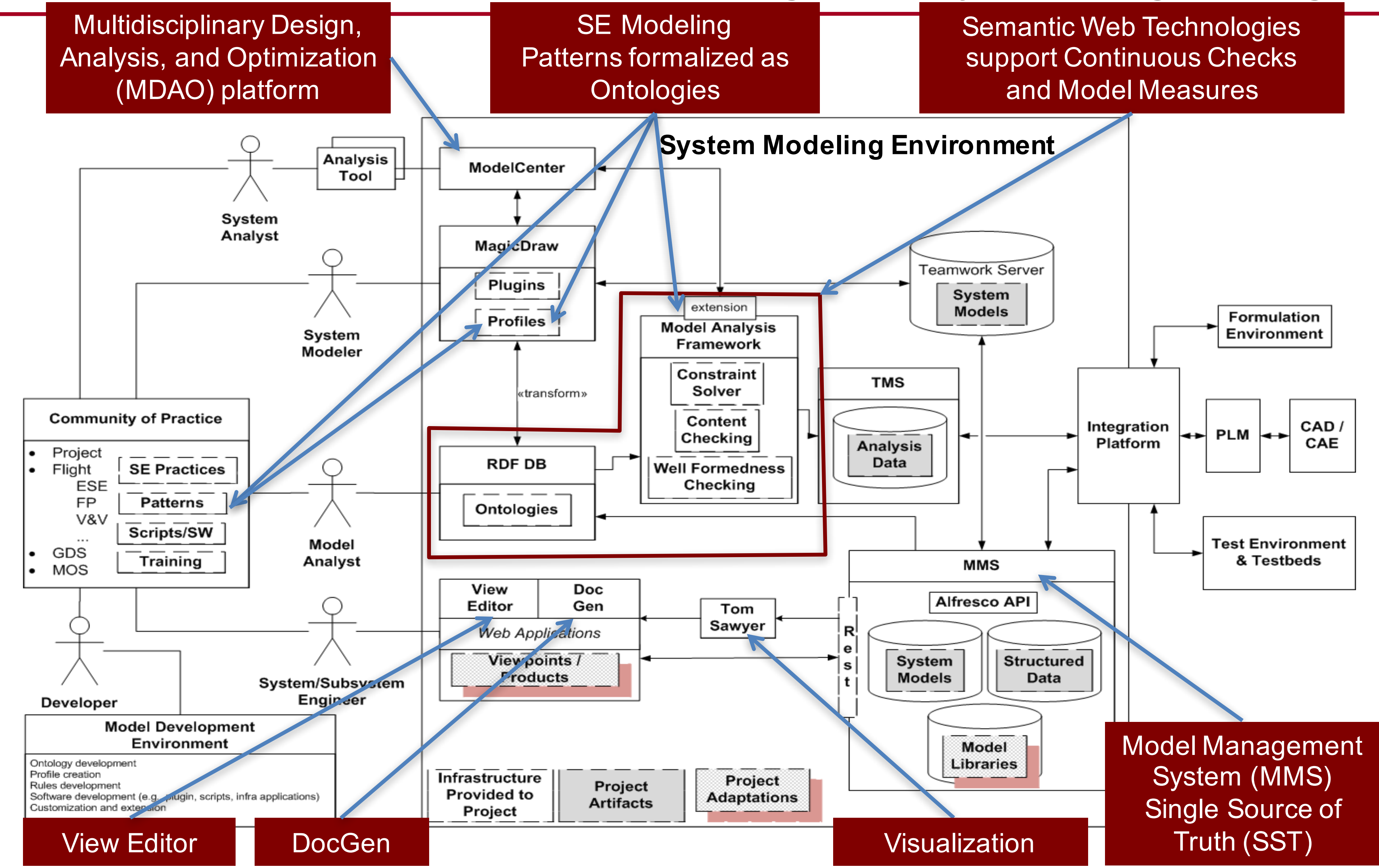


Semantic Web Technologies >
Integrated Modeling Environment >
Modeling Method Alternatives >
MDAO (Time Permitting)

OpenMBEE: Model Development Kit (MDK), MMS, View Editor



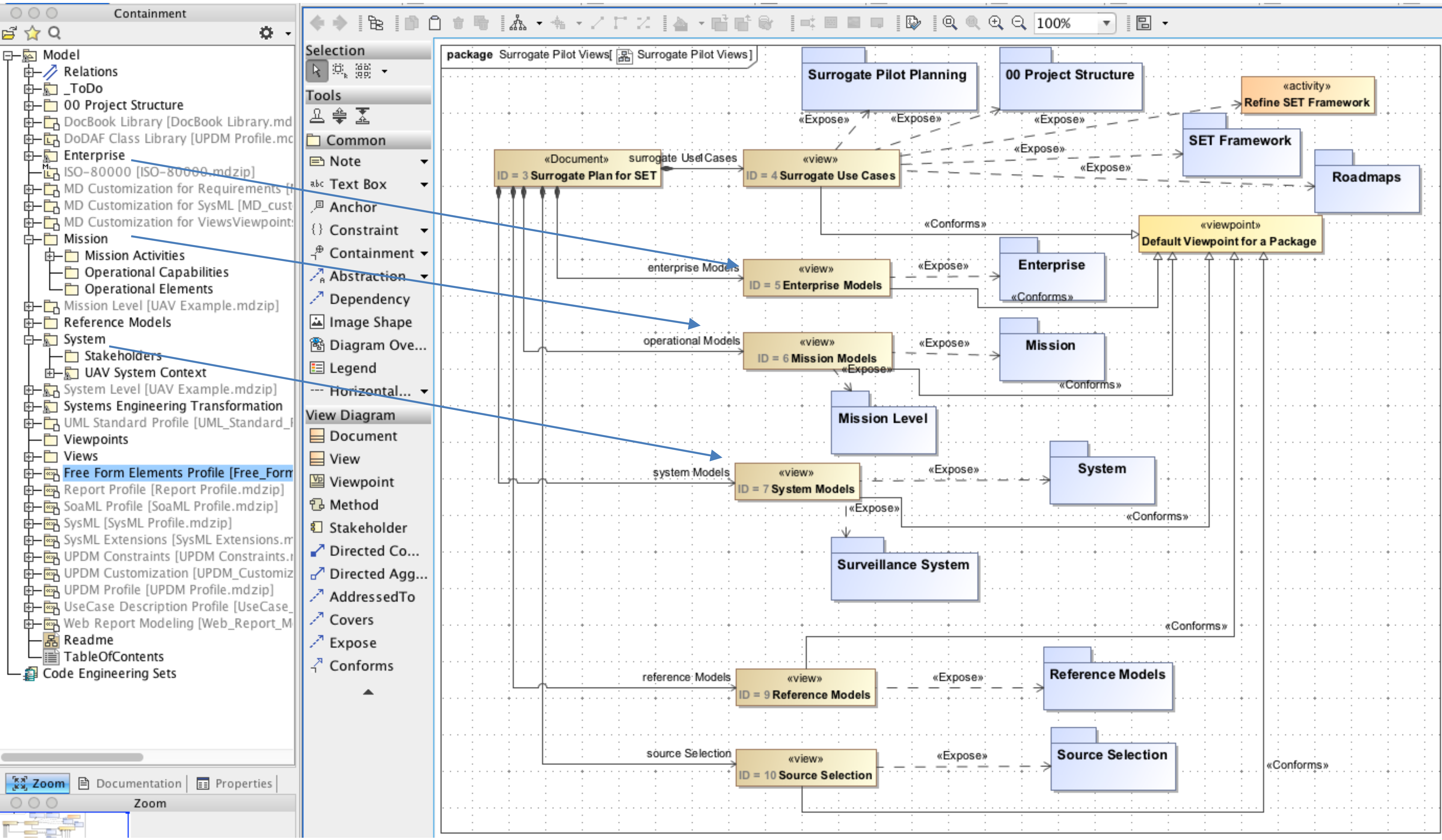
Using OpenMBEE and Look to Adopt Semantic Technologies for Systems Engineering



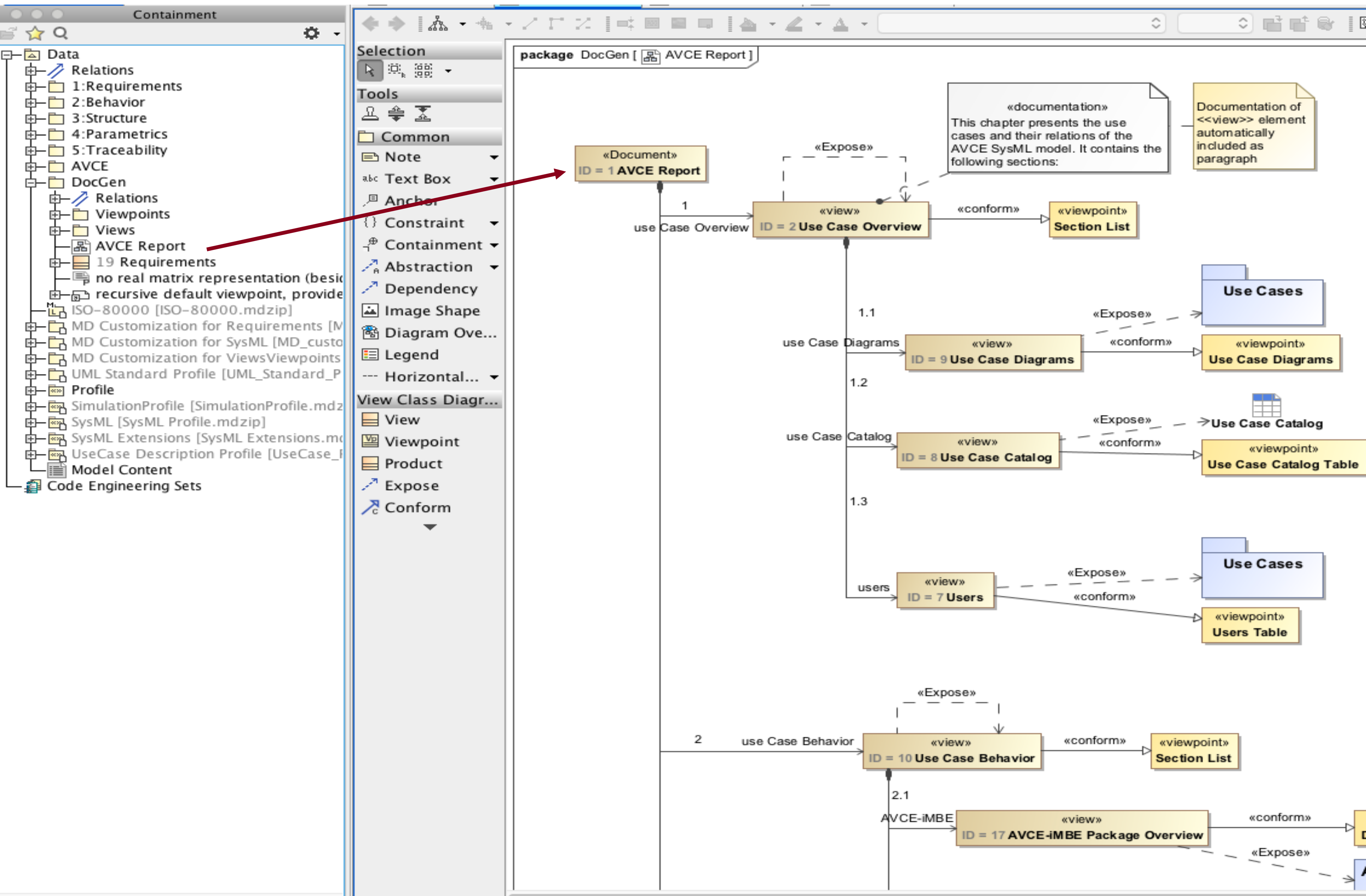
*An Integrated Model Centric Engineering (IMCE) Reference Architecture for a Model Based Engineering Environment (MBEE), NASA/JPL, Sept, 2014.

SERC 168/170.

