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STEVENS INSTITUTE of TECHNOLOGY THE INNOVATION UNIVERSITY

# 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**

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# Opening Thoughts and Perspectives

*Introductions after Opening Thoughts*

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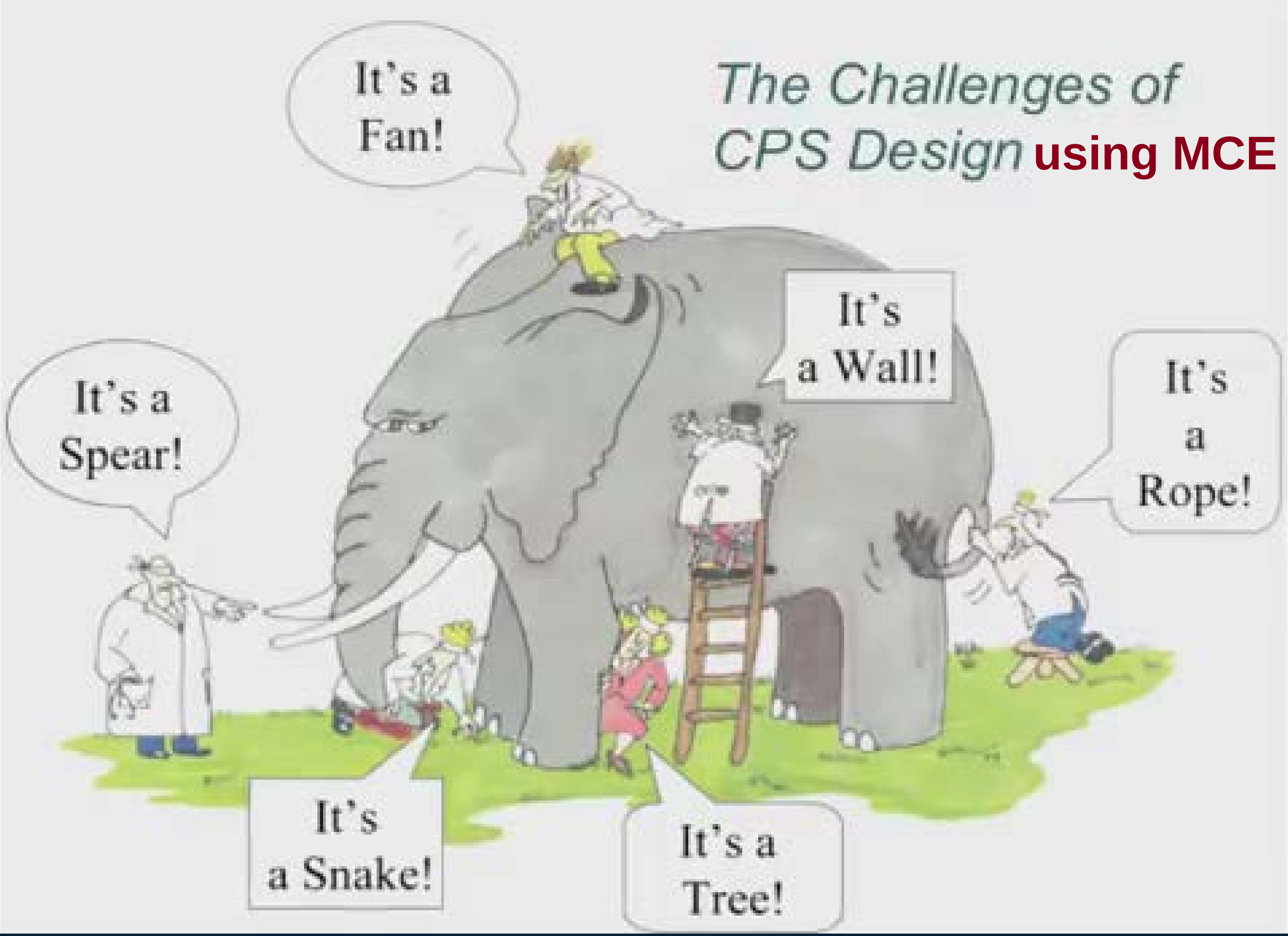
# SE Transformation

- "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

# 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?

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# 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

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# Notation Key – Upper Left on Some Slides

Deep Dive

Example/Definition


Discussion

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# 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

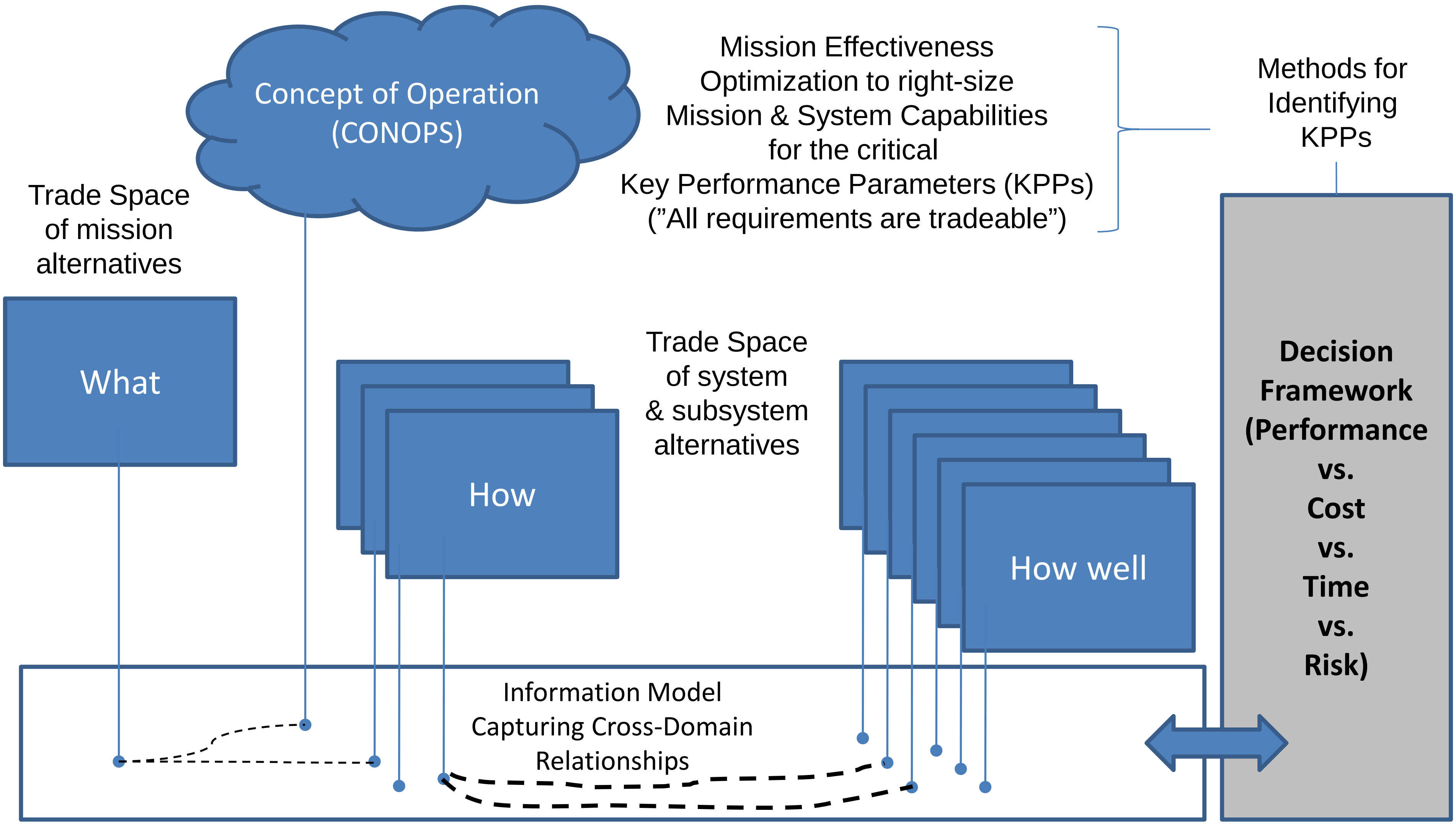
RT-157
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Roger Blake - Stevens
- Mark Austin – Univ. Maryland
- Leonard Petnga – Univ. of Maryland

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:
    - 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

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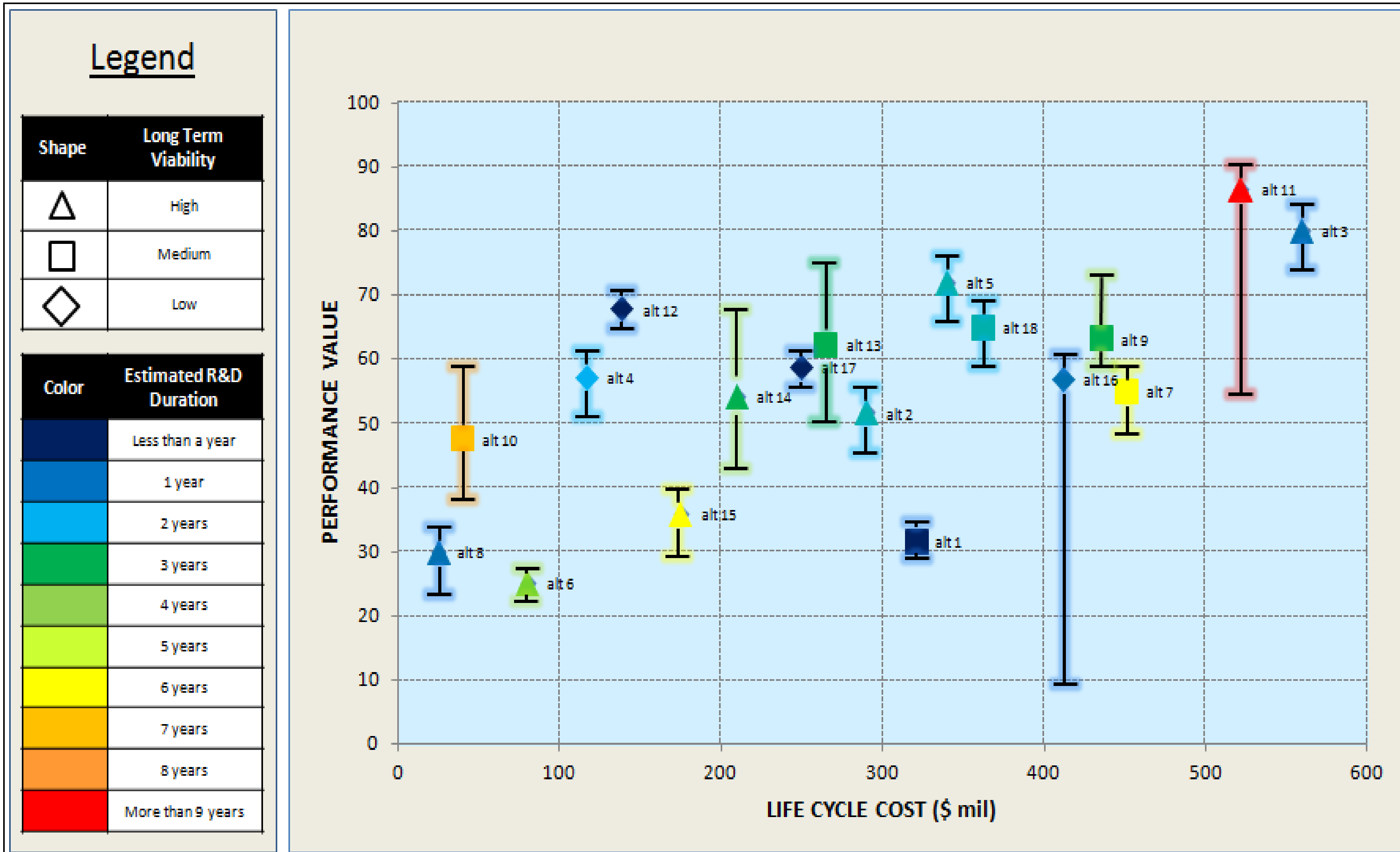
# Example: Cross Domain Relationships Needed for System Trades, Analysis and Design

- 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**

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

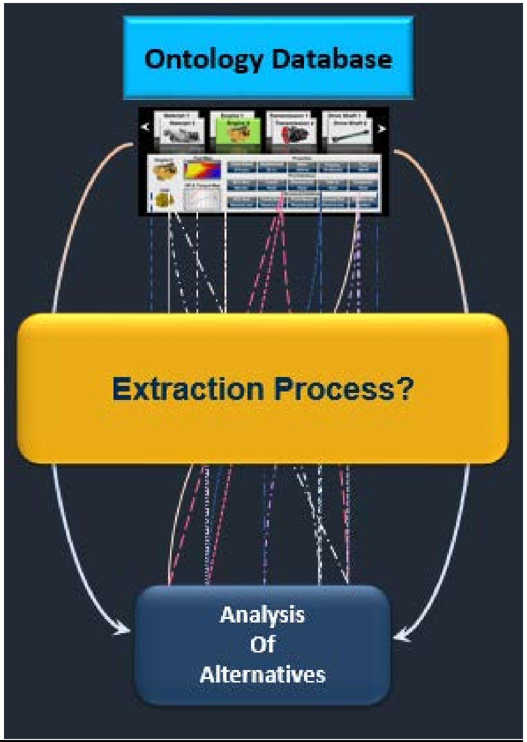


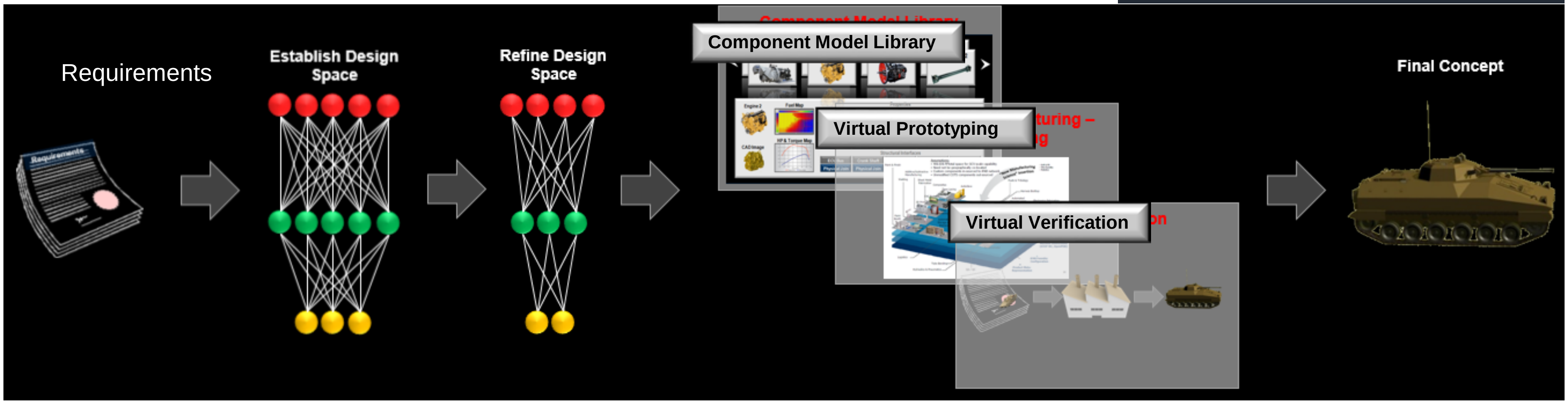

Cilli, M. Seeking Improved Defense Product Development Success Rates Through Innovations to Trade-Off Analysis Methods, Dissertation, Stevens Institute of Technology, Nov. 2015.