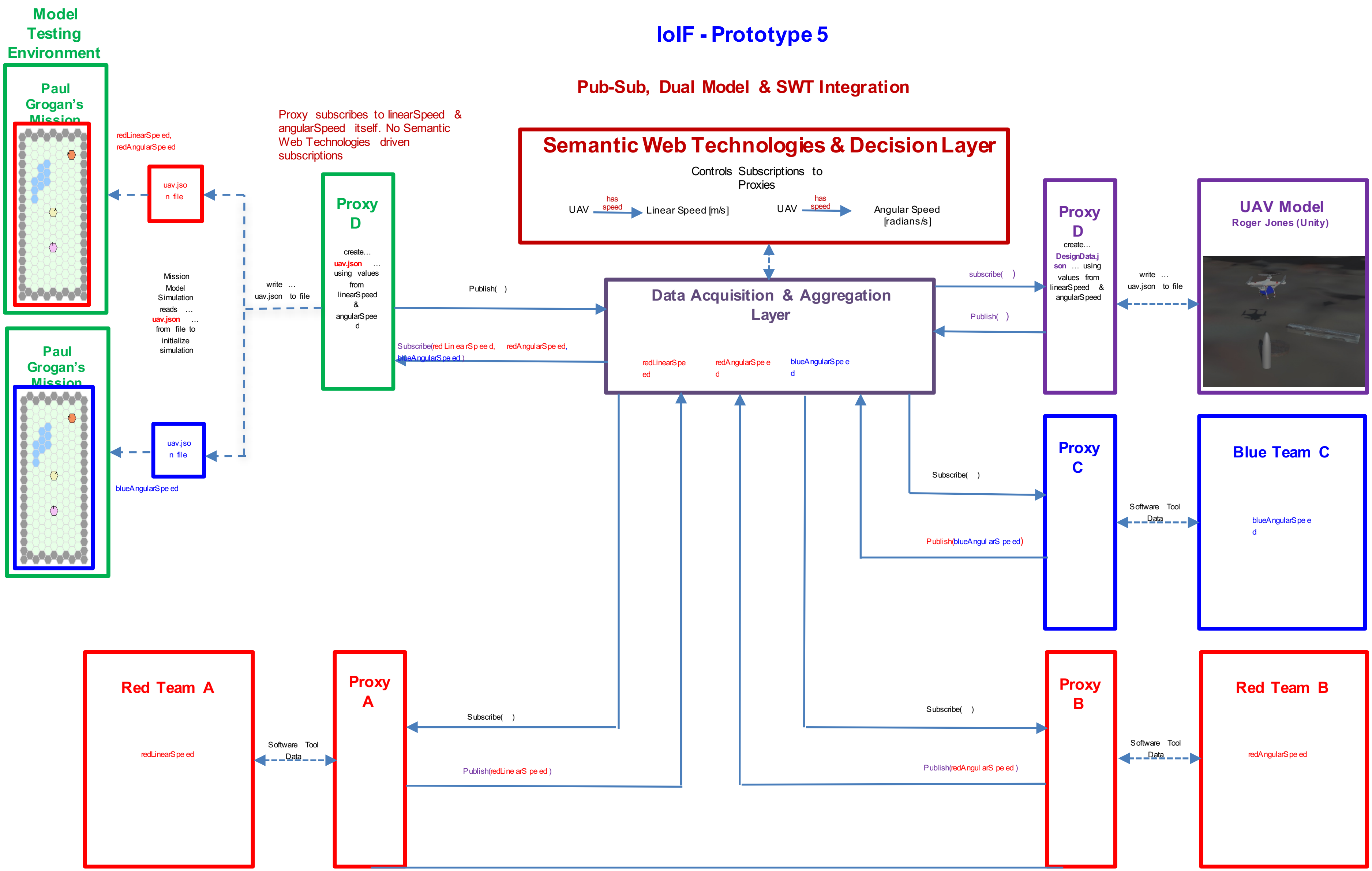
Modeling Enterprise and Model for Systems Engineering Transformation Pilot



View and Viewpoint Hierarchy for AVCE Model



RT168 – High Level Integrating and Interoperability Framework (IoIF) Design



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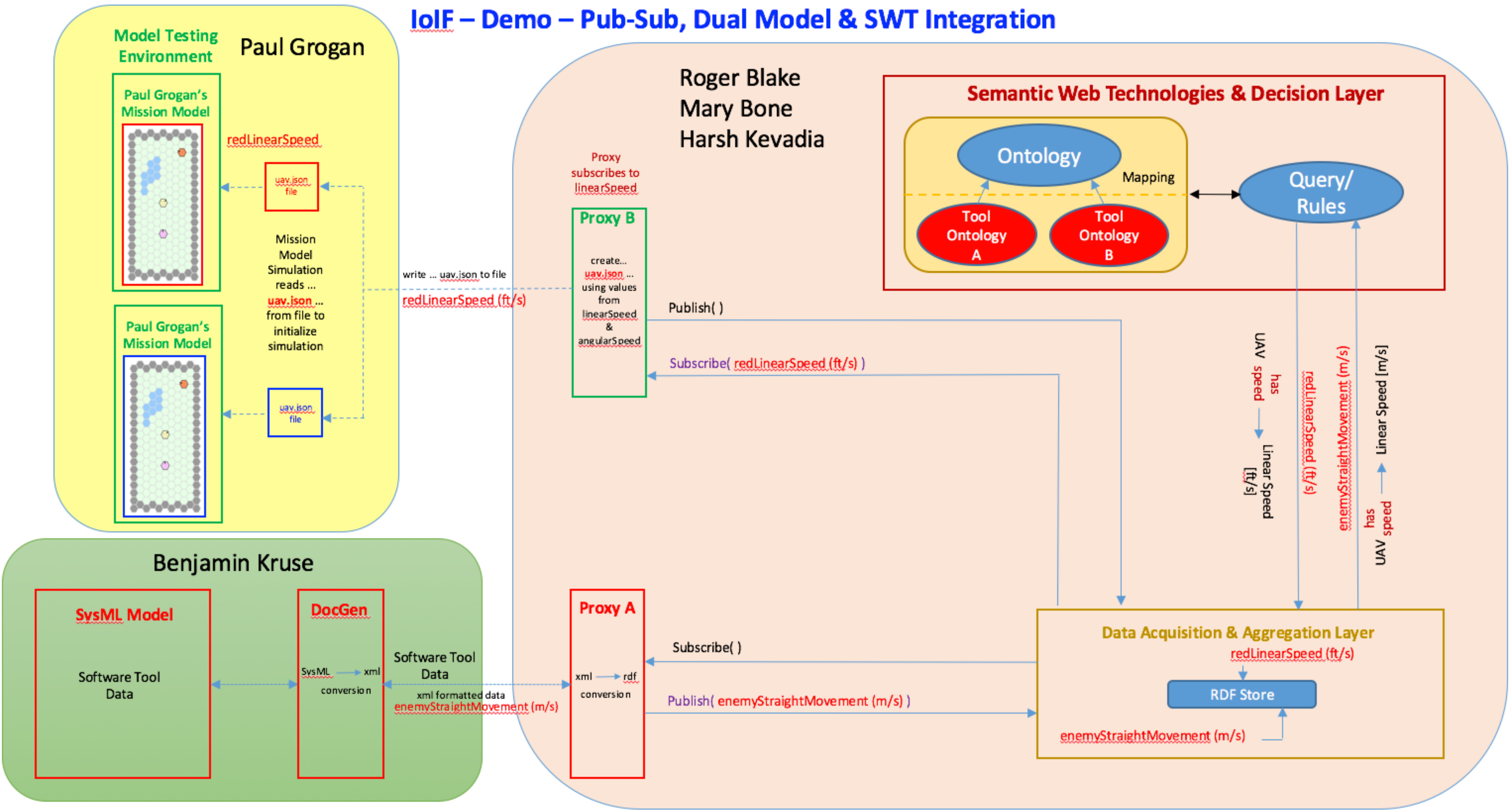
IoIF Uses SWT for Interoperability Among “Any” Type of MCE Capability

RT168 – High Level Integrating and Interoperability Framework (IoIF) Design

IoIF – Demo – Pub-Sub, Dual Model & SWT Integration

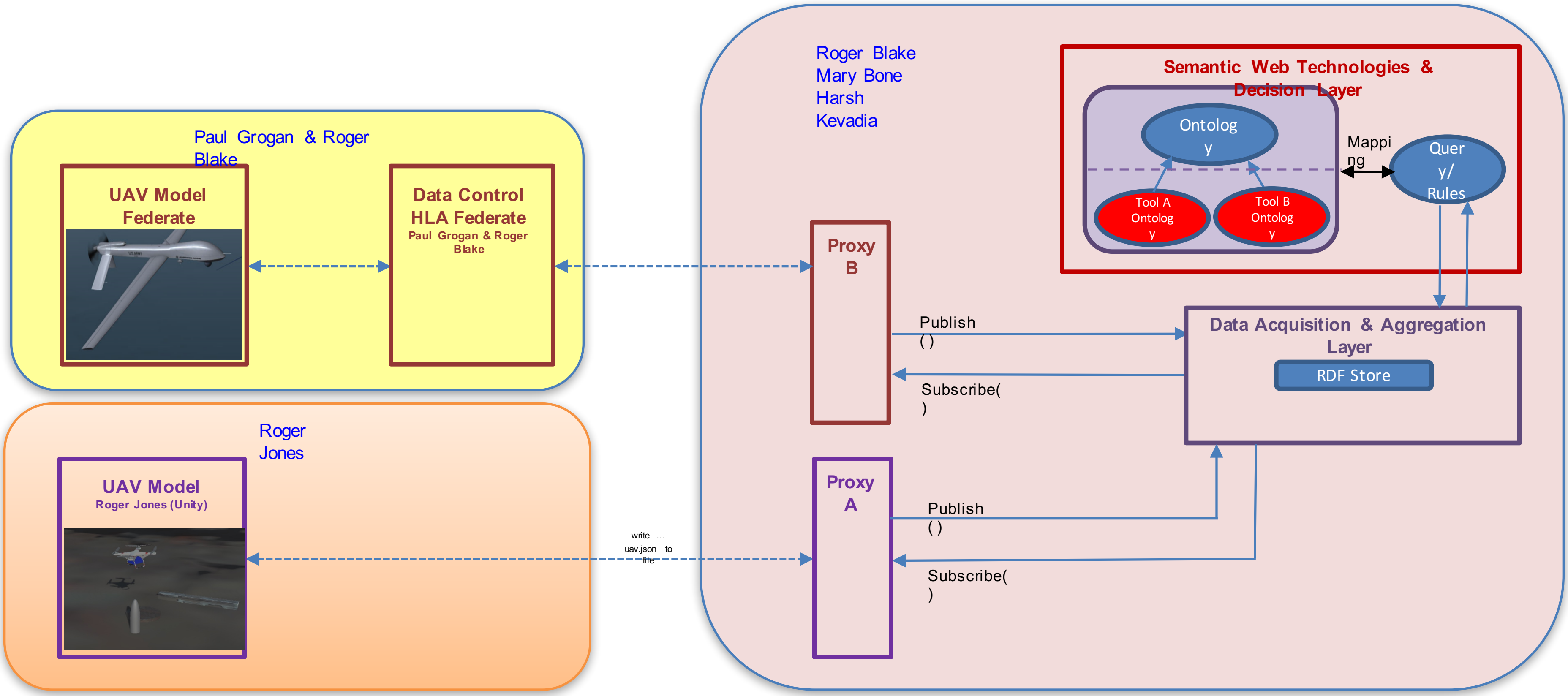


IoIF Integrating High-End Mission and Simulation with Graphical CONOPS

RT168 – High Level Integrating and Interoperability Framework (IoIF) Design

IoIF - Prototype 7

Pub-Sub, Dual Active Models & SWT Integration with Continuous Data Communications



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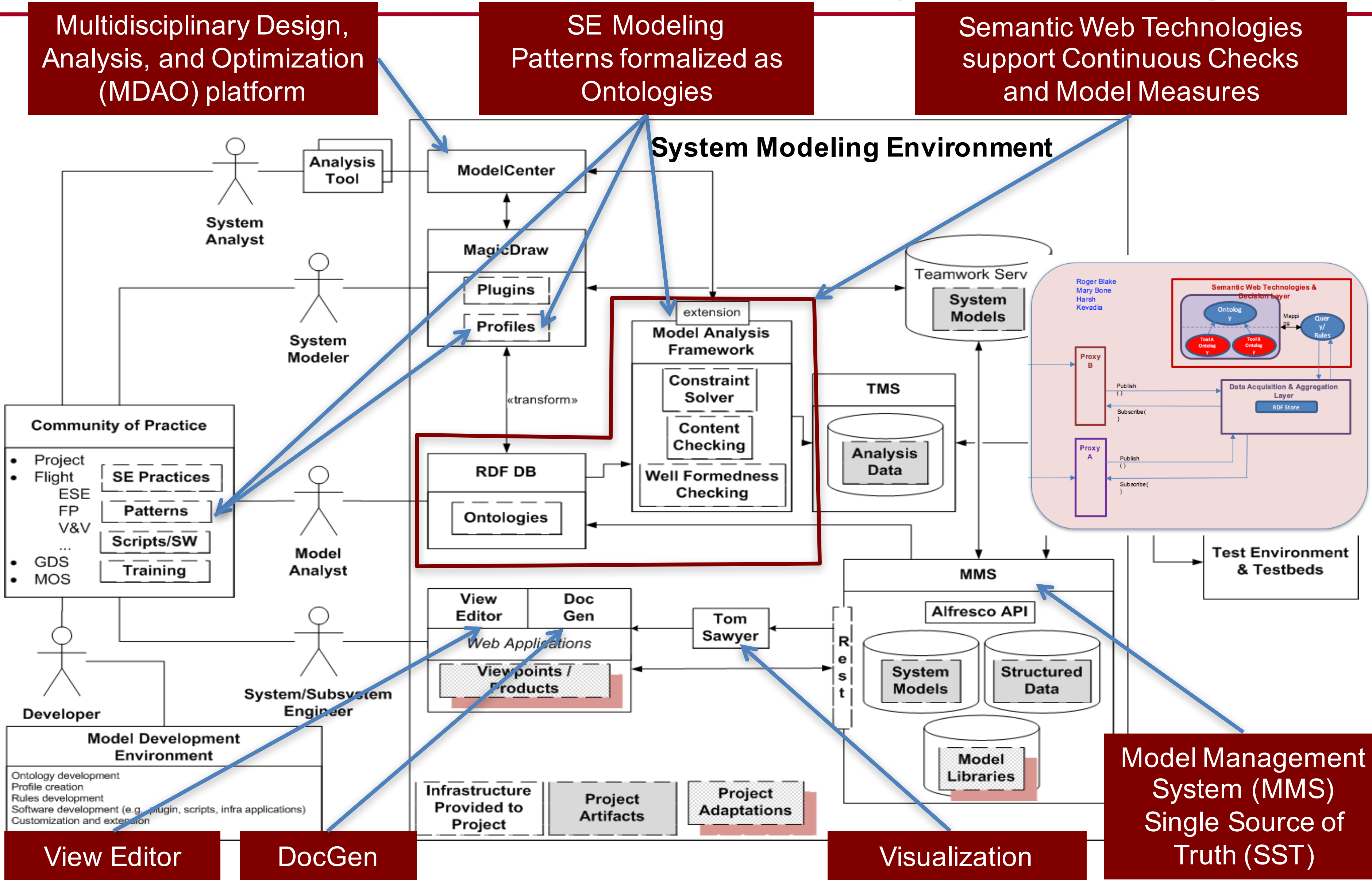
Planned CONCEPT for Integrating Technologies into OpenMBEE through IoIF



*An Integrated Model Centric Engineering (IMCE) Reference Architecture for a Model Based Engineering Environment (MBEE), NASA/JPL, Sept, 2014.

Why Semantic Web Technologies and Ontologies – Realized Benefits in Automotive

- Enabled reusing previous knowledge
- Prevented engineer from entering incorrect information
- Reduce complexity
- Automatically check consistency between two (or more) models
- Makes visible to engineer dependencies in other models, and how a change in their model might affect corresponding model
- Better management and building of models
- Define meta-rules that constrain correct models, and which can be checked at model building time
- Improved model management process

S. Biffl and M. Sabou, Eds., *Semantic Web Technologies for Intelligent Engineering Applications*. Cham: Springer International Publishing, 2016.

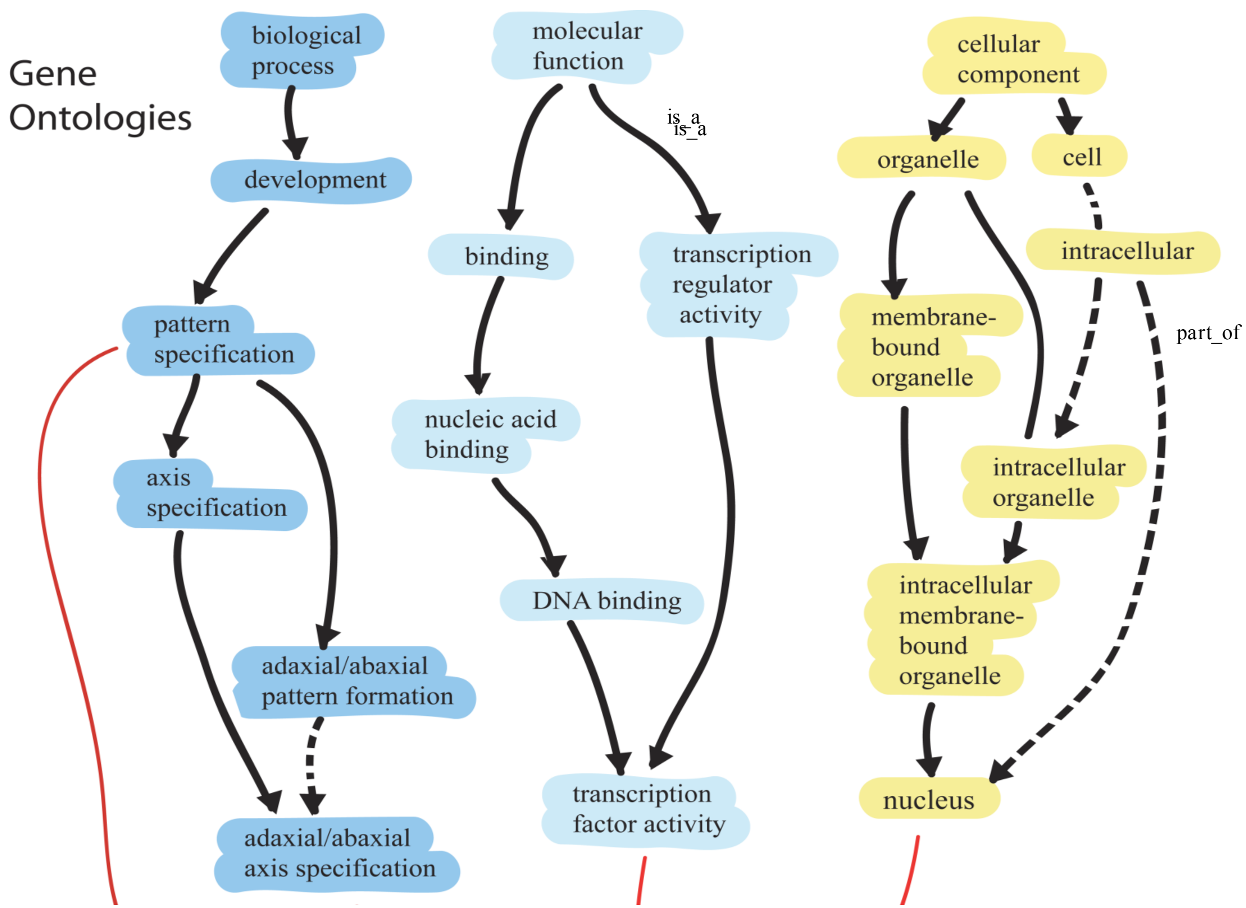
Open Biomedical Ontologies (OBO) Successful Results from Interoperable Ontologies

- Value of any kind of data is greatly enhanced when it exists in a form that allows it to be integrated with other data
  - One approach is through annotation of multiple bodies of data using common controlled vocabularies or 'ontologies'
  - Unfortunately, the very success of this approach has led to a proliferation of ontologies, which itself creates obstacles to integration
- OBO ontologies, including the Gene Ontology, are undergoing coordinated reform, and new ontologies are being created on basis of evolving set of shared principles governing ontology development
- Result is an expanding family of ontologies designed to be **interoperable** and logically well formed and to incorporate accurate representations of biological reality
- Collaborator: Dr. Barry Smith

Gene Ontology (GO) Concept

GO's three sub-ontologies

biological process | molecular function | cellular component



SERC 168/170.

Original OBO (Open Biomedical Ontologies) Foundry: Creating Interoperable Ontologies

- Resulted in coordination to solve Genome
- Are there parallels to Systems Engineering?

<table>
<tr><th rowspan="2">RELATION TO TIME
GRANULARITY</th><th colspan="4">CONTINUANT</th><th rowspan="2">OCCURRENT</th></tr>
<tr><th colspan="2">INDEPENDENT</th><th colspan="2">DEPENDENT</th></tr>
<tr><td>ORGAN AND ORGANISM</td><td>Organism (NCBI Taxonomy)</td><td>Anatomical Entity (FMA, CARO)</td><td>Organ Function (FMP, CPRO)</td><td rowspan="2">Phenotypic Quality (PaTO)</td><td rowspan="2">Biological Process (GO)</td></tr>
<tr><td>CELL AND CELLULAR COMPONENT</td><td>Cell (CL)</td><td>Cellular Component (FMA, GO)</td><td>Cellular Function (GO)</td></tr>
<tr><td>MOLECULE</td><td colspan="2">Molecule (ChEBI, SO, RnaO, PrO)</td><td colspan="2">Molecular Function (GO)</td><td>Molecular Process (GO)</td></tr>
</table>

Original OBO (Open Biomedical Ontologies) Foundry
(Gene Ontology in yellow)

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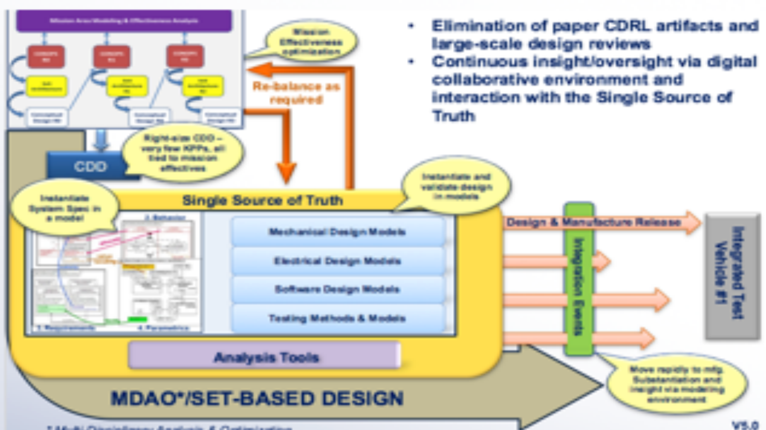
Surrogate Pilot Modeling Concept for NAVAIR SE Transformation

Update: 7/31/2017



Integrated Systems Engineering Decision Management (ISEDM) Process Enabled by Digital Engineering Technologies

Dr. Matt Cilli

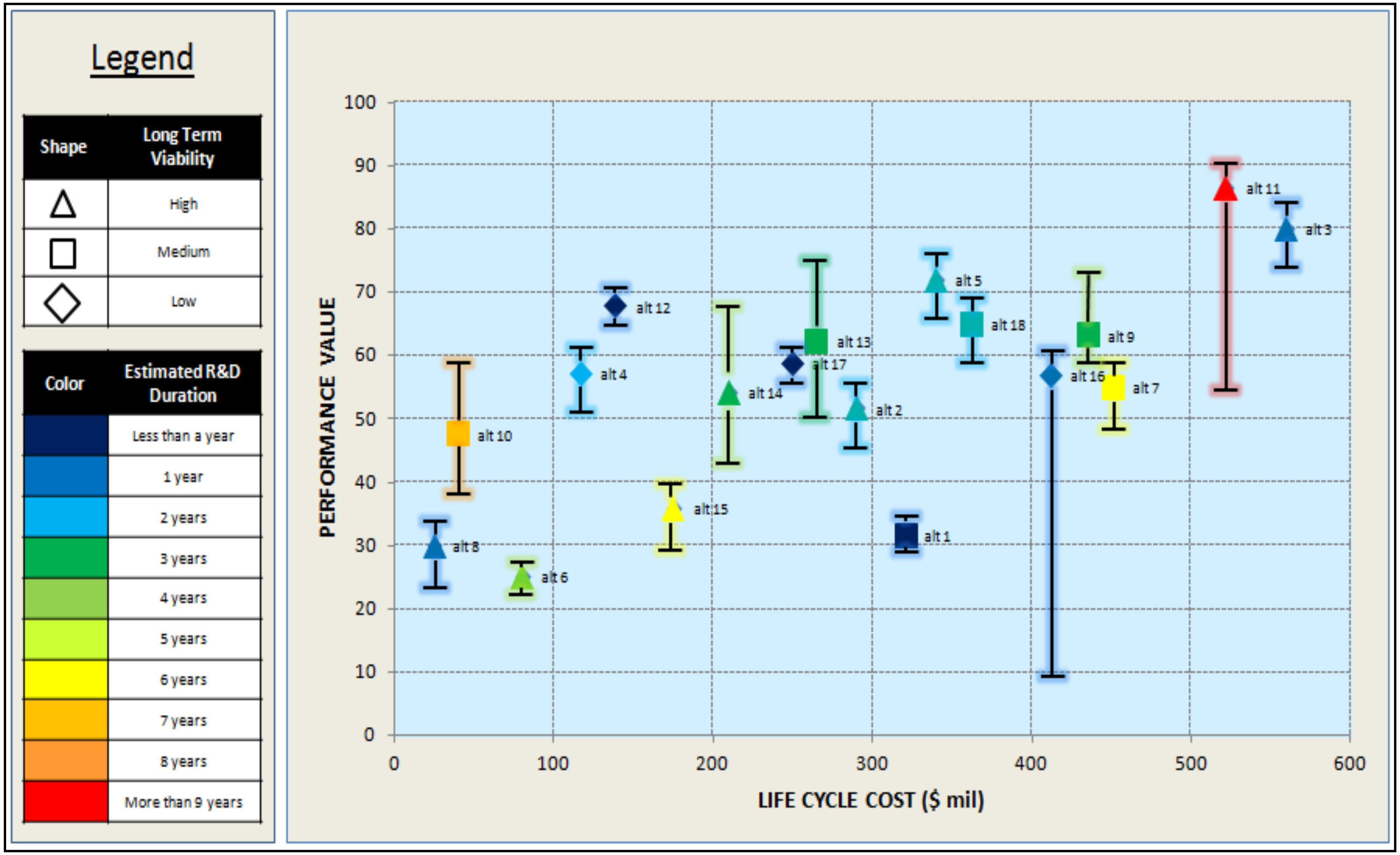
Semantic Technologies and Ontologies Research to enable Trade Space Analytics for Engineered Resilient Systems

Dr. George Ball

SYSTEMS ENGINEERING
Research Center

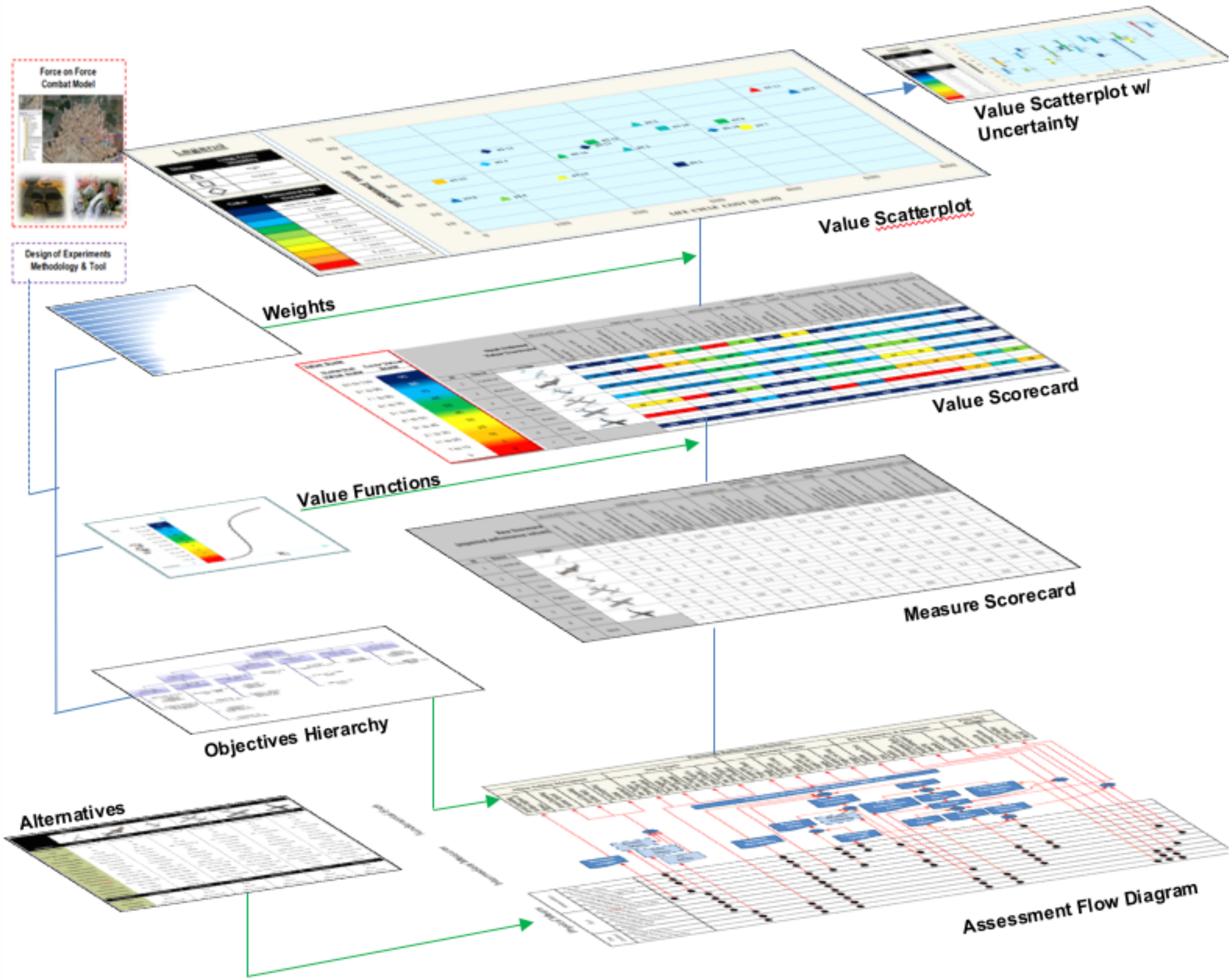
Semantic Web Technologies >
Integrated Modeling Environment >
Modeling Method Alternatives >
MDAO (Time Permitting)

Synthesizing Results – Value Scatterplot with Assessing Impact of Uncertainty*



Cilli, M. Seeking Improved Defense Product Development Success Rates Through Innovations to Trade-Off Analysis Methods, Dissertation, Stevens Institute of Technology, Nov. 2015.