# 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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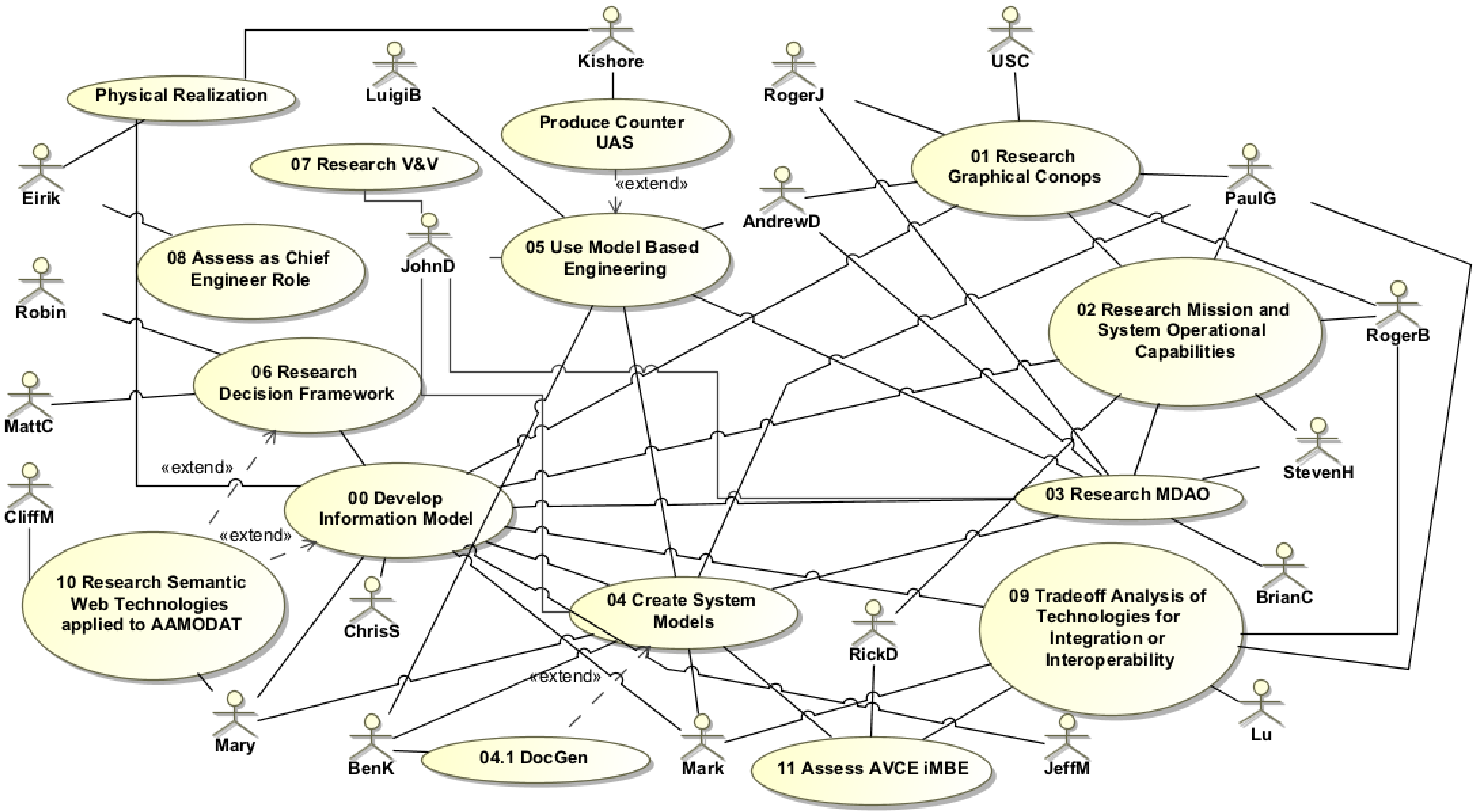
# Agenda

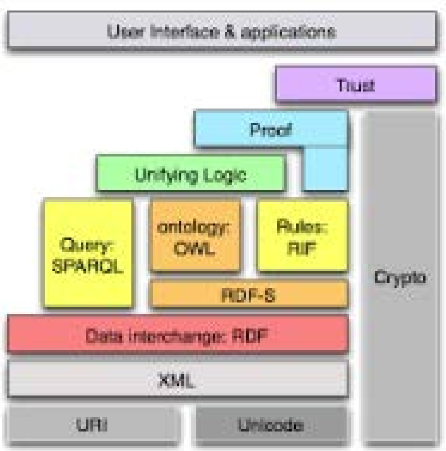
| | July 31, 2017 @ Stevens | |
|---|---|---|
| 8:15 | Introductions – Why Here and Goals for the Day | SERC/Stevens |
| 8:30 | Past - Why and Present - What | Dr. Mark Blackburn |
| 10:15 | Break | |
| 10:30 | Future - How - Digital Engineering Transformations<br>(Deep Dive a Few Research Topics) | 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<br>• Breakout 1: Risk for Digital Engineering Transformation<br>• Breakout 2: Priorities for Digital Engineering Transformation | Dr. Mary Bone<br>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**

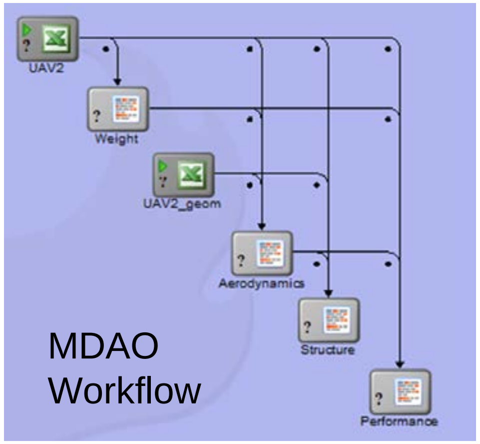
## Modeling Methodologies

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

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

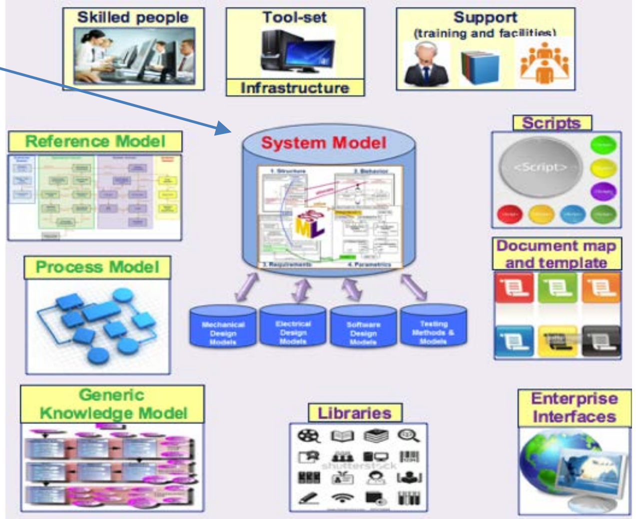
Digital System Model:
Single Source of Truth
(*authoritative source of truth)*

## 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

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# 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-suites/

# 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:

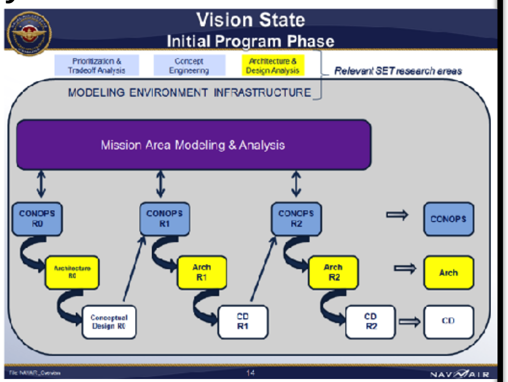
How do we know that models/simulations used to assess **Performance** have the needed **Integrity** to ensure predictions are accurate (i.e., that we can trust the models)?

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

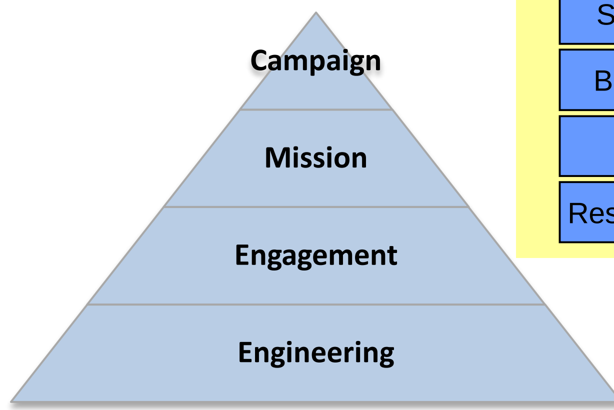


## 1) Global scan and classification of holistic state-of-the-art MBSE

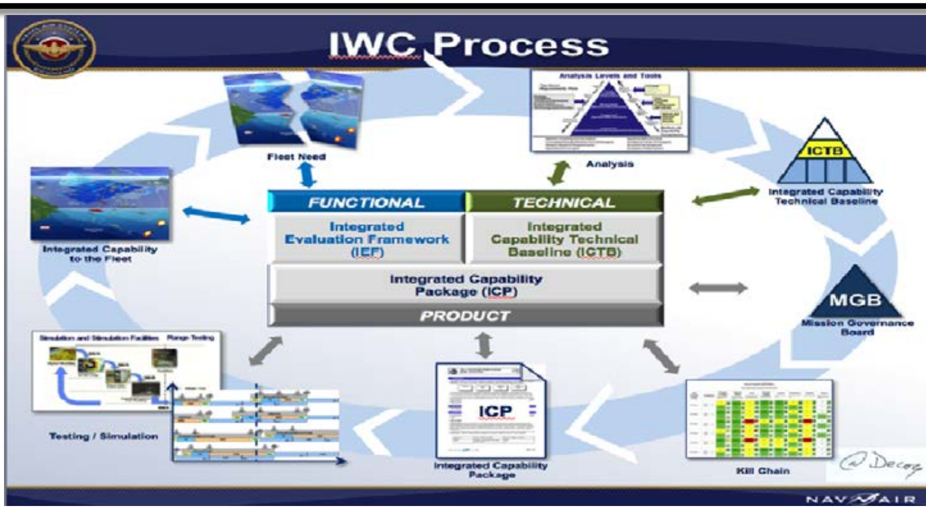
- Use discussion framework to survey government, industry and academia
- Quantify, link and trace realized modeling capabilities to Vision (task 3)



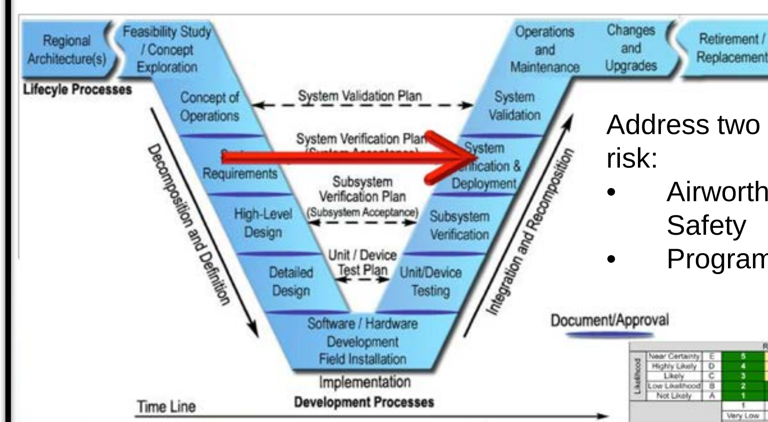

## 2) Develop Common Lexicon for Model Levels, Types, Uses, and Representations




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

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

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# 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 |

# 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

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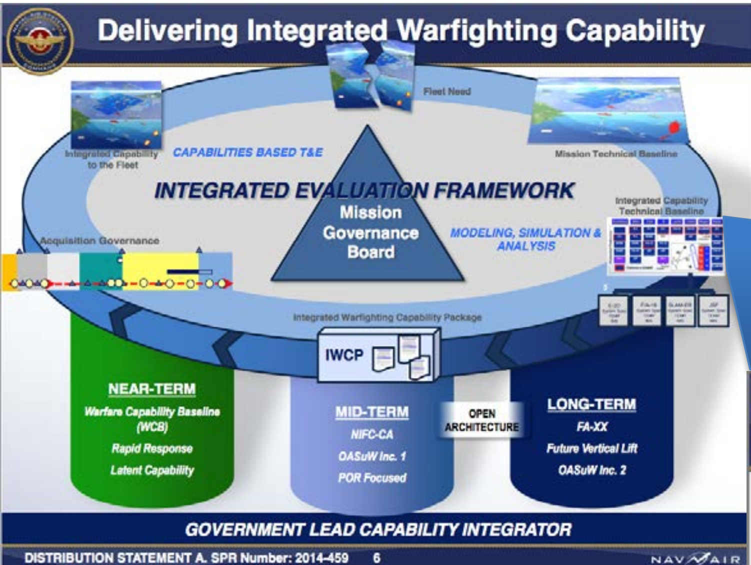
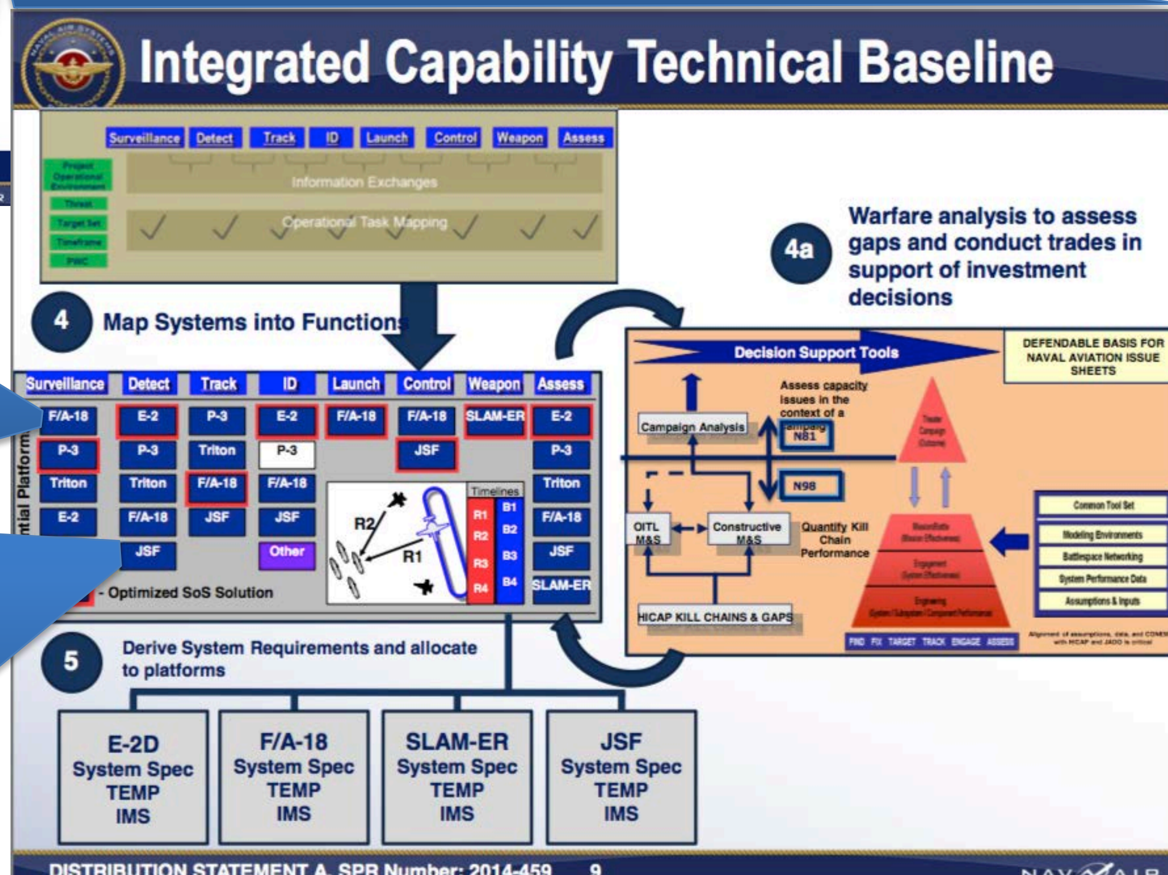
# Tracing Mission Effectiveness Analysis to System Capabilities of Evolving Platforms

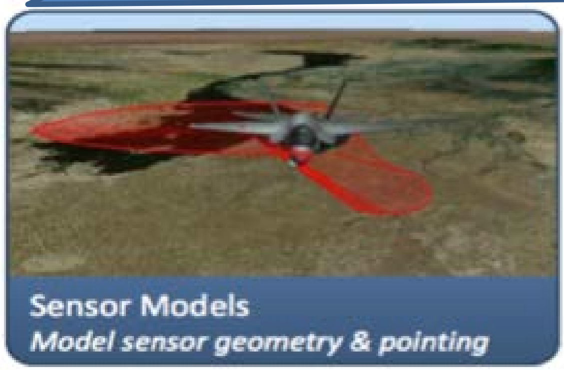


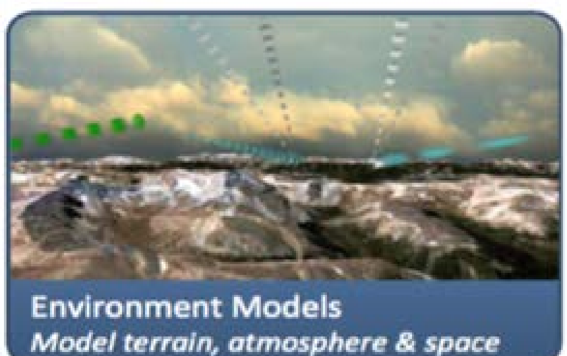



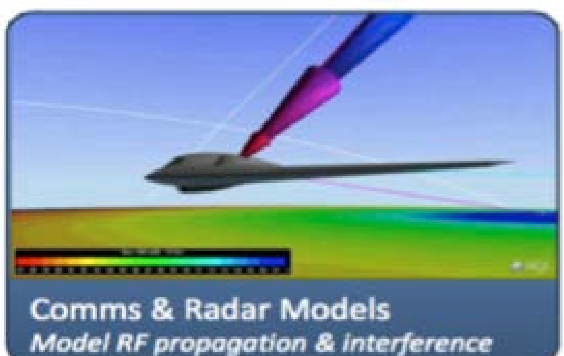
# Dynamic CONOPS Integrated with Mission Simulations to Better Understand Needed System Capabilities

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



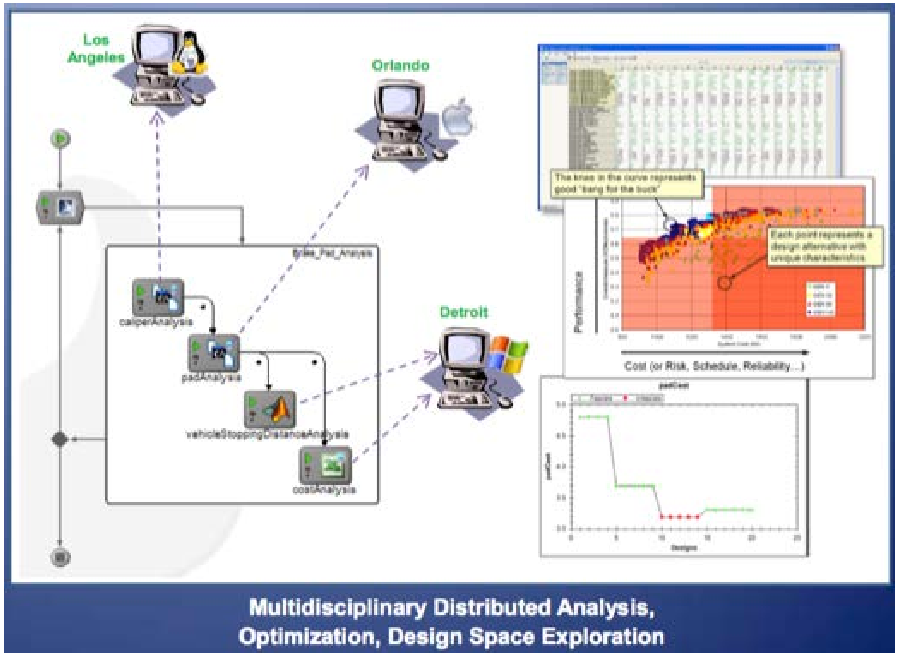


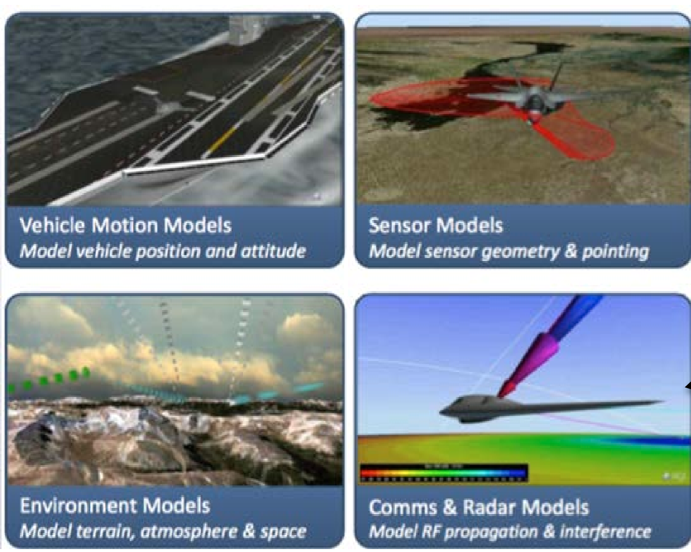



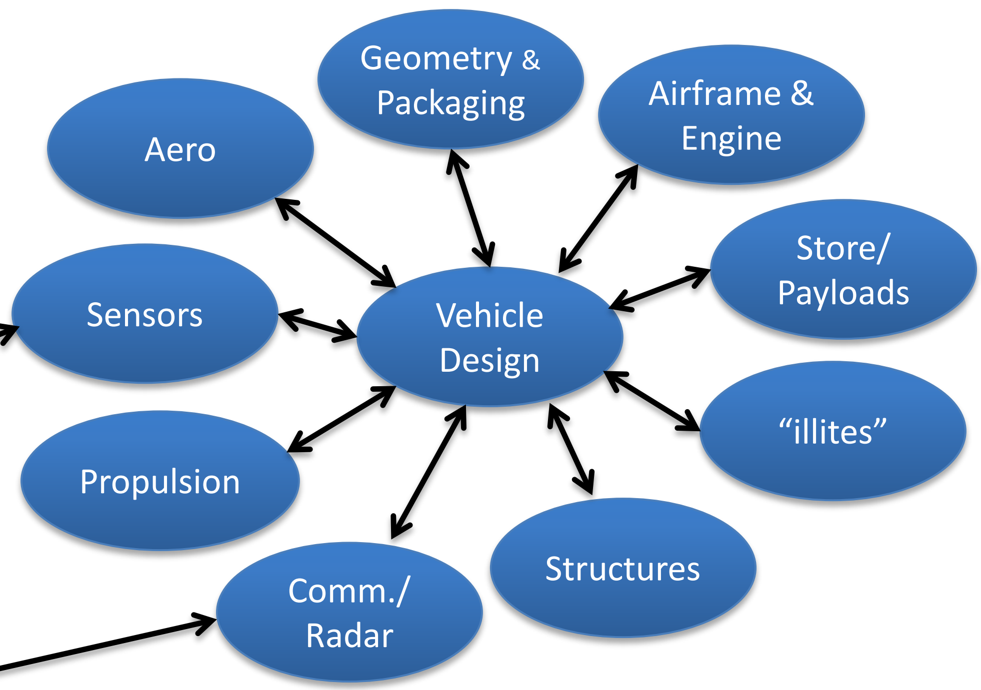

Integrates with libraries of system and environmental models (e.g., AGI System Tool Kit)

# Multidisciplinary Design, Analysis and Optimization Supports Tradespace Analysis Across Disciplines



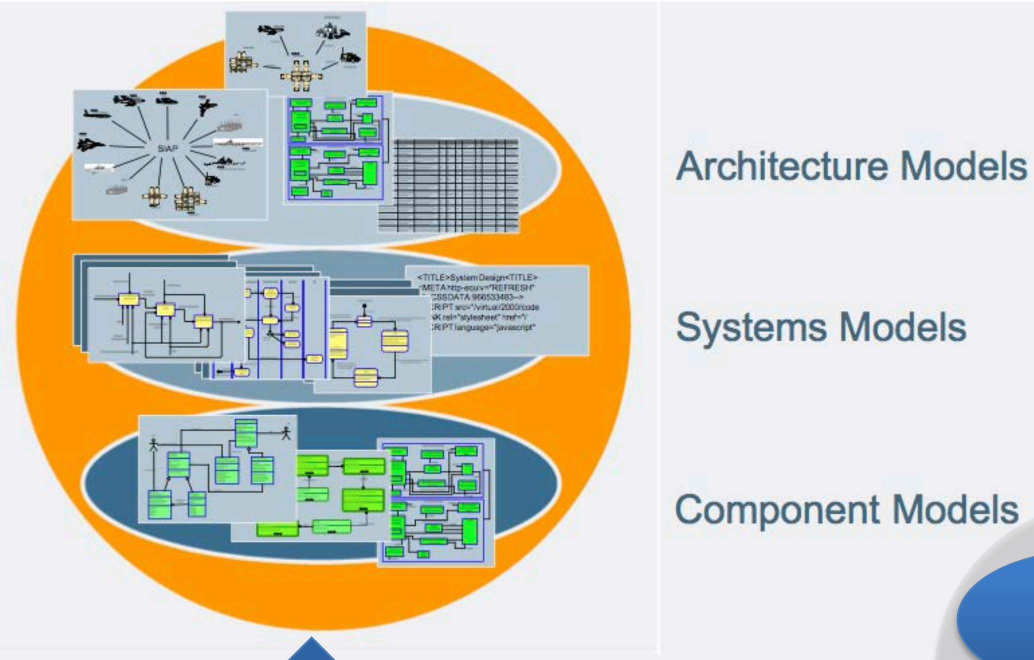

MDAO Implements Workflows with Solvers to Evaluate Trades Systematically Driven by Design of Experiments