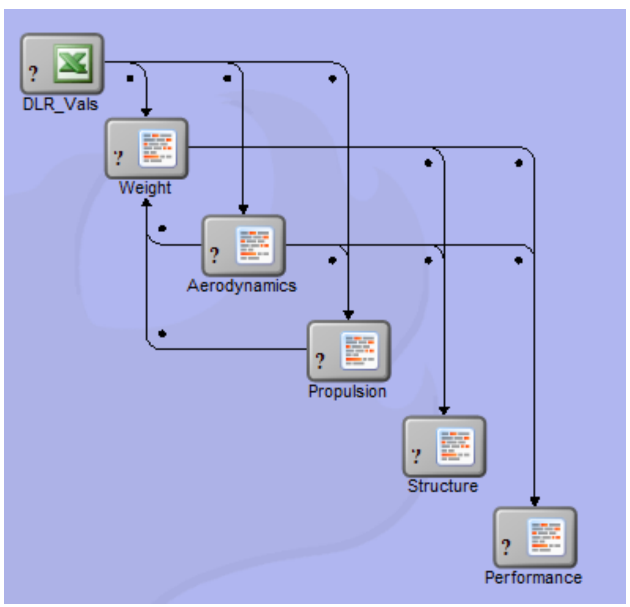
Decision Support Model Construct

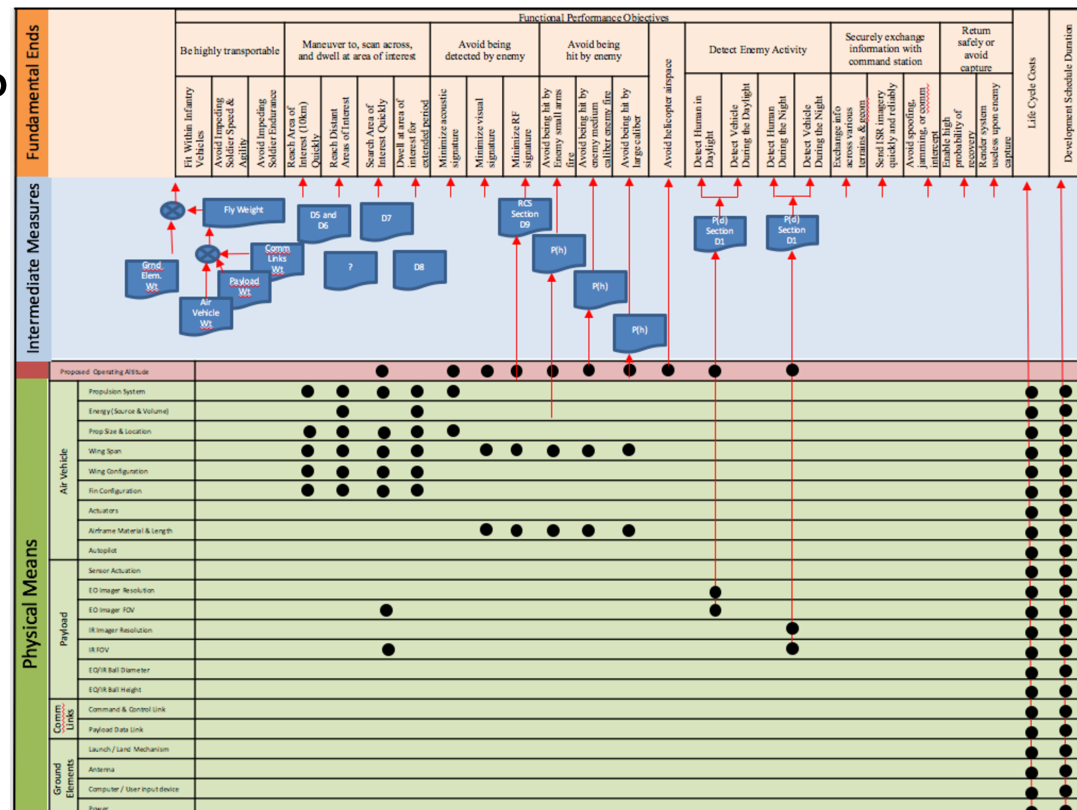


Cilli, M. Seeking Improved Defense Product Development Success Rates Through Innovations to Trade-Off Analysis Methods, Dissertation, Stevens Institute of Technology, Nov. 2015.

Decision Framework

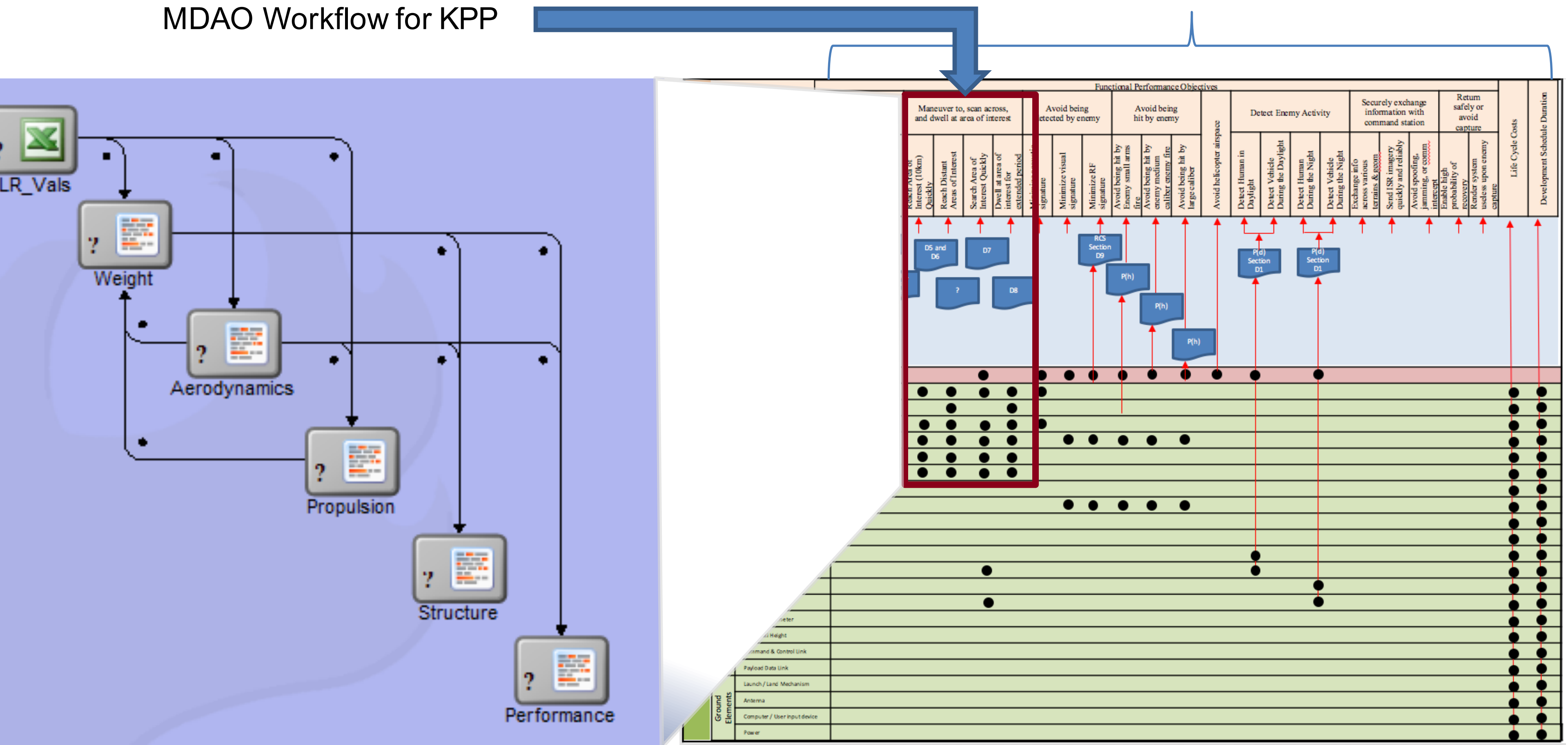
- SWT application to AAMODAT
- Templates for objective hierarchies
- Can MDAO represent Assessment Flow Diagram?
- Does AFD characterize needed MDAO workflows?





Key Performance Function
(Key Performance Parameter [KPP])

MDAO Workflow for KPP



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)

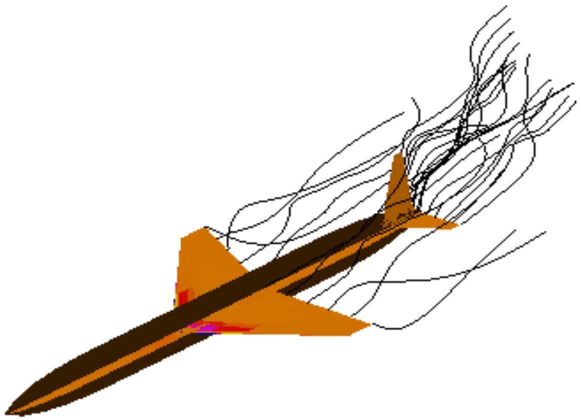
Reasoning
(e.g. interpreting results, choosing options)

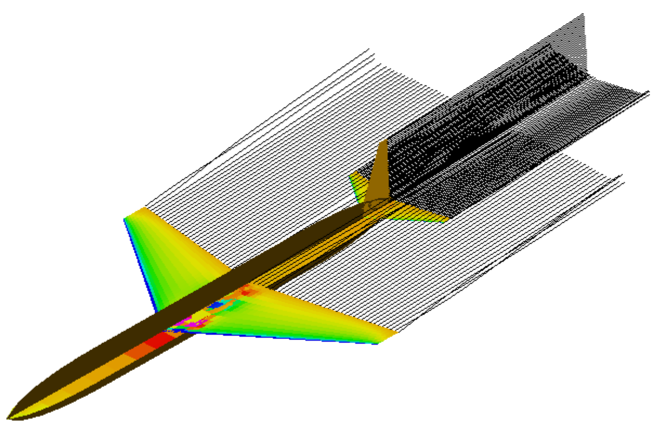
Forest Flager and John Haymaker, A Comparison of Multidisciplinary Design, Analysis and Optimization Processes in the Building Construction and Aerospace, Stanford, December 2009

Since March Working Session

- Equation-based Models
  - —Fixed-wing
  - —Quadcopter

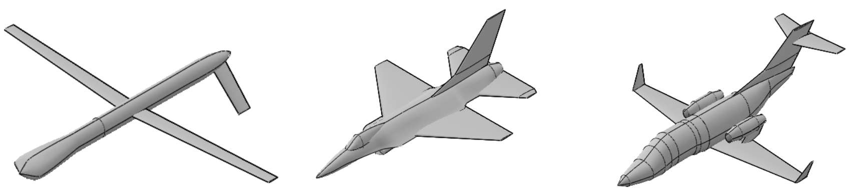
- Simulation-based Model
  - —OpenVSP geometry and VSPAero CFD tool wrapped into ModelCenter
  - —Extensive debugging completed
  - —Suitable CFD mesh found balancing results and computational cost

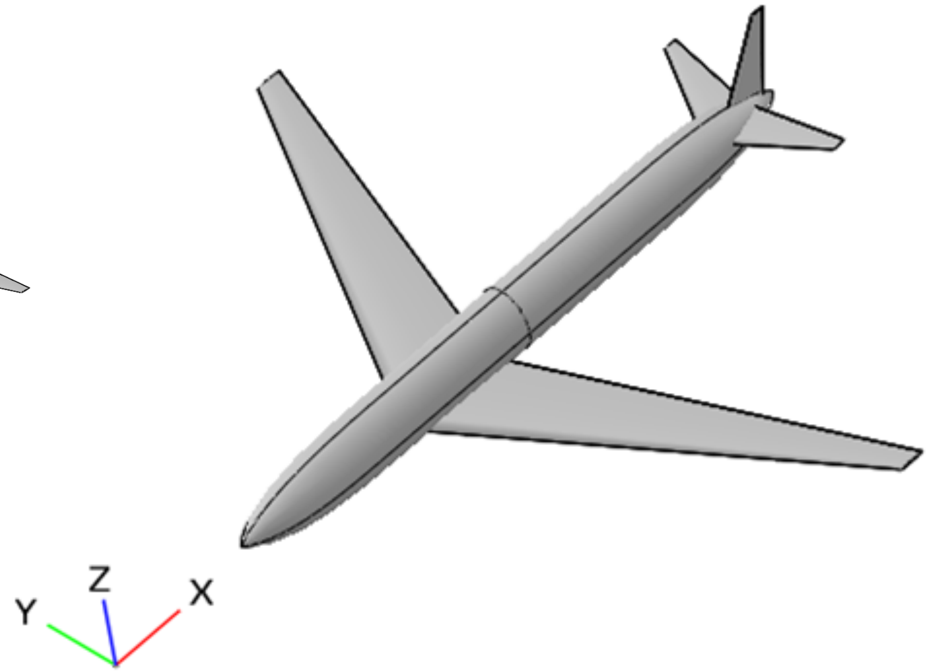




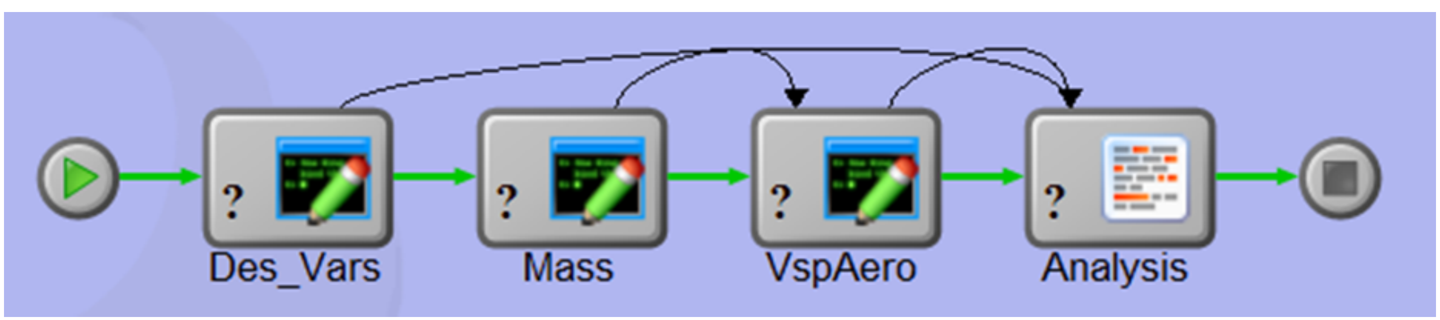
Current Model Status

- UAV Geometry
  - —Easy to change





- ModelCenter Workflow
  - —Adjusts geometry and flight conditions for MDAO
  - —About 1 minute per run



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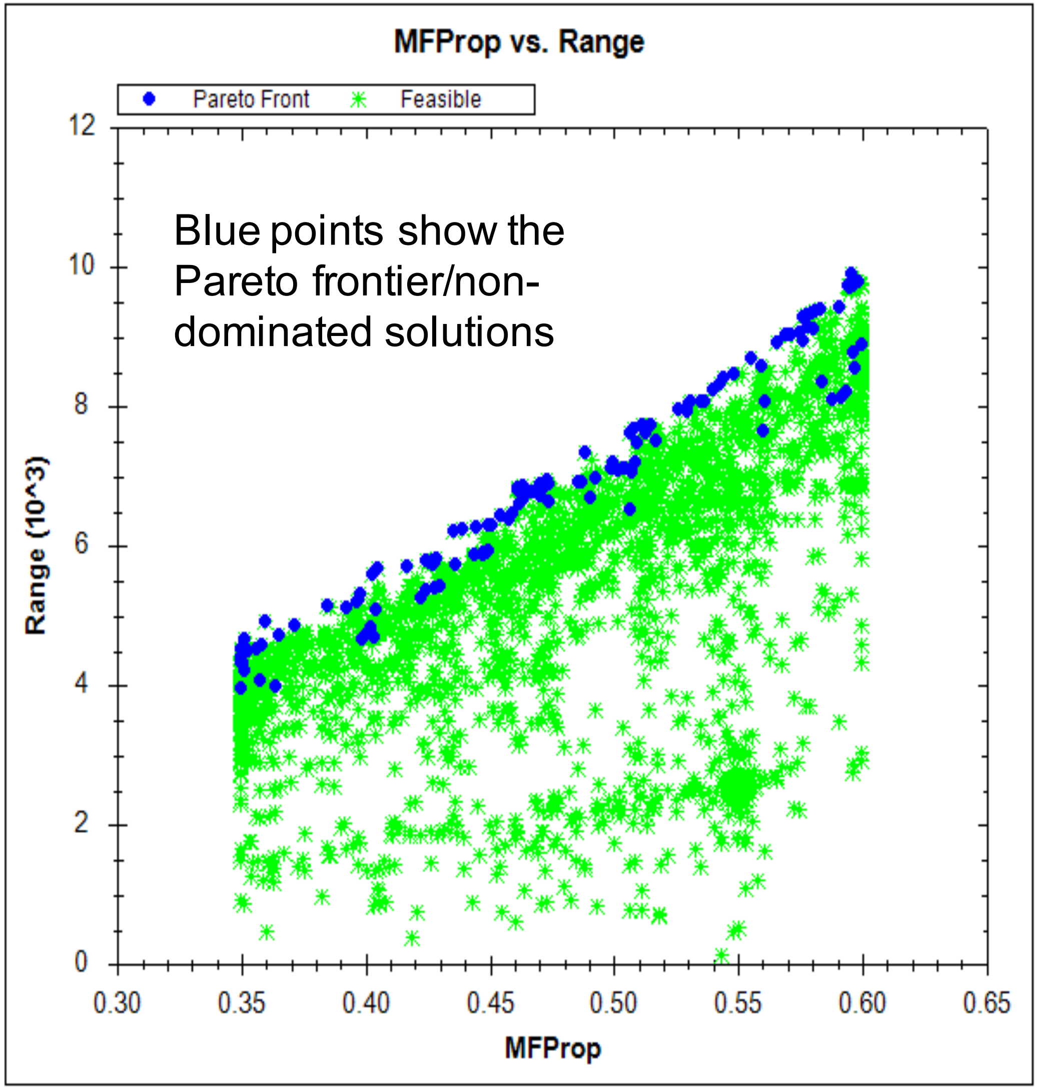
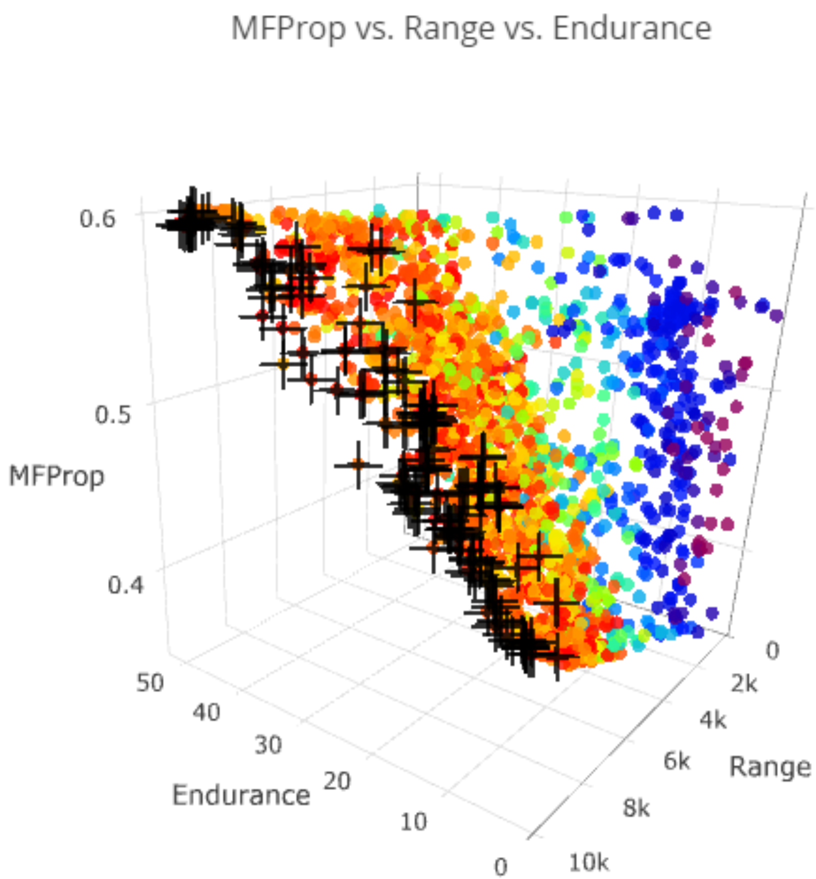
Optimization

- Tri-objective optimization using Darwin algorithm:
  - Maximize range
  - Maximize endurance
  - Minimize fuel mass fraction
  - ~2600 runs in ~2 days
- 9 design variables
  - Fuel mass fraction
  - Wing span
  - Average wing chord
  - Tail span
  - Average tail chord
  - Tail Y-rotation
  - Wing X-location
  - Airspeed
  - Angle of Attack