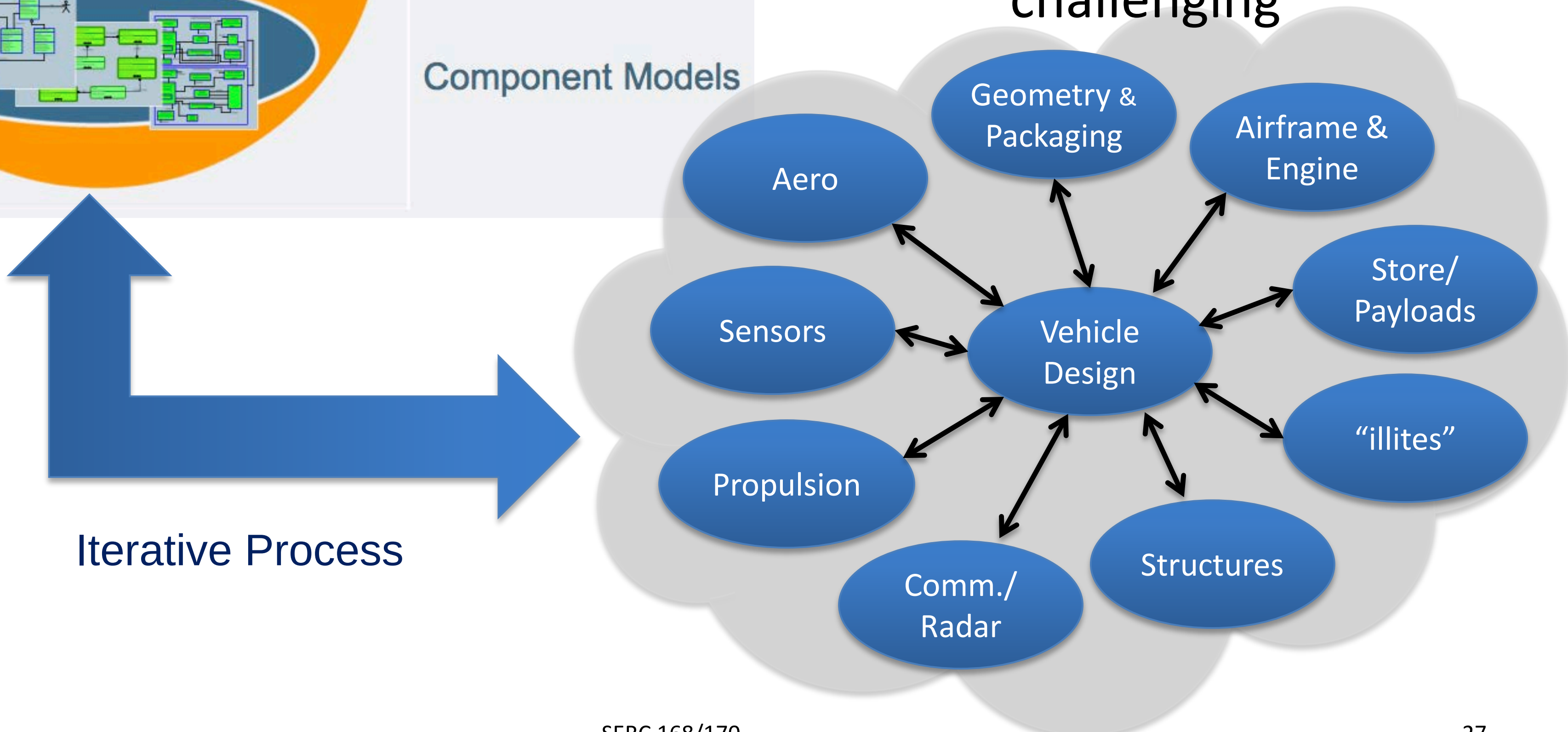




Detailed Design from Associated Disciplines Across Domains

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

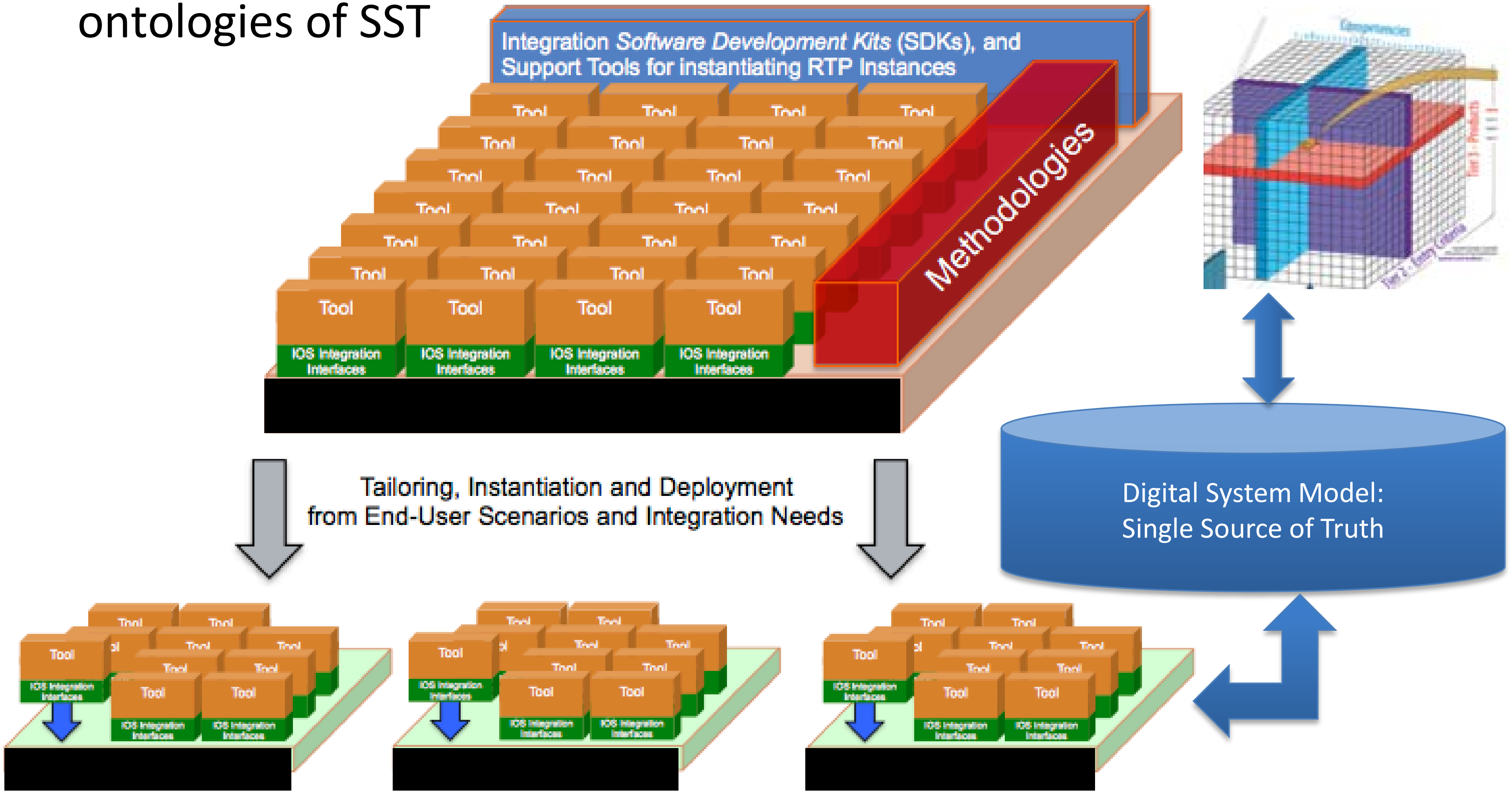



Architectural, System and Component Models Define Cross-Domain Relationships but Integration of Detailed Behaviors is limited or challenging



# 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

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# 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**

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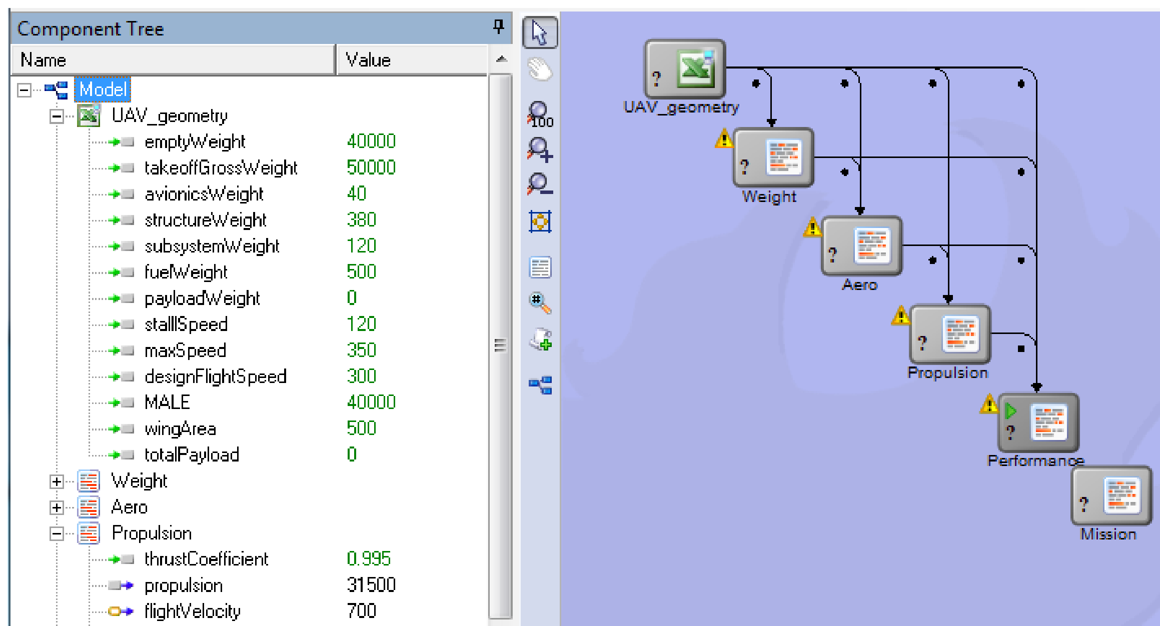
# All Major Contractors Have These MDAO Environments

## 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



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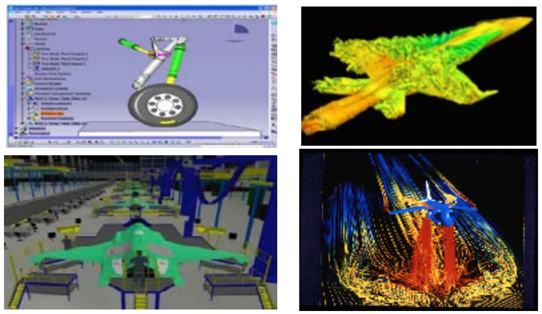
# Organizations are Modeling and Simulating Manufacturing Before Tooling

- 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

## 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 Truth:**
Tool Agnostic, Semantically Precise Cross Domain Integration & Interoperability enabled by HPC

PLM

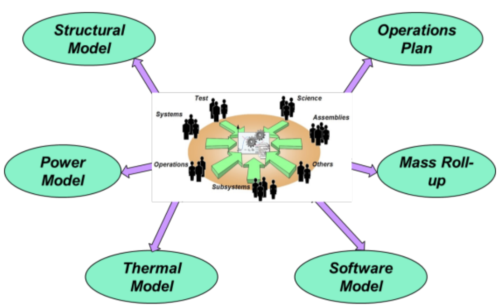
| Performance | Integrity | Cost & Schedule | "Illities" | Knowledge | … | Systems, Surrogates & Platforms |
|---|---|---|---|---|---|---|

# Critical Technical Feasibility Items

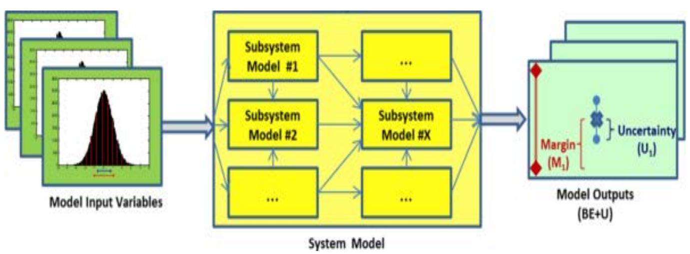
I. Cross-domain and multi-physics model integration

II. Technologies to establish & quantify model integrity

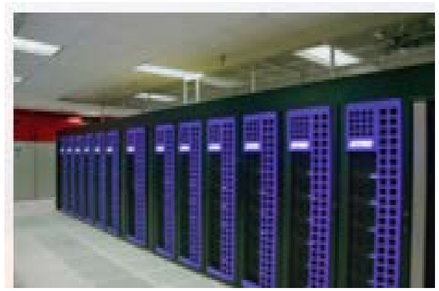
III. High Performance Computing[1] (HPC)




Cross-Domain Model Integration




Model Integrity



HPC

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

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# 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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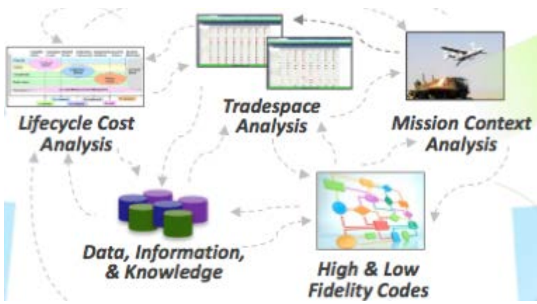
# Present: NAVAIR: SE Transformation Phase II

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

### 1) Model Cross-Domain Integration

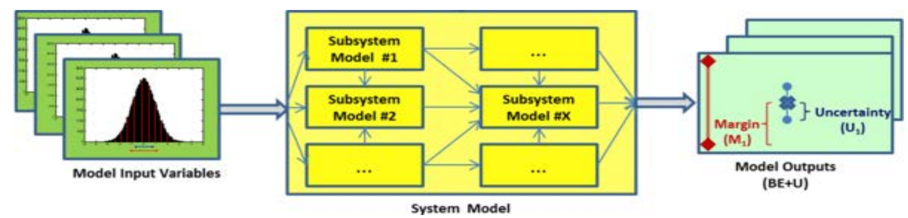
Targeted discussions with Government, Industry & Academia on developing and operating in modeling framework enabling cross-domain model integration & Single Source of Truth (SST) methodology

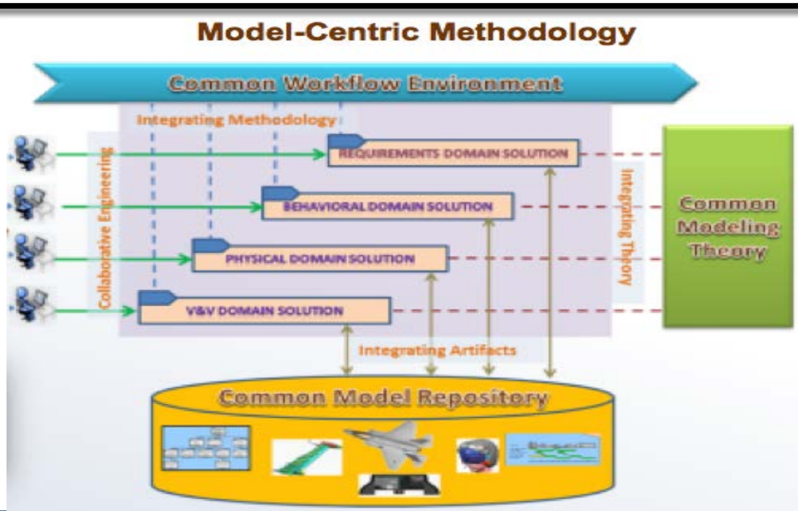



### 2) Model Integrity

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

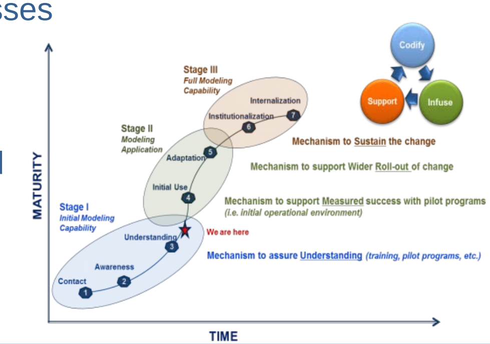



### 3) Modeling Methodology Implementation at NAVAIR

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

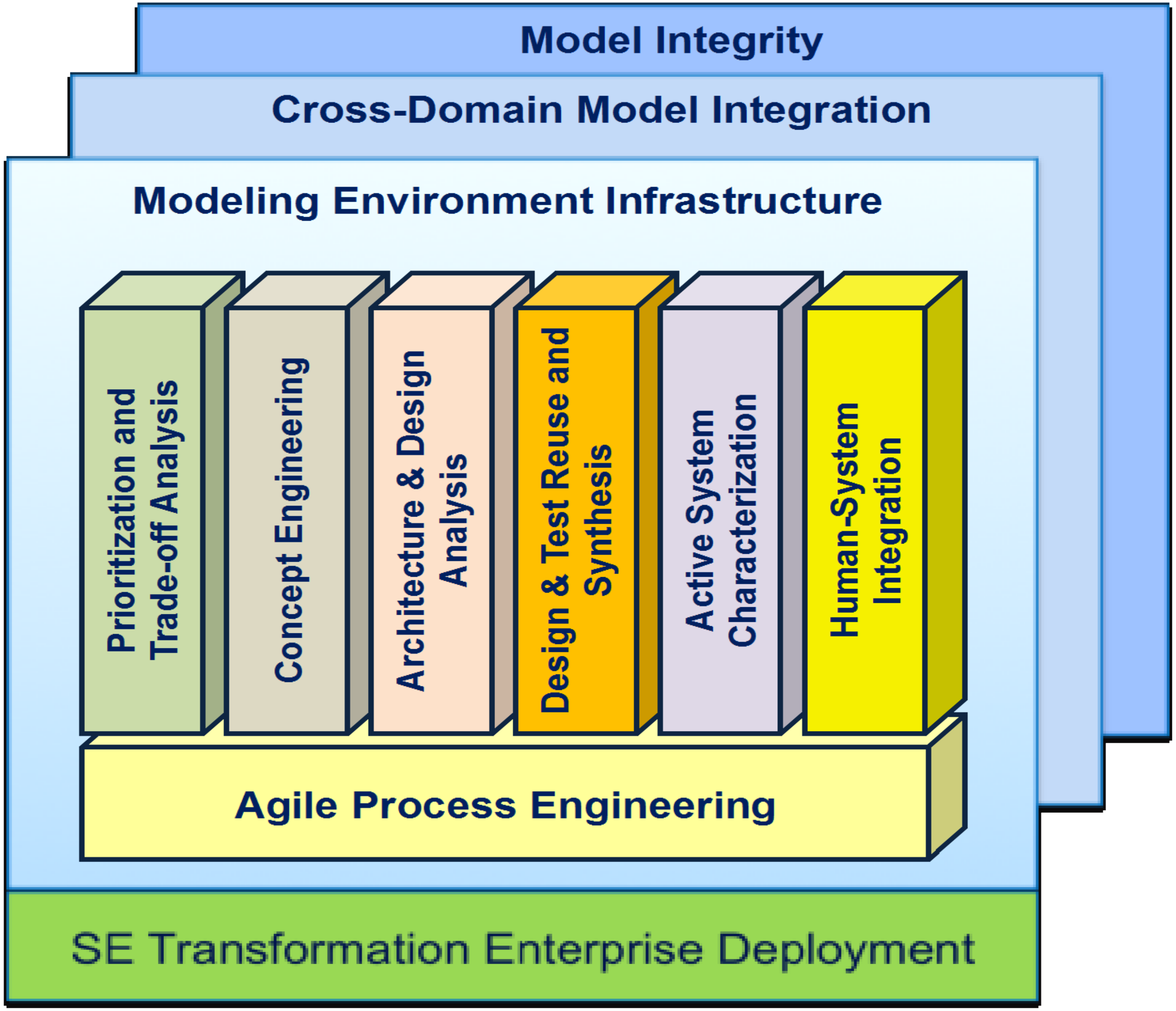
**March 2016: Change of Command has Accelerated the Systems Engineering Transformation and Broadened the Scope**

# SE Transformation (SET) Expanded Research Areas

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

**Modeling Methodology at NAVAIR**

**SET Roadmap**



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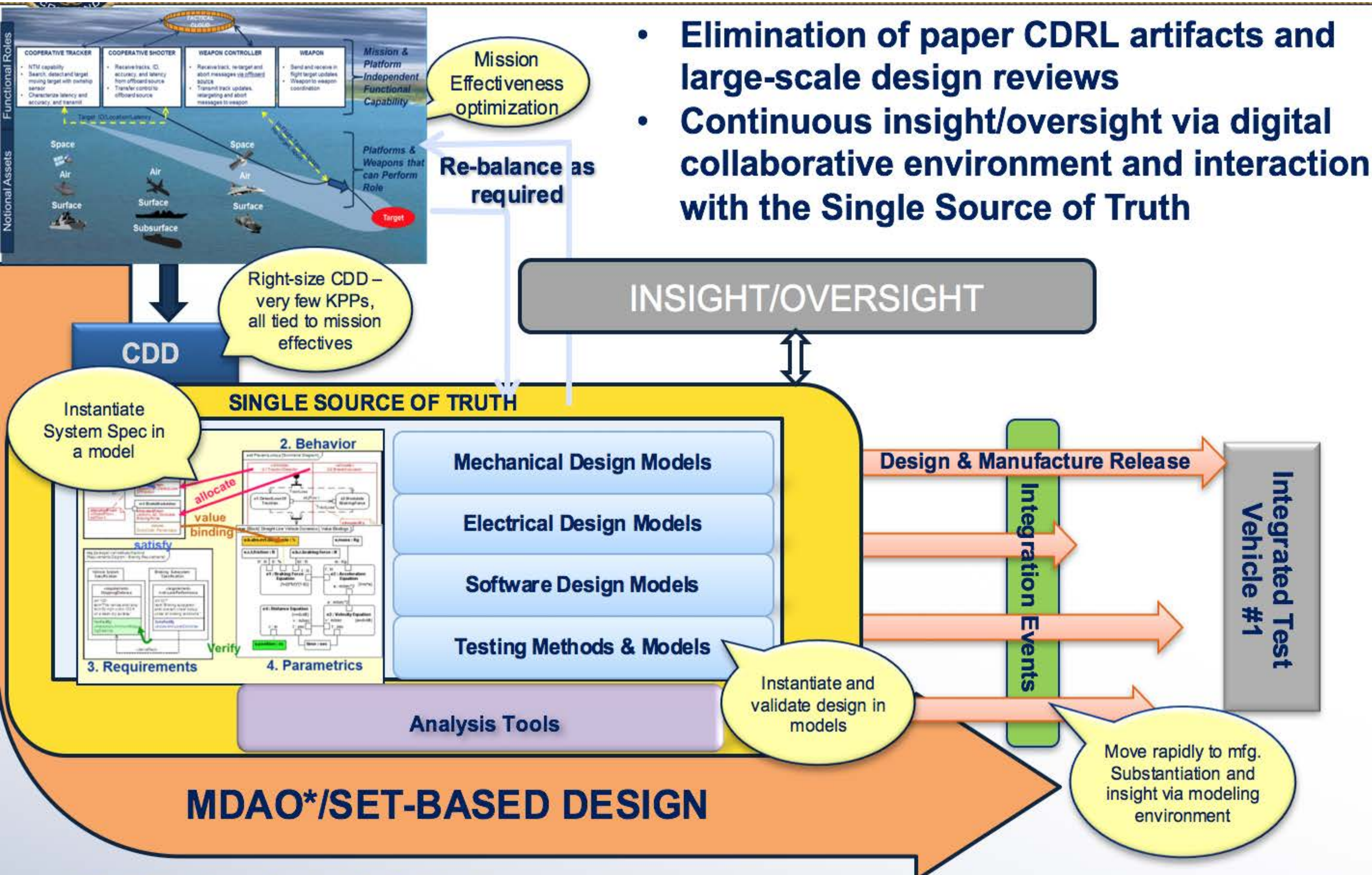
# Model-Centric Engineering Can Enable New Types of Coordination & SET Demands It

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

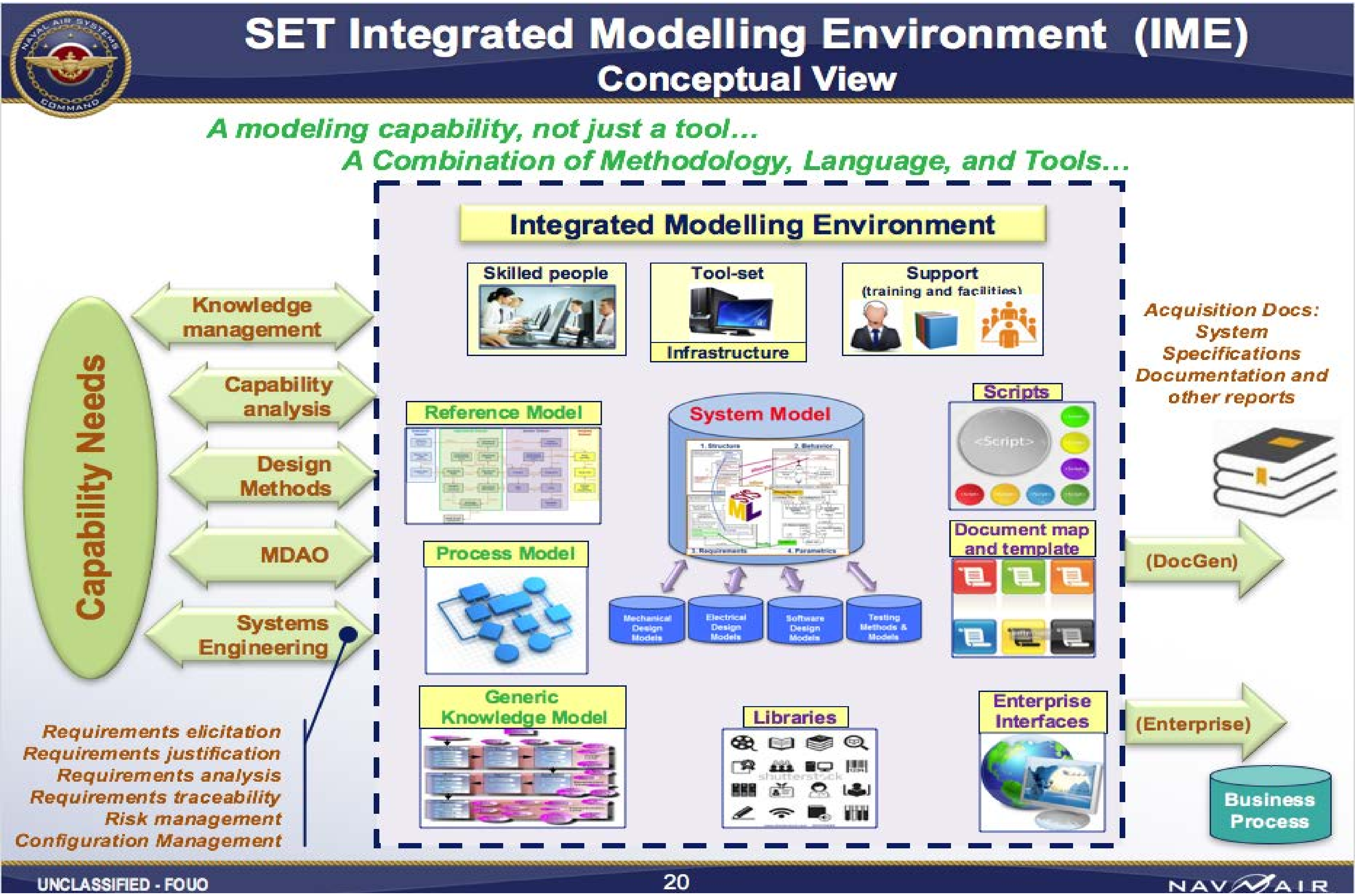
# Framework for New Operational Paradigm Between Government and Industry

- **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**

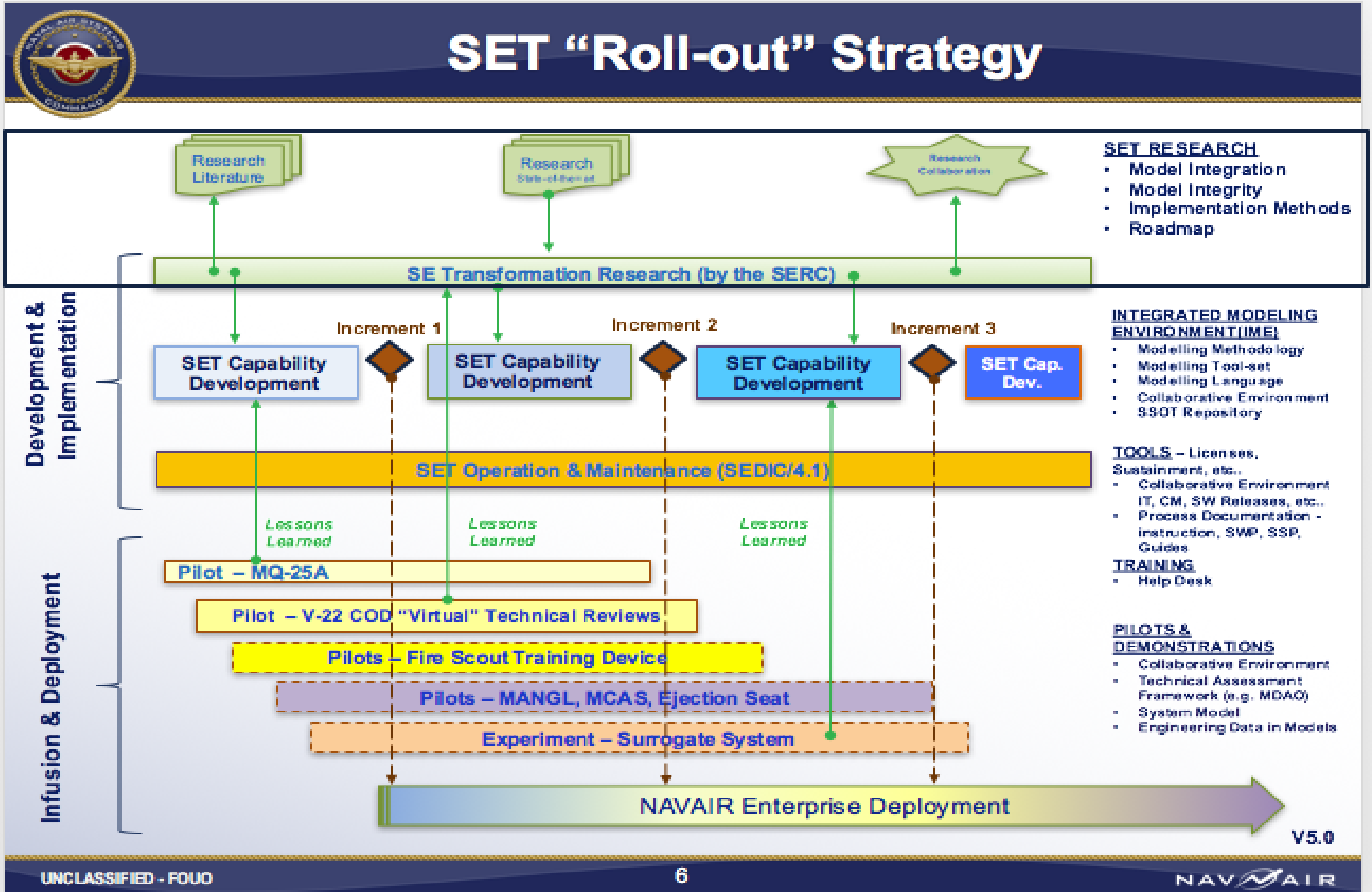



* *Multi-Disciplinary Analysis & Optimization*

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



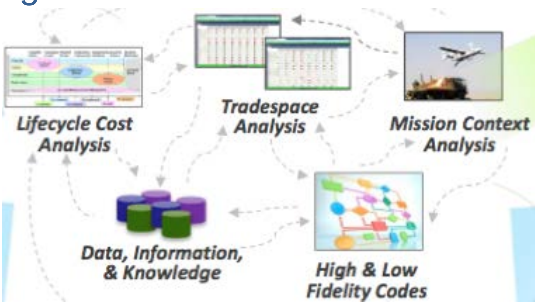
# SE Transformation "Role-out" Strategy



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

## 1) MCE Framework

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



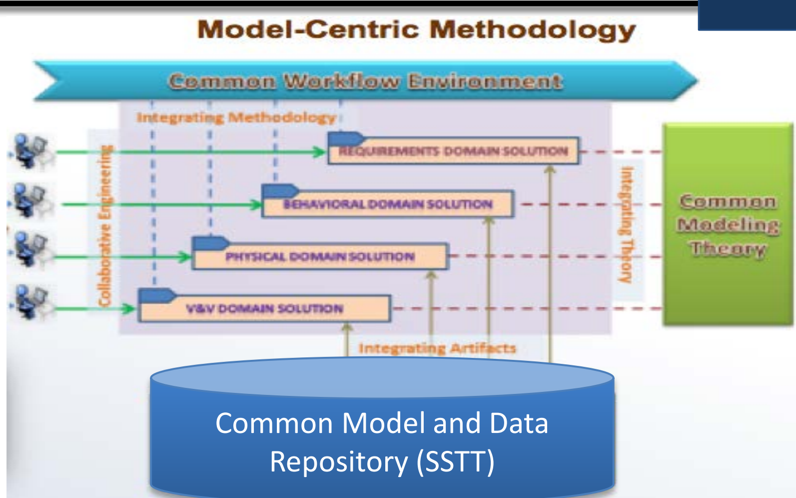

## 2) Formalization of Information Model for ARDEC-relevant Domains

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)