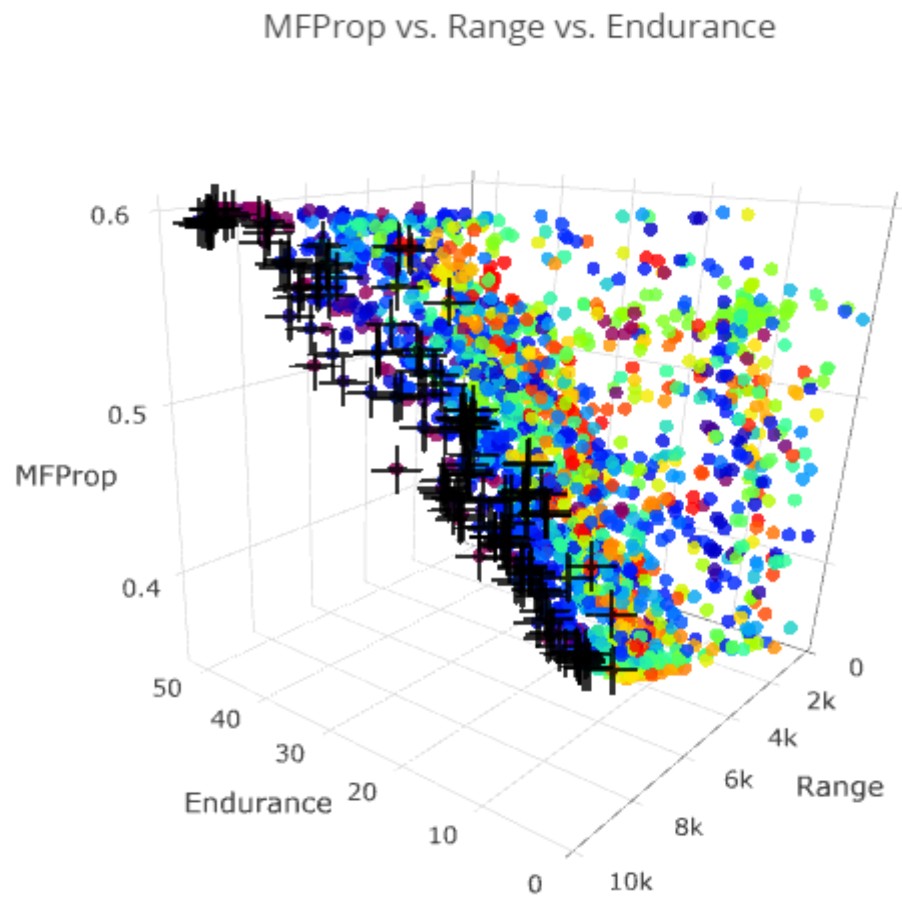


Range (mi) vs. Fuel Mass Fraction

Optimization Visualizations



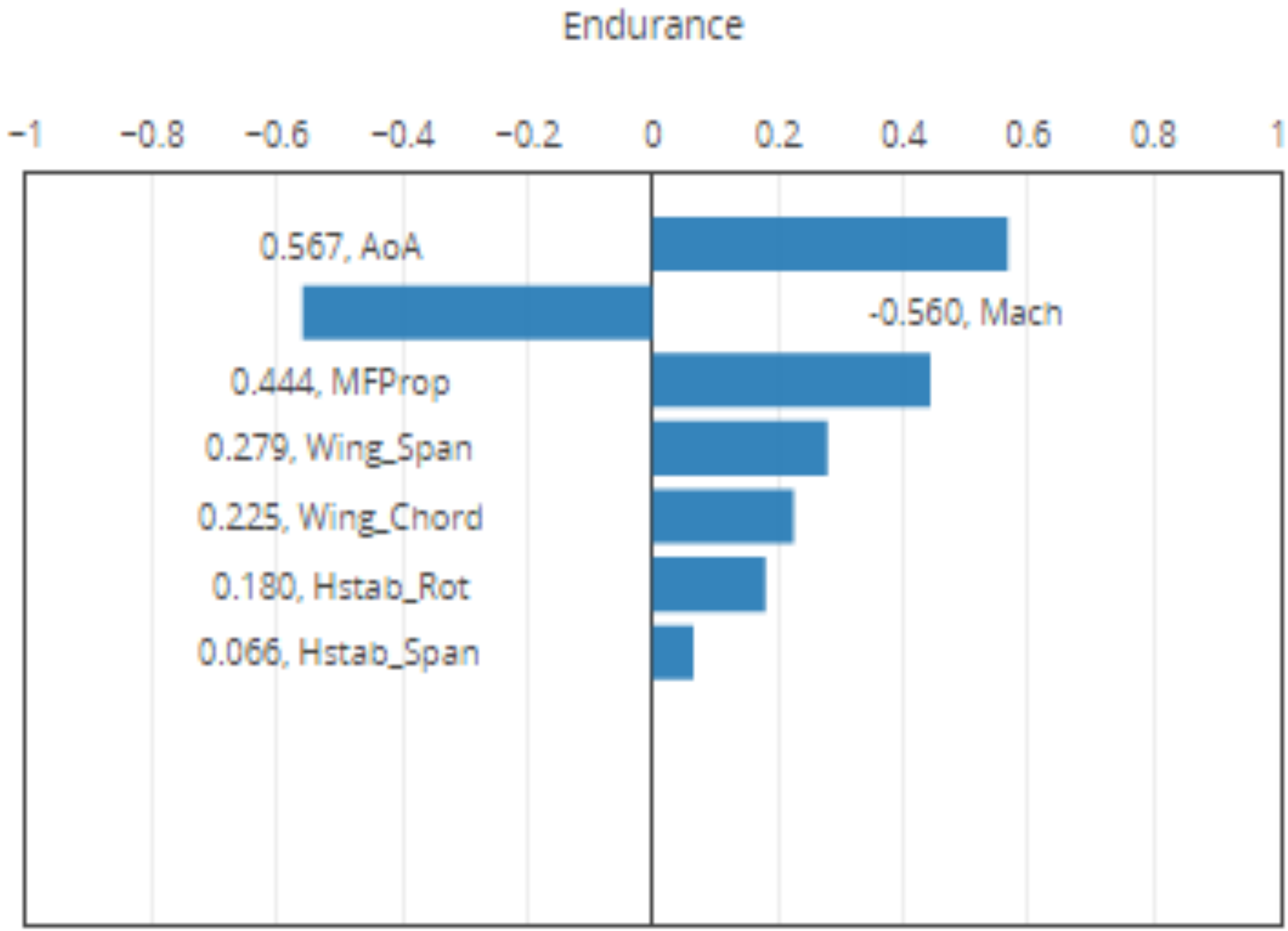
Colors Represent Angle of Attack



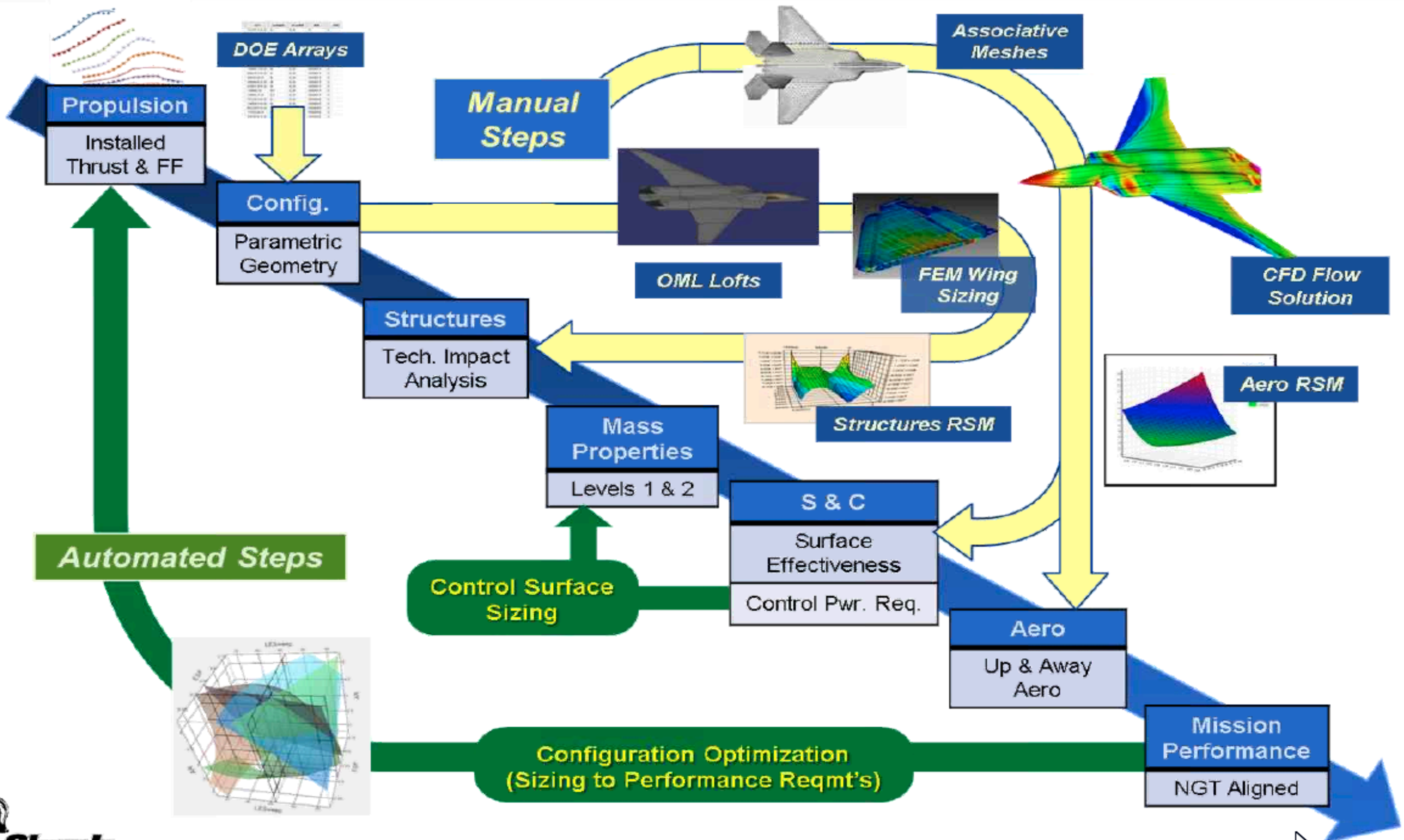
Colors Represent Mach # (airspeed)

- Can likely set angle of attack to maximum to avoid "Curse of Dimensionality"

Sensitivity Analysis



Modelcenter Process Changes – ESAVE Program



MDAO Supported by ModelCenter

- I think that there are a number of briefings on the ModelCenter website that are also informative (http://www.phoenix-int.com/learn-more/webinars/)
- Here are a few related to NAVAIR contractors that use ModelCenter and they gave webinars:
- MDAO for Conceptual Aircraft Design at Northrop Grumman
- Introduction to MBSEPak (explains how the parametrics that are used in an MDAO workflow can be captured in a SysML – which means we could "generate them into the spec")
- Phoenix Integration and the Skunk Works® A History of Success, A Path to the Future
- Boeing had videos too.

Collaborators

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Research Center

RT-170 Task - Mission Engineering and Analysis using MDAO Methods

Semantic-driven Modeling and Reasoning for Systems Engineering Transformation

Mark Austin

University of Maryland

austin@isr.umd.edu NAVAIR Presentation

November 8, 2016

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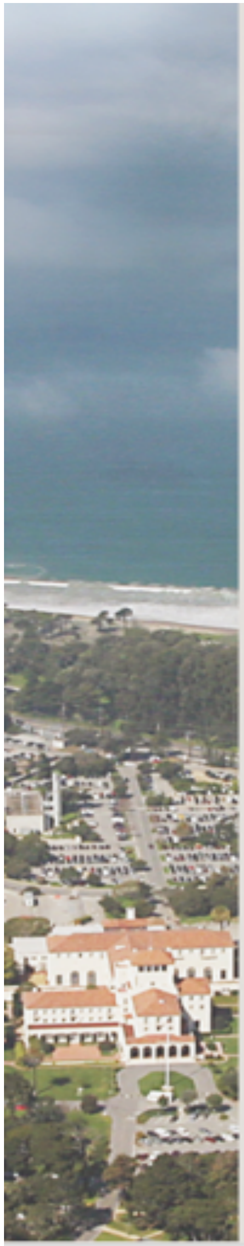
RT-176 – Supports Model Integrity through V&V of System Behavioral Specifications



NAVAL
POSTGRADUATE
SCHOOL

Role of Monterey Phoenix in Early V&V

RT 176: Verification and Validation (V&V) of System Behavior Specifications

Kristin Giammarco, Ph.D.
Department of Systems Engineering

9 MAR 2017

Monterey, California
WWW.NPS.EDU

Semantic Technologies Foundation Initiative for Systems Engineering

Charter

- The Semantic Technologies Foundation Initiative for Systems Engineering is to promote and champion the development and utilization of ontologies and semantic technologies to support system engineering practice, education, and research.

Mission

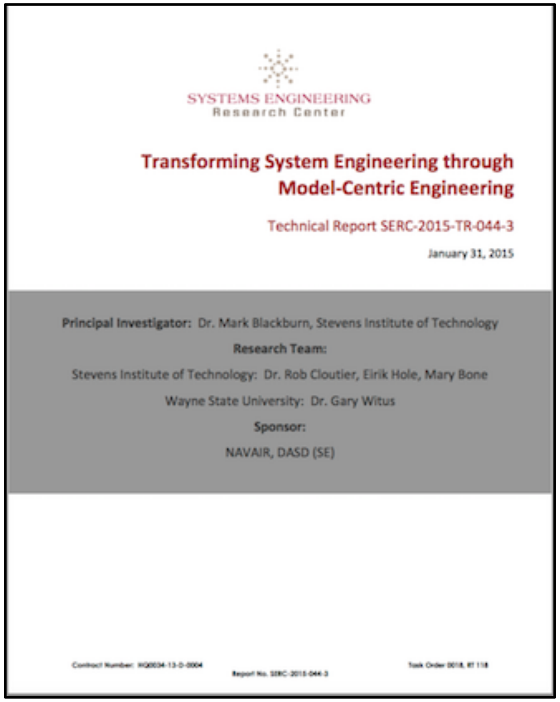
- The mission of the initiative is to collect a suite of interoperable ontologies that are logically well-formed and accurate from both scientific and engineering points of view. The initiative will charter a collective of stakeholders that are committed to collaboration and adherence to shared semantic principles for the advancement of systems engineering. To achieve this, initiative working group participants will voluntarily adhere to and contribute to the development of an evolving set of principles including open use, collaborative development, and non-overlapping and appropriately-scoped content. They will capture and maintain metadata for each ontology to encourage implementation and reuse.

Collaborations

- Digital Engineering Working Group
- Airspace Industry Association: CONOPS for Industry/Government Collaborative Framework
- NDIA Working Group– Using Digital Engineering for Competitive Down Select

Thank You

- For more information contact:
  - —Mark R. Blackburn, Ph.D.
  - —Mark.Blackburn@stevens.edu
  - —Stevens Institute of Technology
  - —Links to technical reports: http://www.sercuarc.org/researcher-profile/mark-blackburn/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Transforming System Engineering through Model-Centric Engineering

Technical Report SERC-2015-TR-044-3

January 31, 2015

Principal Investigator: Dr. Mark Blackburn, Stevens Institute of Technology

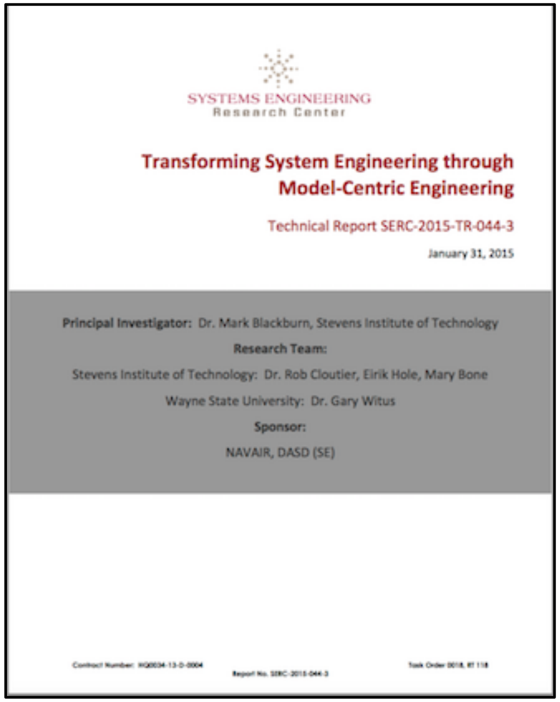
Research Team:

Stevens Institute of Technology: Dr. Rob Cloutier, Eirik Hole, Mary Bone

Wayne State University: Dr. Gary Witus

Sponsor:

NAVAIR, DASD (SE)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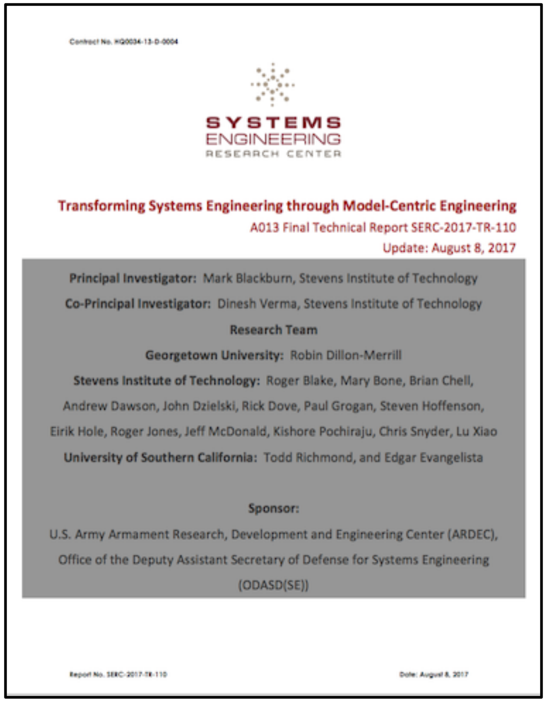
SYSTEMS ENGINEERING RESEARCH CENTER

Transforming Systems Engineering through Model-Centric Engineering

A013 Final Technical Report SERC-2017-TR-110

Update: August 8, 2017

Principal Investigator: Mark Blackburn, Stevens Institute of Technology

Co-Principal Investigator: Dinesh Verma, Stevens Institute of Technology

Research Team

Georgetown University: Robin Dillon-Merrill

Stevens Institute of Technology: Roger Blake, Mary Bone, Brian Chell, Andrew Dawson, John Dzielski, Rick Dove, Paul Grogan, Steven Hoffenson, Eirik Hole, Roger Jones, Jeff McDonald, Kishore Pochiraju, Chris Snyder, Lu Xiao

University of Southern California: Todd Richmond, and Edgar Evangelista

Sponsor:

U.S. Army Armament Research, Development and Engineering Center (ARDEC), Office of the Deputy Assistant Secretary of Defense for Systems Engineering (ODASD(SE))