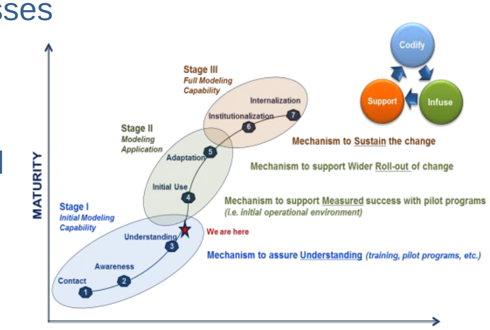
## 4) Challenge Areas




## 3) Modeling Methodology Implementation at ARDEC

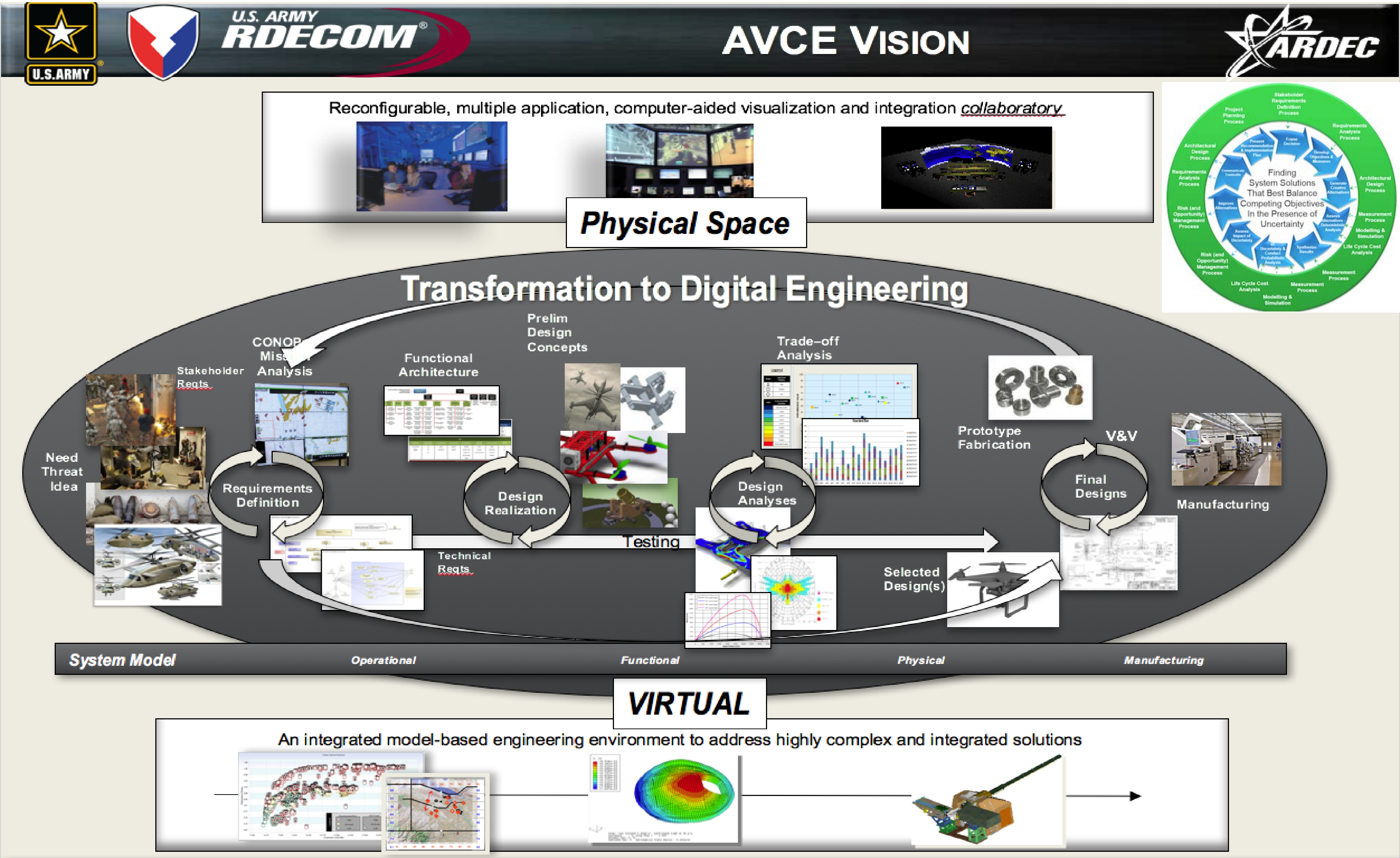
Develop a roadmap to rollout capabilities addressing all five perspectives in parallel:

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

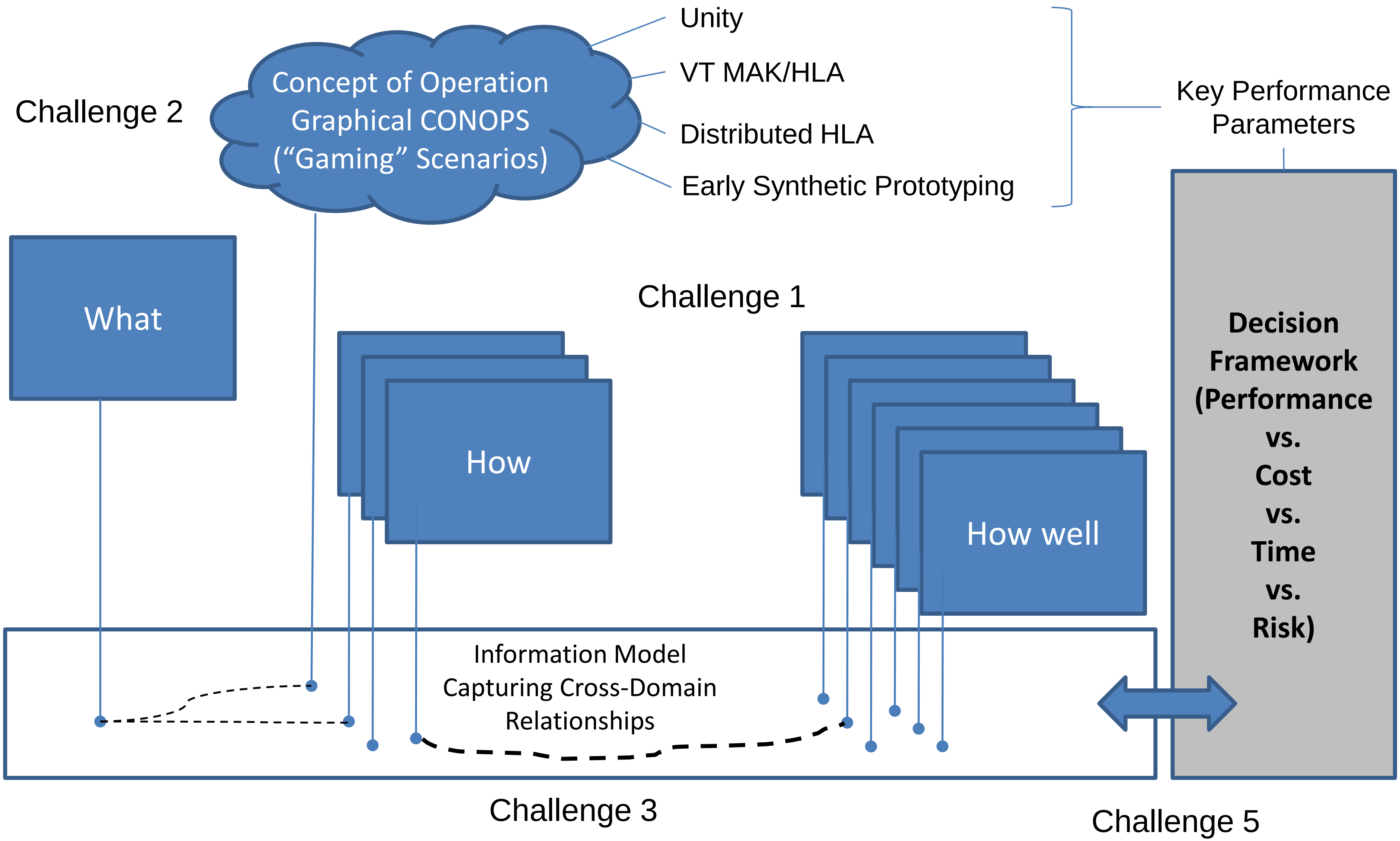



## 5) SE Transformation Roadmap

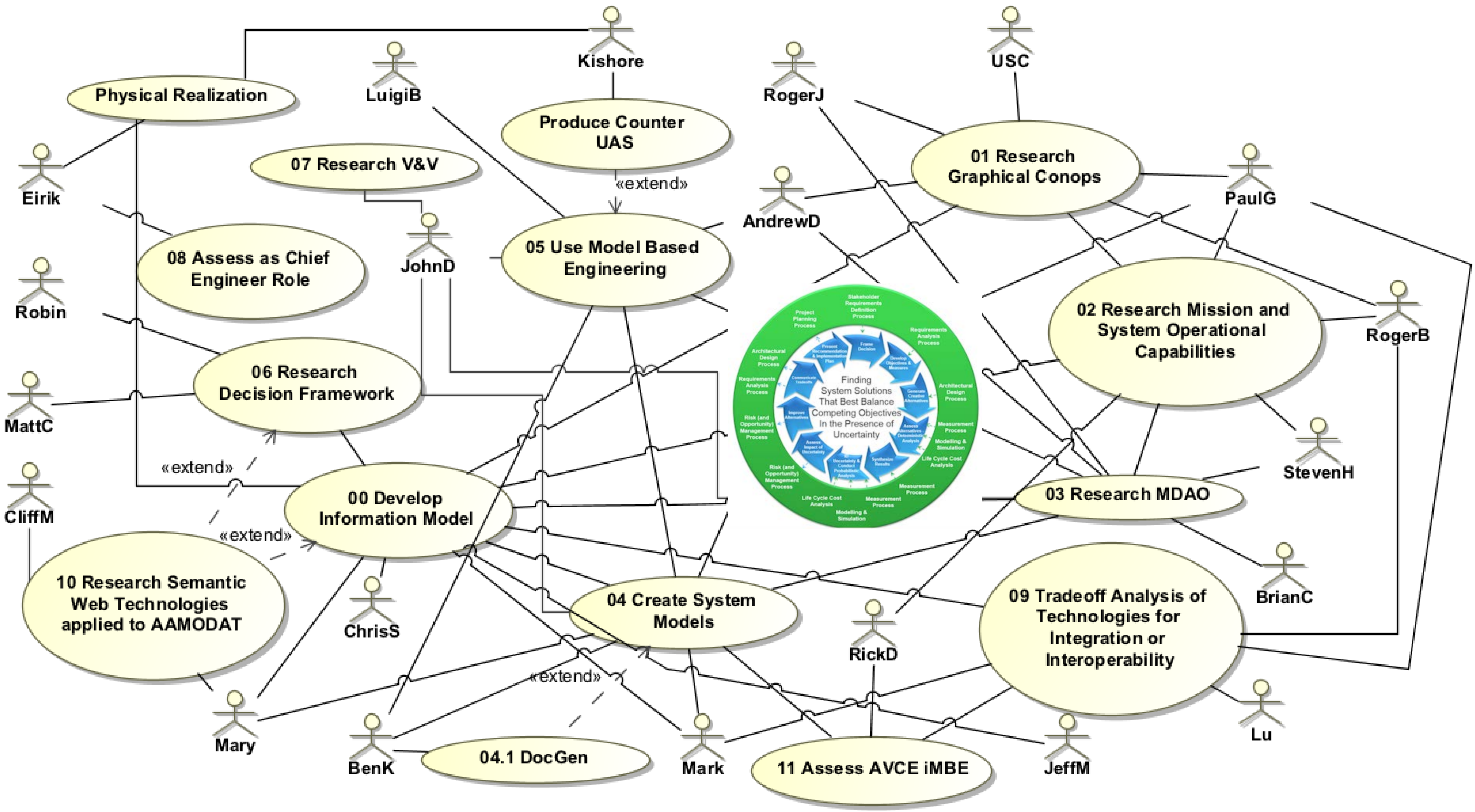
# Armaments Virtual Collaborative Environment (AVCE) integrated Model Based Environment (iMBE)



# Perspectives on the Challenge Areas



# RT-168 Use Case Perspective and Team

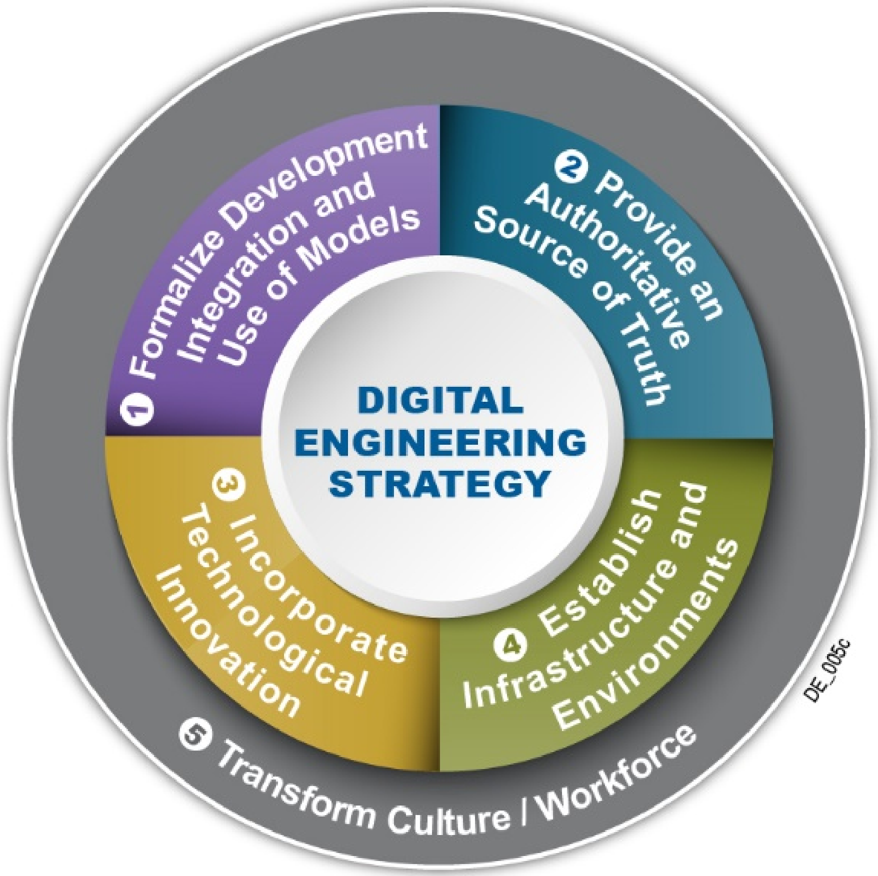


# How?

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….."***

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# 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

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# 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 |

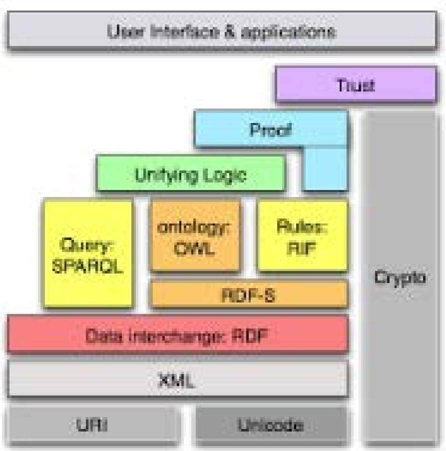
## Breakout Areas

| Risks | Priorities |
|---|---|
| | |

# Deep Dive Research Topics

# Review: Deep Dive Topics

## Semantic Web Technologies




Enforces **Modeling Methods**

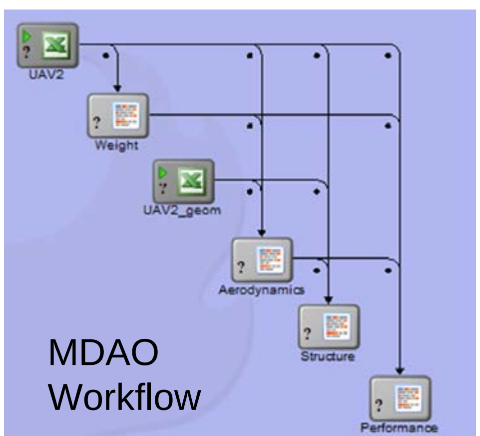
Underlying technologies for reasoning about completeness and consistency **Across Domains** in modeling tool agnostic way

## Modeling Methodologies

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

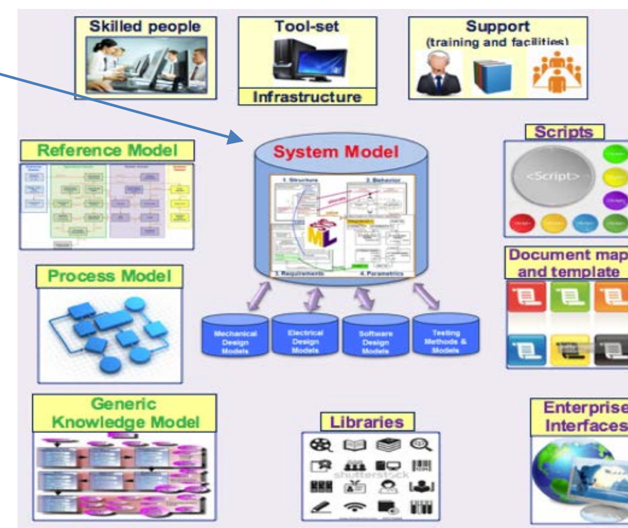
**Digital System Model: Single Source of Truth (*authoritative source of truth*)**

## 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



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

# INCOSE MBSE Roadmap

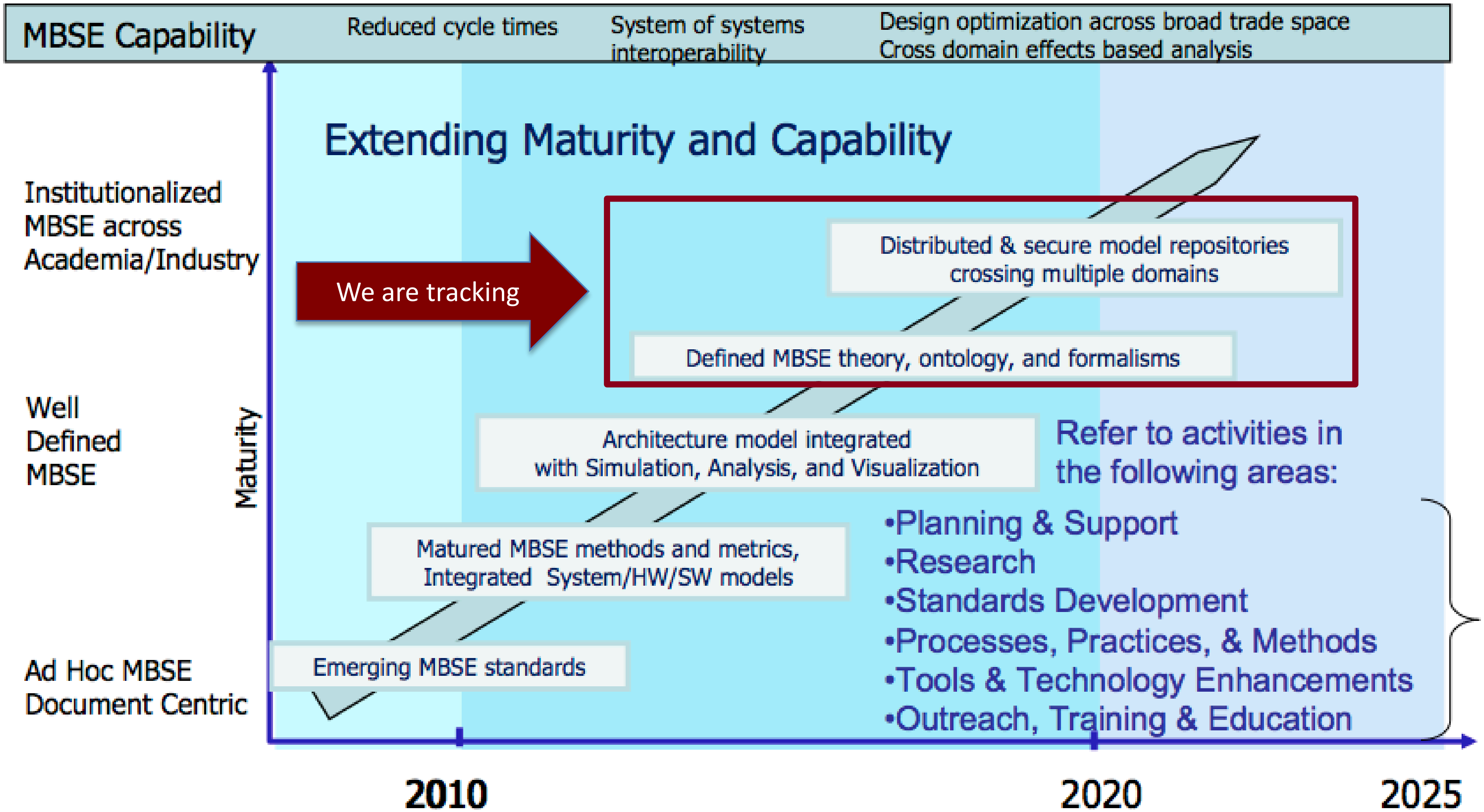
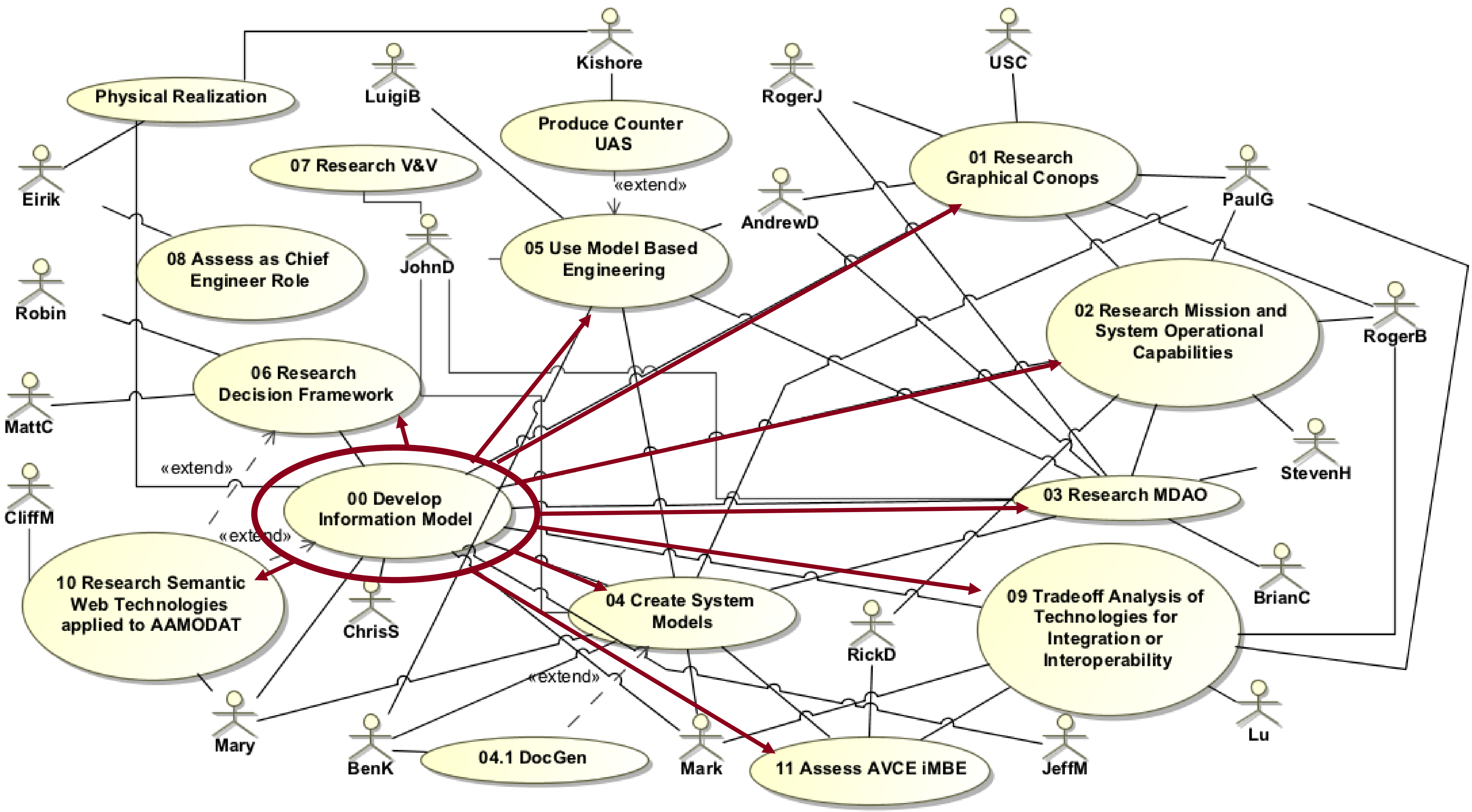
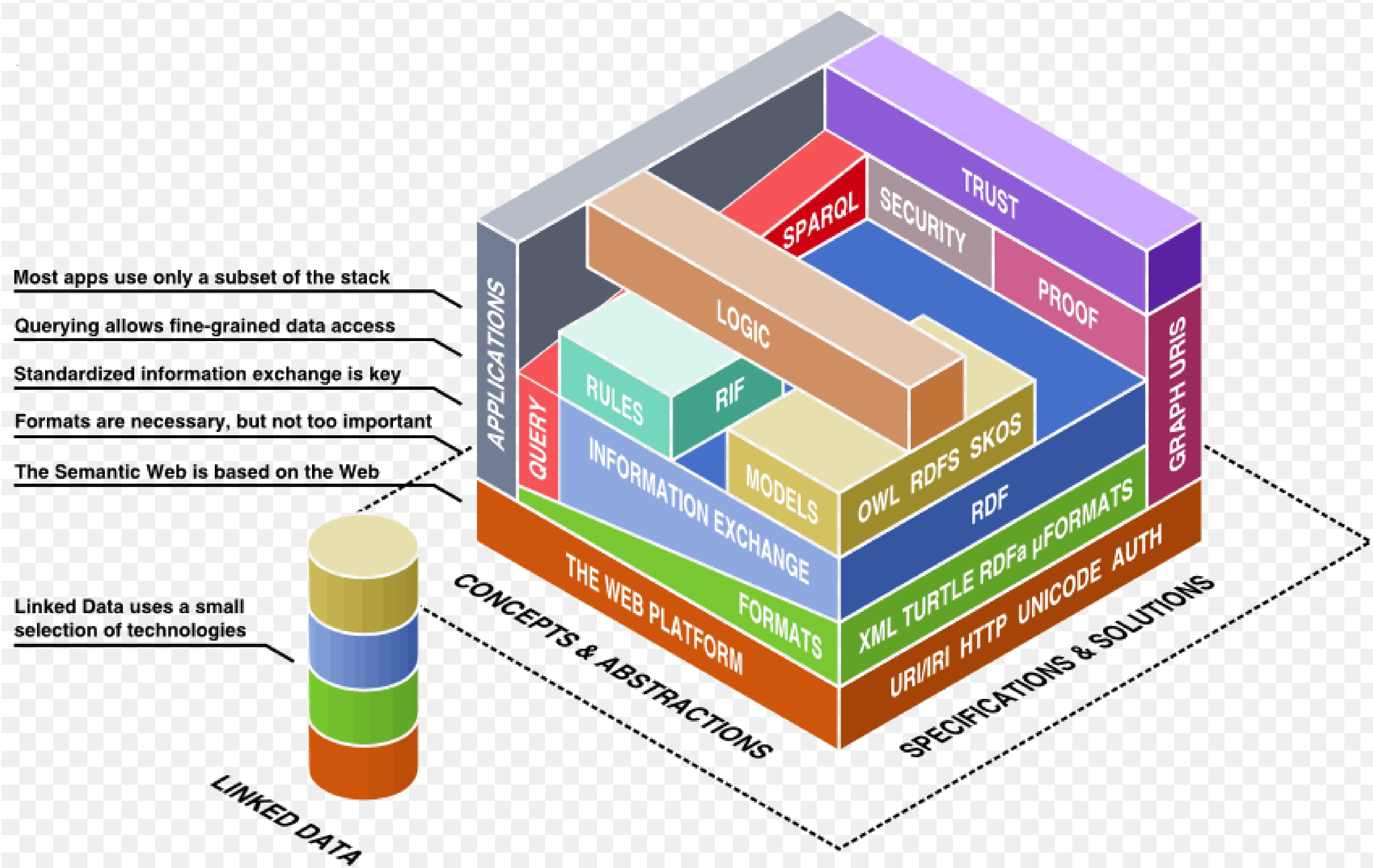



**Figure 2-4: INCOSE MBSE Roadmap**

# RT-168 Use Case Perspective and Team



# Semantic Web Technologies is More than Ontologies



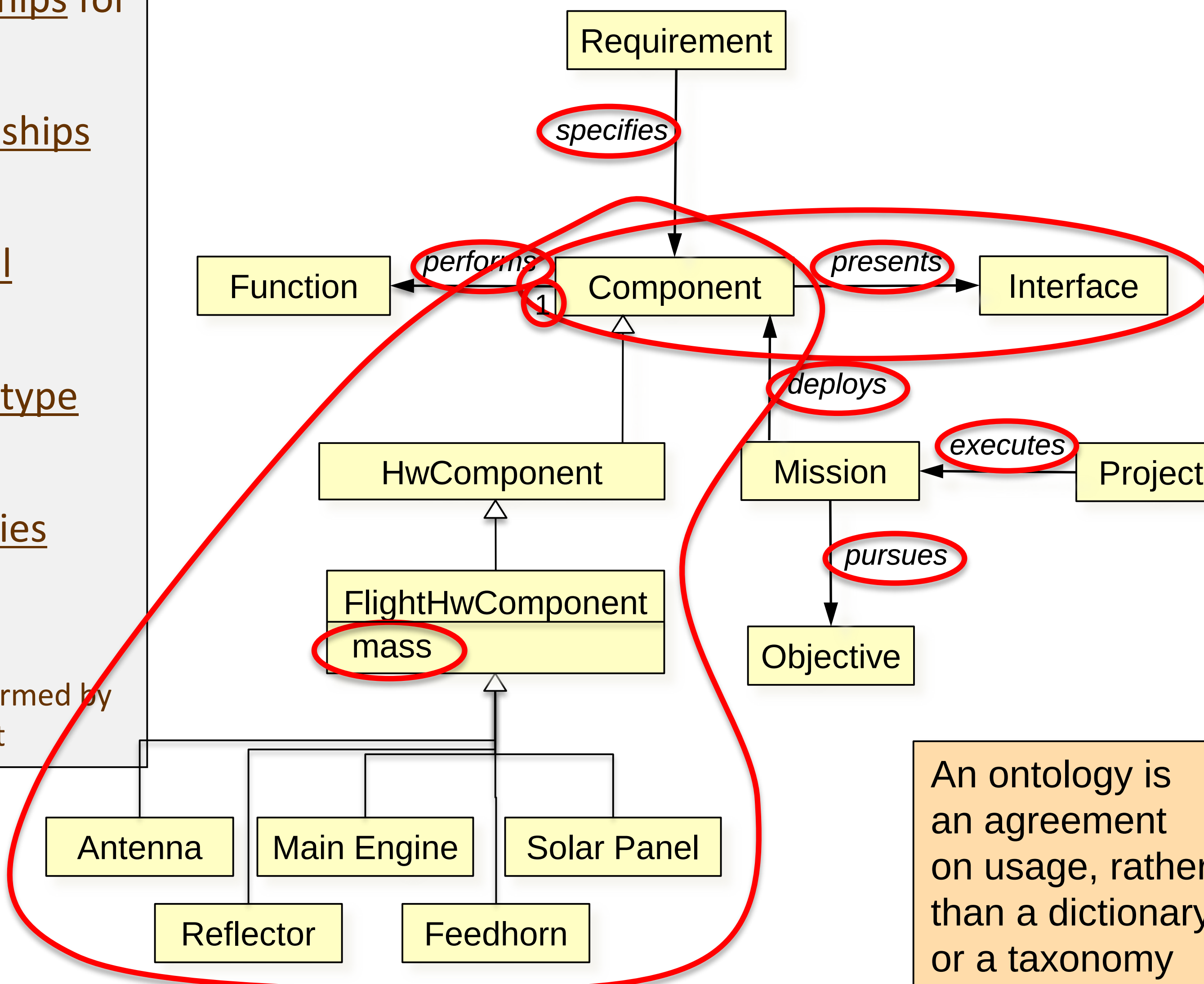

https://adl.gitbooks.io/companion-specification-for-xapi-vocabularies/content/semantic_web_technology,_linked_data,_and_rdf/ SERC 168/170.