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Acronyms

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

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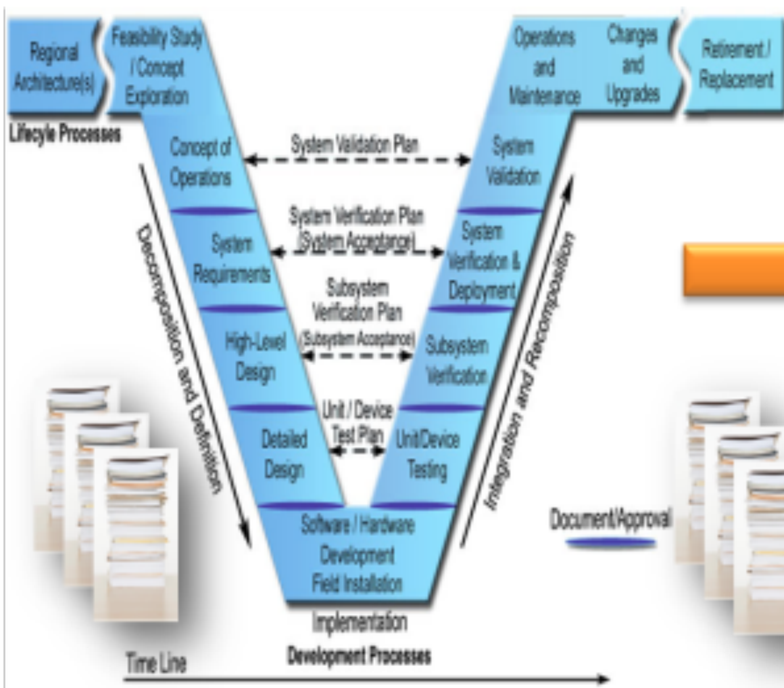
Model-Centric Systems Engineering Methodology

Growing System Complexity

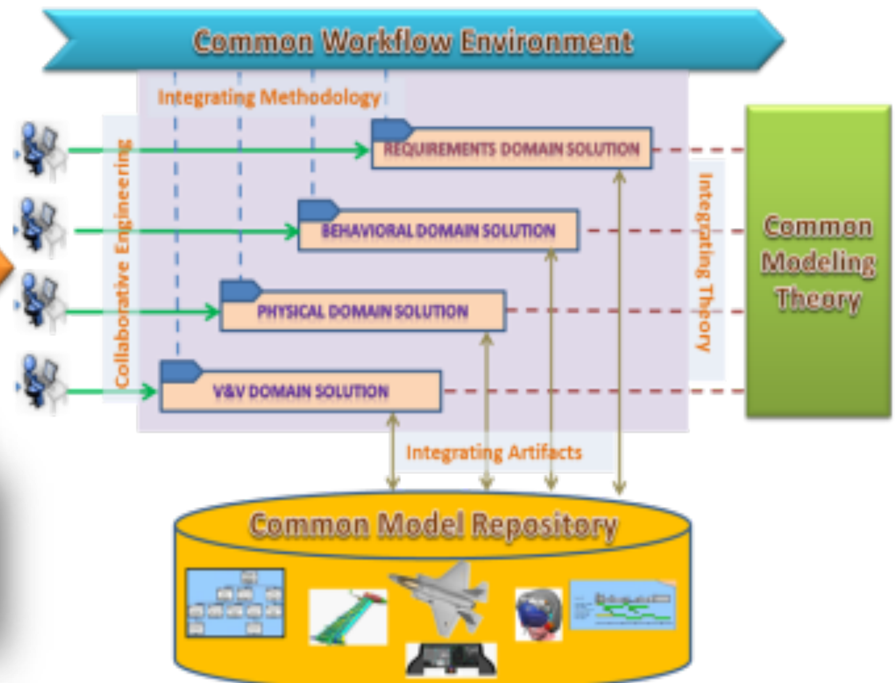
4^{th} Gen Fighter ~
20 sub-sys
10^3 interfaces
40% functions in SW

5^{th} Gen Fighter ~
130 sub-sys
10^5 interfaces
90% functions in SW

Document-Centric Methodology



Model-Centric Methodology



Single Source of Technical Truth

Design System for Managing Complexity in Aerospace Systems, Sandor Becz1, 2010

Semantic Web Technology Stack Supports Different Levels of Abstraction

Layers of Abstraction

Ontology and reasoning layers

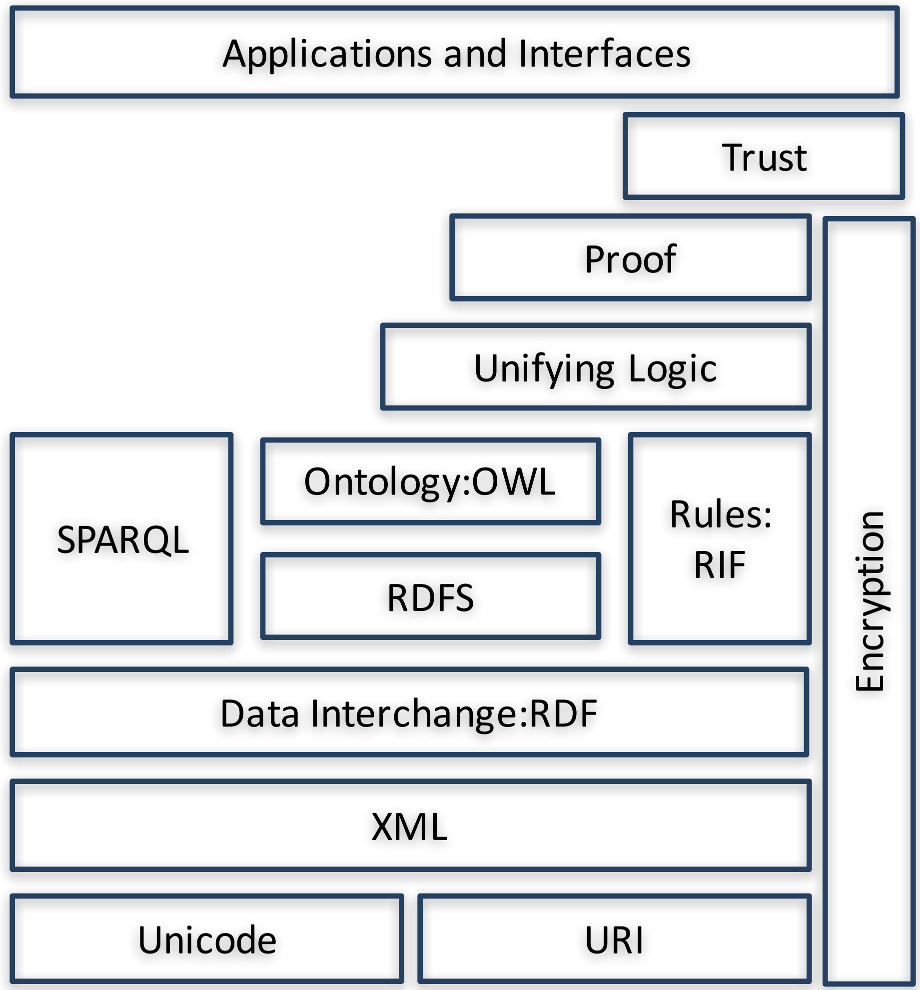
Analytical Knowledge

Data layers

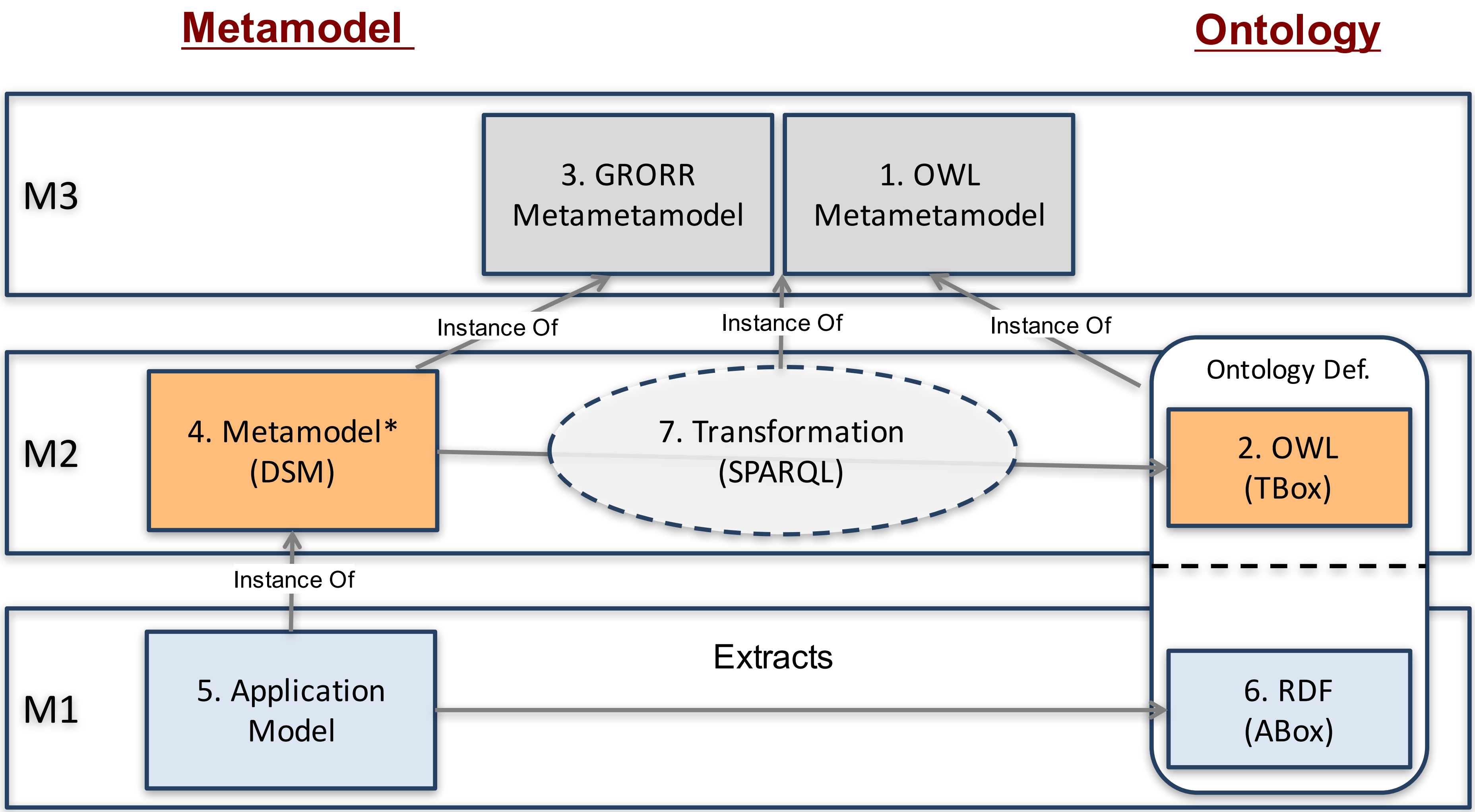
RDF triple

Representation / syntax layers

Semantic Web Technology Stack

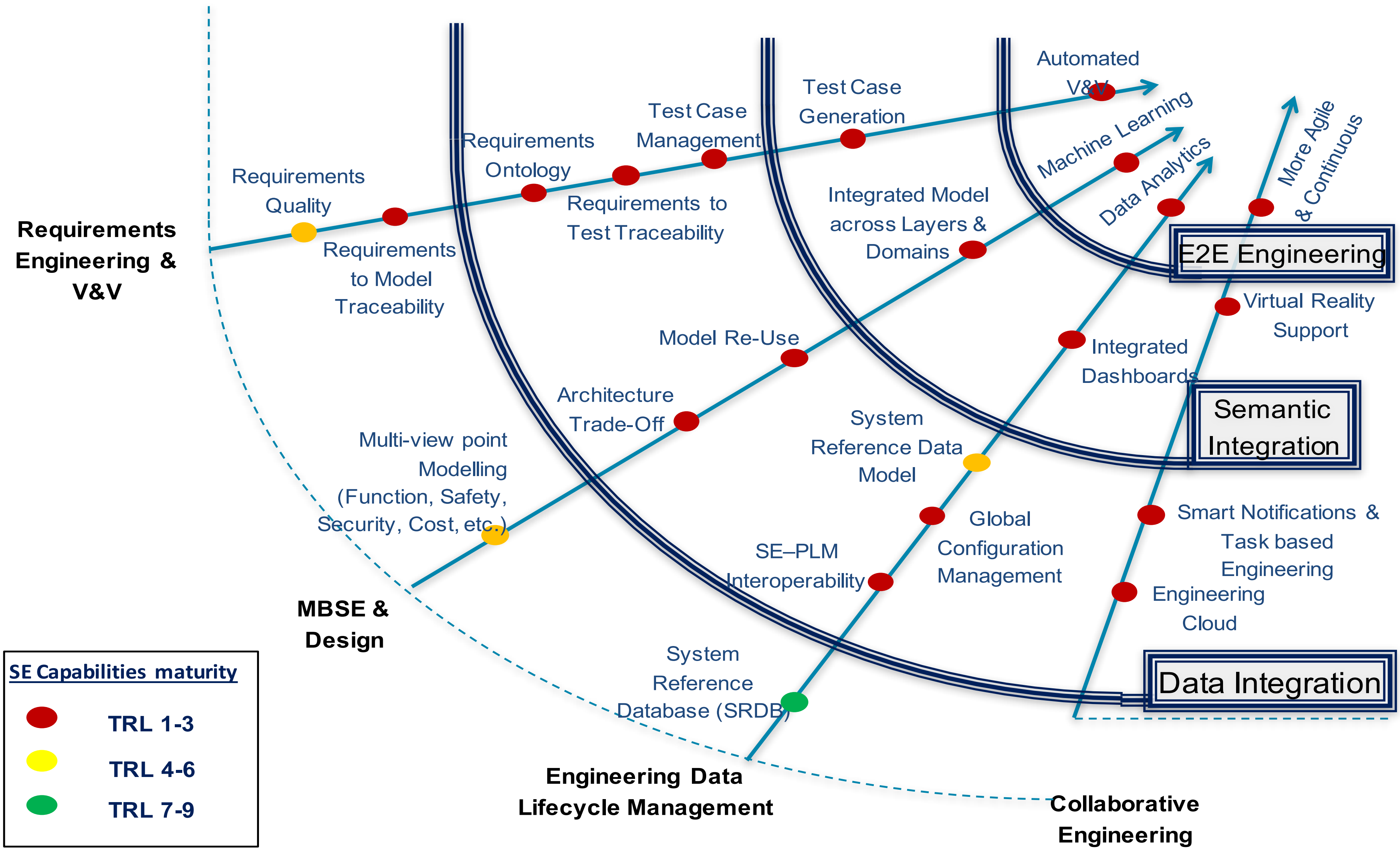


Formalizing Viewpoint Semantics for Integration of Modeling & Analysis



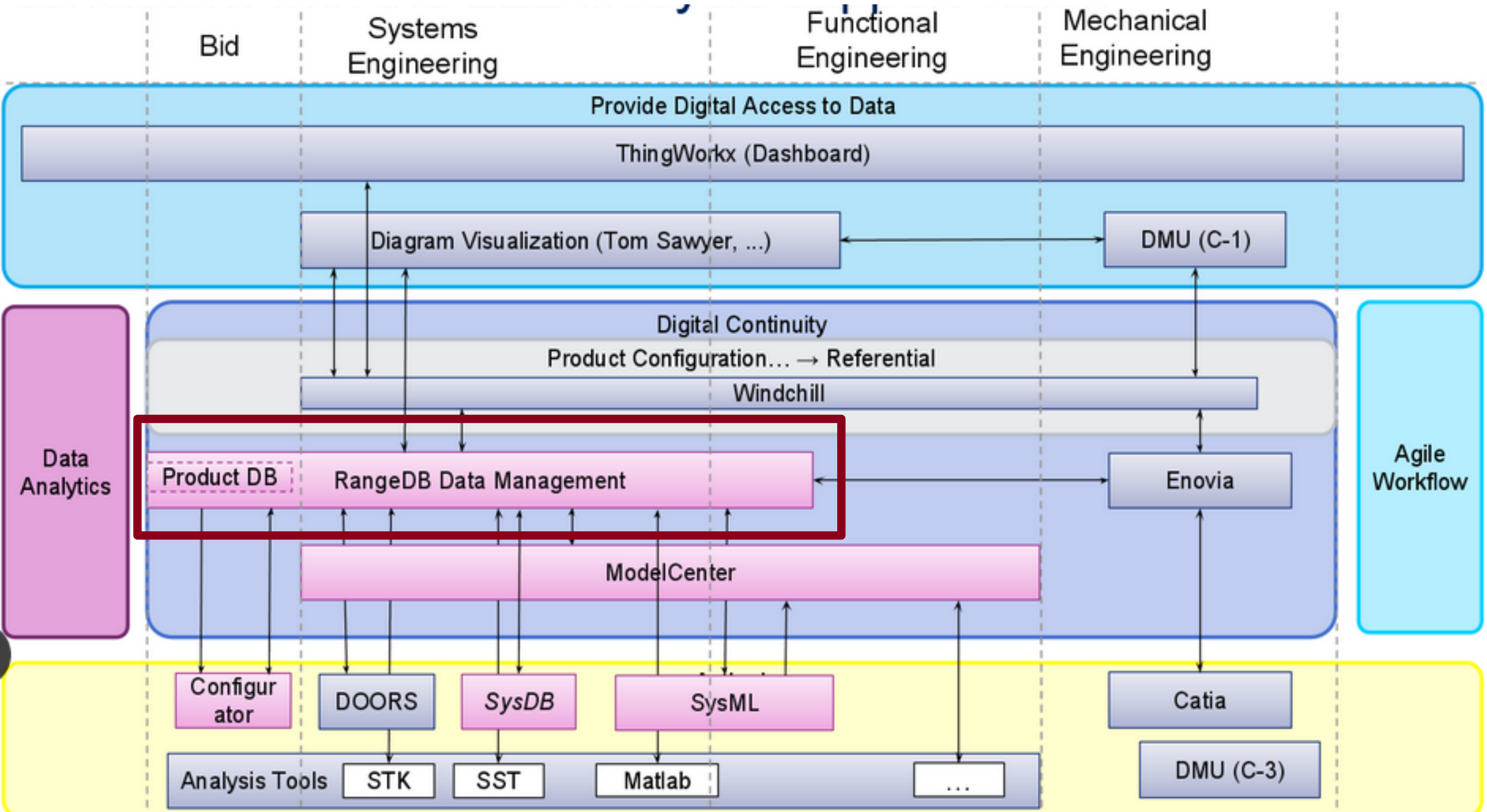
*Simulink, Modelica, Excel, BNF, SQL, SPARQL, and maybe some General Modeling Languages too etc.
MOF, KM3, GRORR, etc.

Multiple Dimensions of Airbus Technology Roadmap: Perspective of Information Model



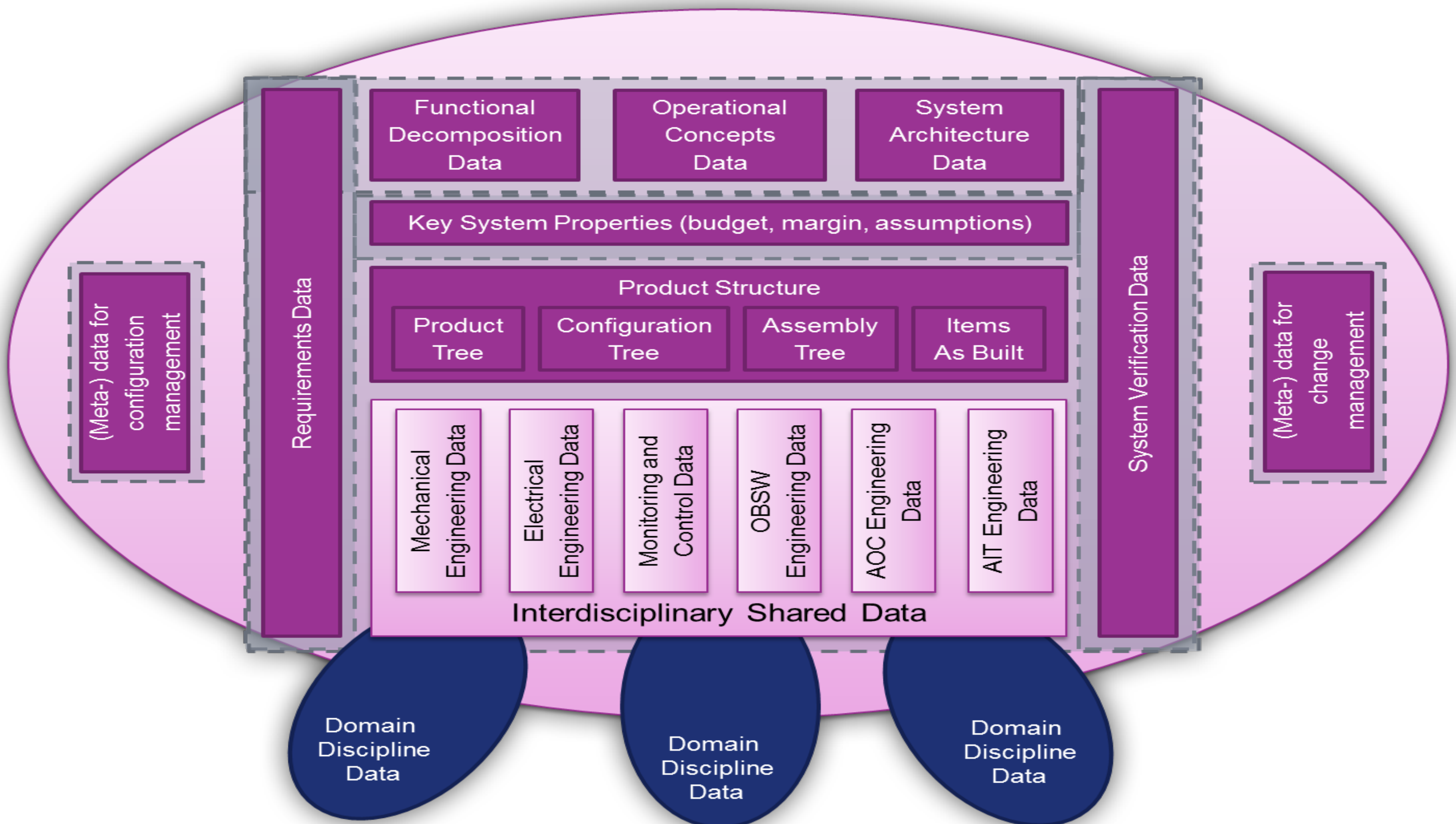
Hartmann, R., Digital Environment and MBSE Progress at Airbus Space, NASA JPL Symposium and Workshop on Model Based Systems Engineering, January 2017.

Airbus Digital Engineering Environment



Hartmann, R., Digital Environment and MBSE Progress at Airbus Space, NASA JPL Symposium and Workshop on Model Based Systems Engineering, January 2017.

Semantic Data Model for Multi-Disciplinary Integration



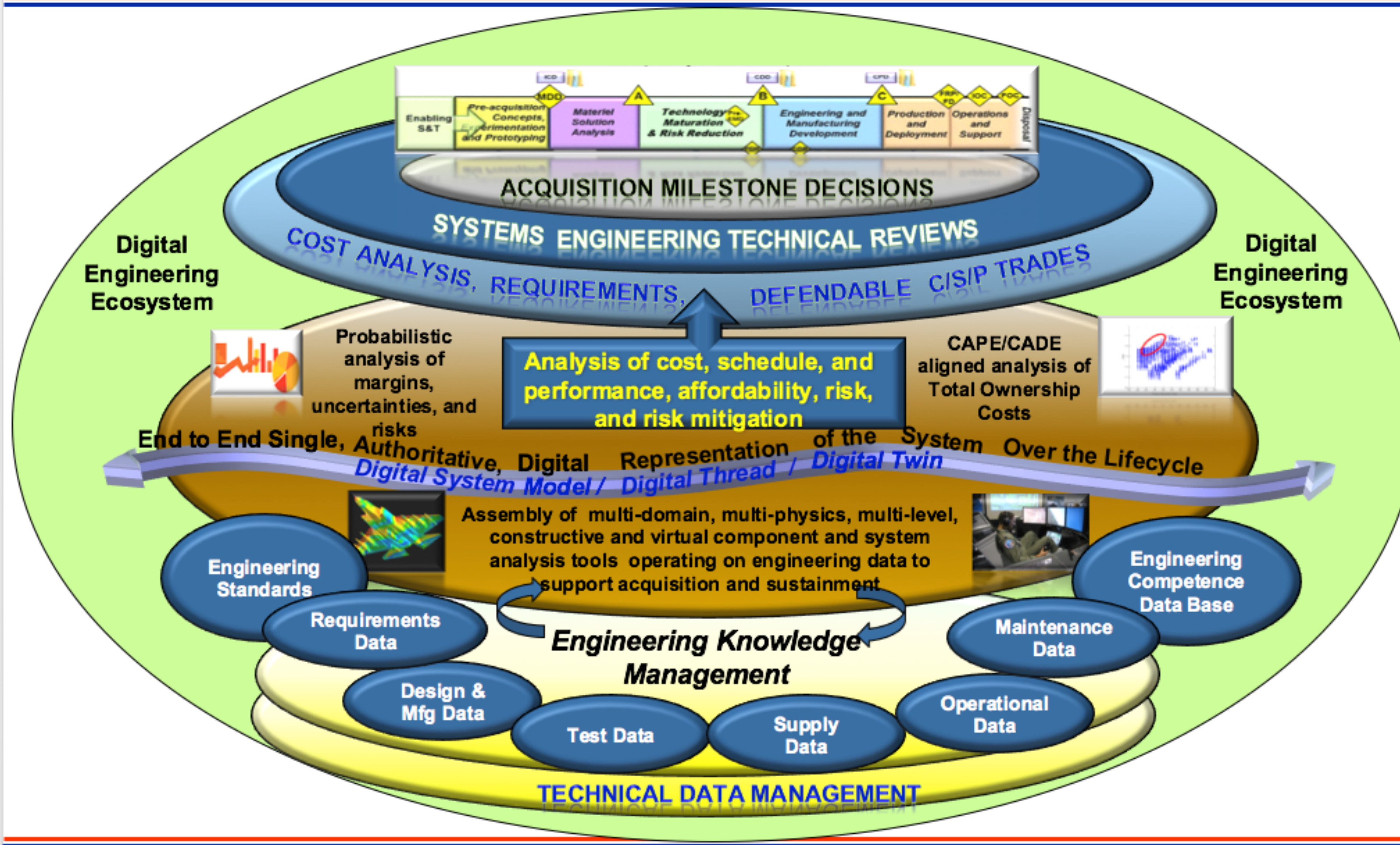
Hartmann, R., Digital Environment and MBSE Progress at Airbus Space, NASA JPL Symposium and Workshop on Model Based Systems Engineering, January 2017.

Uses Cases for Multi-Disciplinary Engineering (Systems Engineering)

Production System Engineering Needs & Use Cases		UC1	UC2	UC3	UC4
N1	Explicit engineering knowledge representation	✓	✓	✓	✓
N2	Engineering data integration	✓	✓	✓	✓
N3	Engineering knowledge access and analytics	✓	✓	✓	✓
N4	Efficient access to semi-structured data in the organization and on the Web	✓	✓		✓
N5	Flexible and intelligent engineering applications		✓		✓
N6	Support for multidisciplinary engineering process knowledge	✓	✓	✓	✓
N7	Provisioning of integrated engineering knowledge at production system runtime			✓	✓

Semantic Web Capabilities & Needs		N1	N2	N3	N4	N5	N6	N7
C1	Formal and flexible semantic modeling	++	+	++	+	+	+	+
C2	Intelligent, web-scale knowledge integration	+	++	++	++	++	++	
C3	Browsing and exploration of distributed data set			+	++	+	+	+
C4	Quality assurance of knowledge with reasoning					++	++	++
C5	Knowledge reuse	+	+	++			++	+

A Holistic View of Digital Engineering Support to DoD Acquisition



Graphical CONOPS with Unity