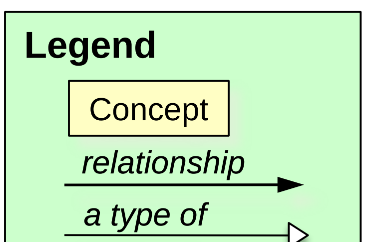
# Excellent Videos on Semantic Technologies for Systems Engineering

- 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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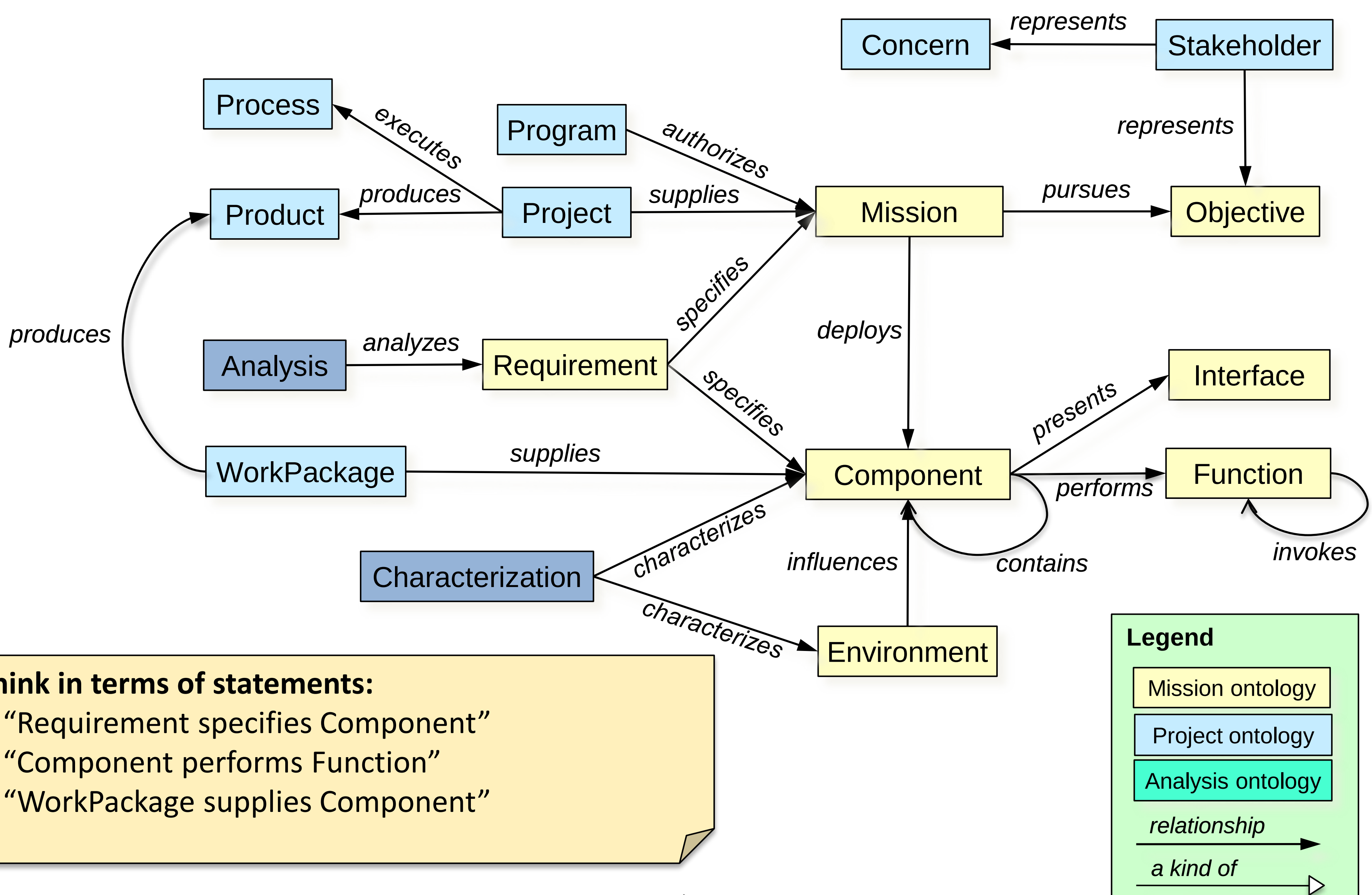
**(animated)**




**Think in terms of statements:**

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

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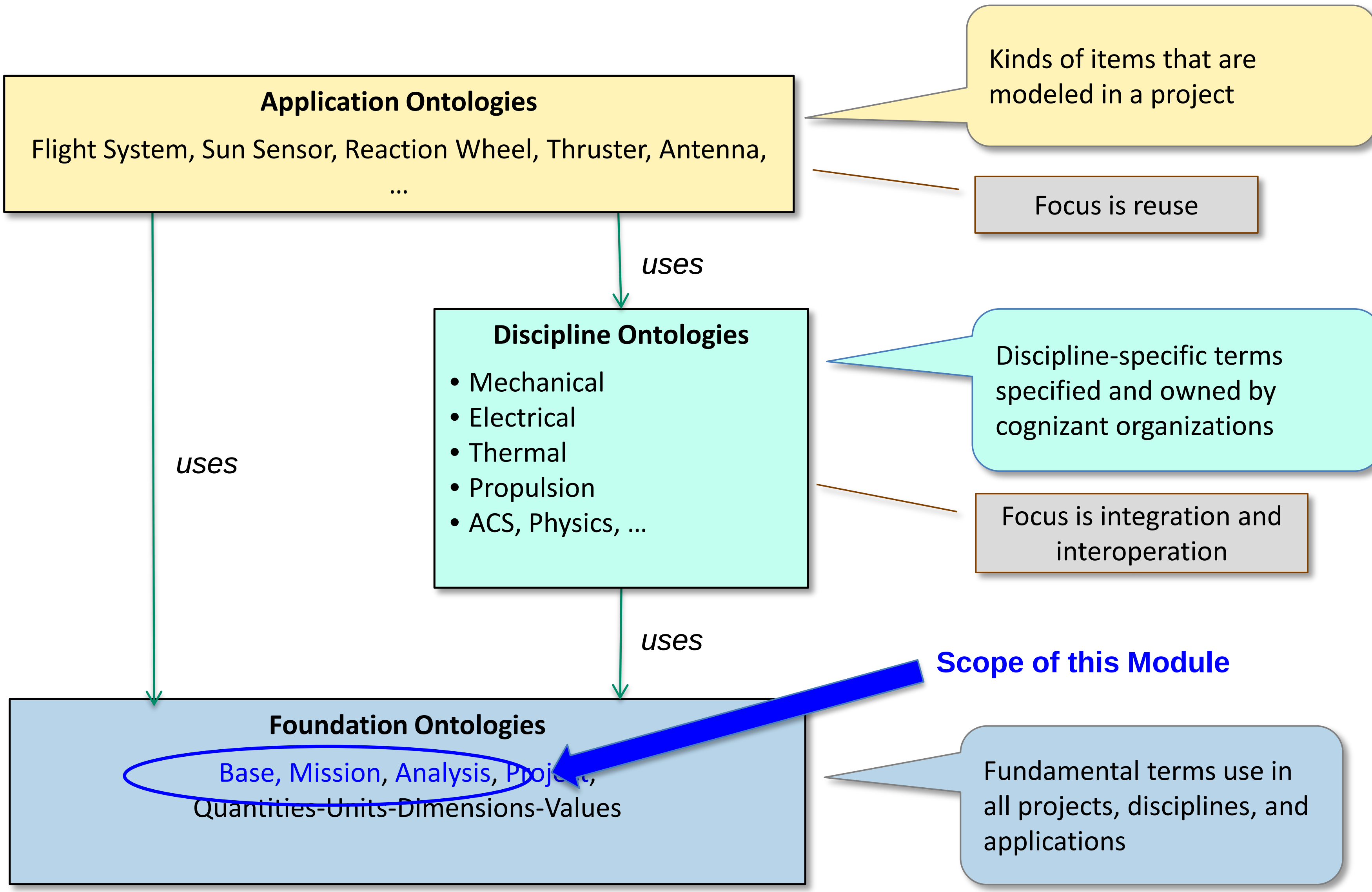
# Systems Engineering Ontologies

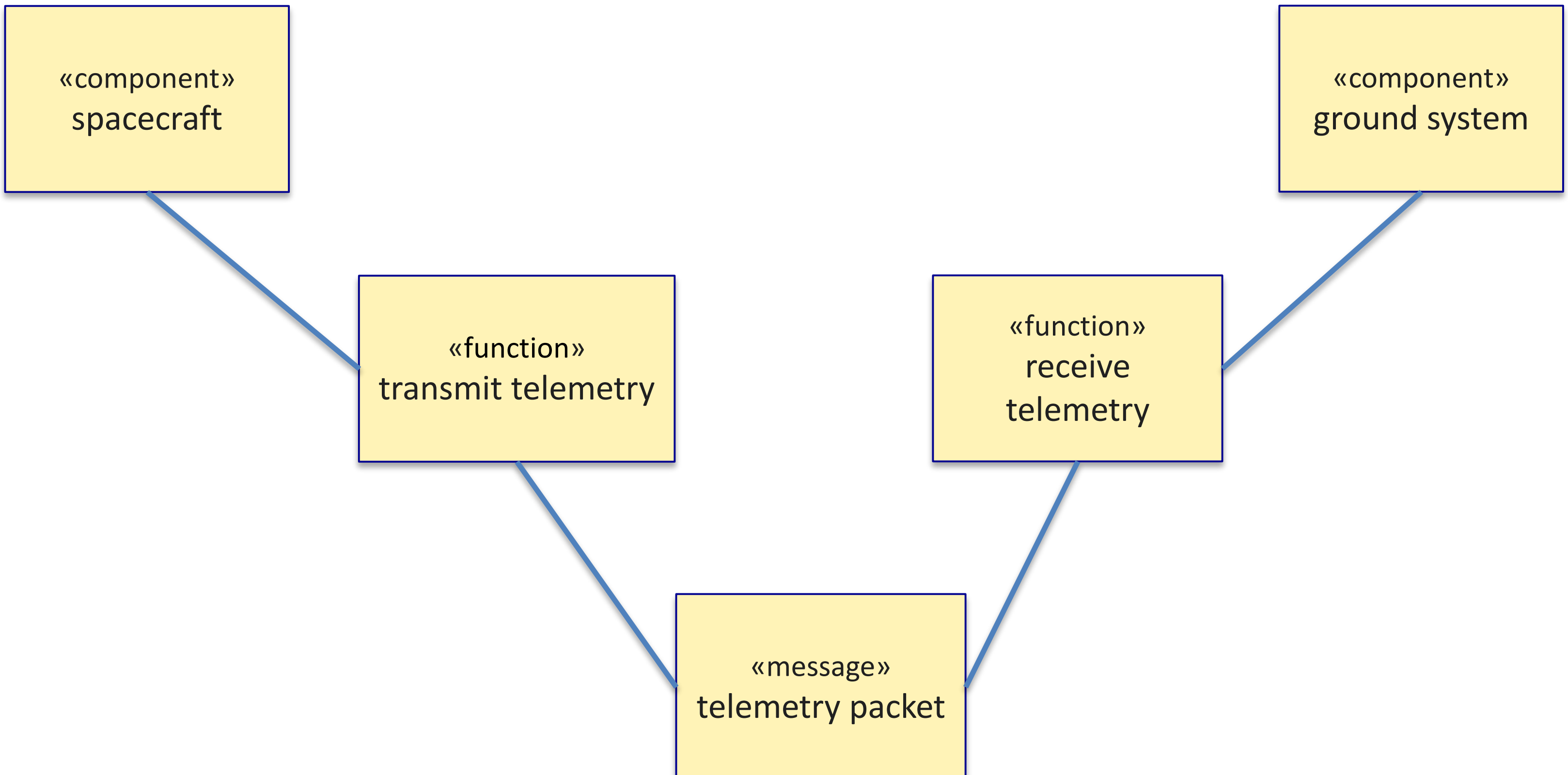


Semantic Web Technologies >
Integrated Modeling Environment >
**Modeling Method Alternatives >**
MDAO (Time Permitting)

# 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

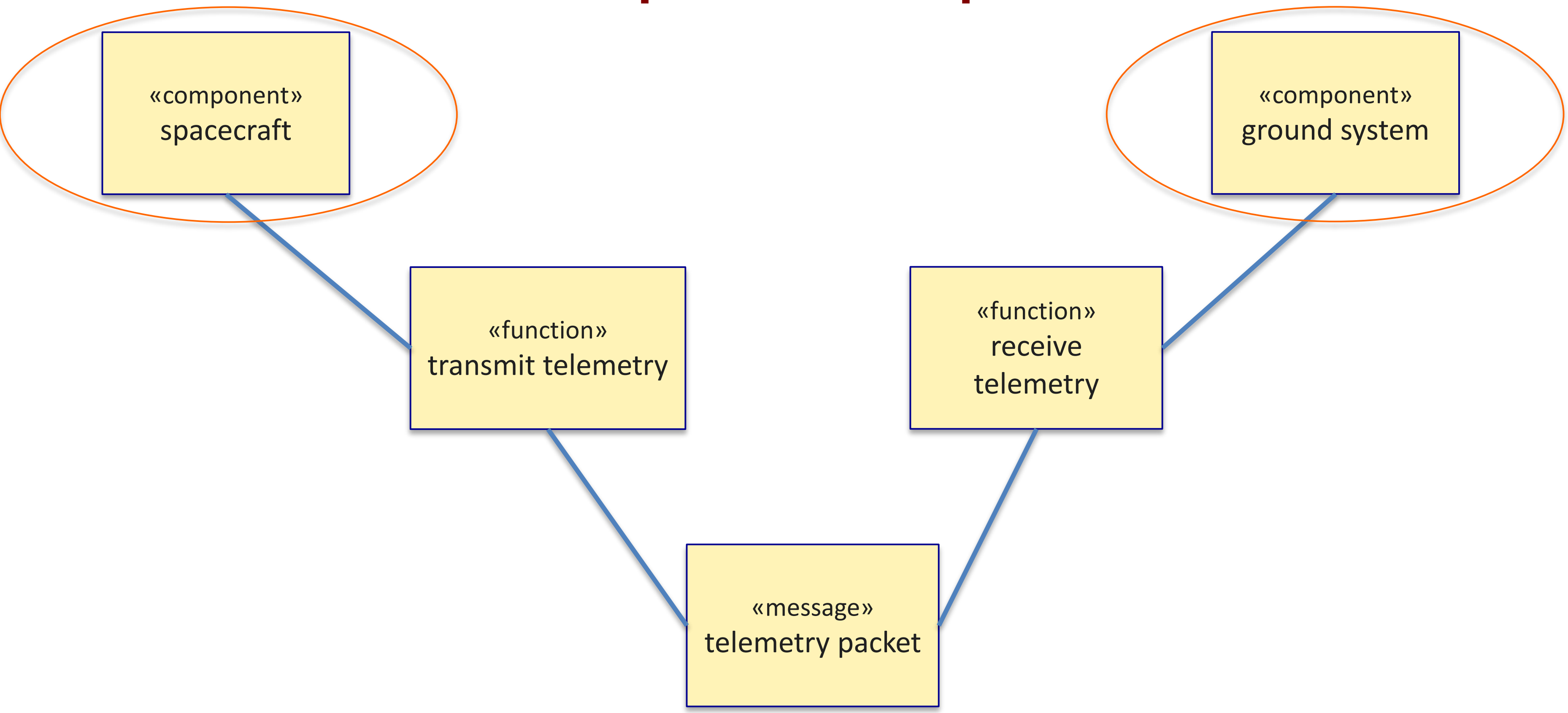
# Model With Typed Elements



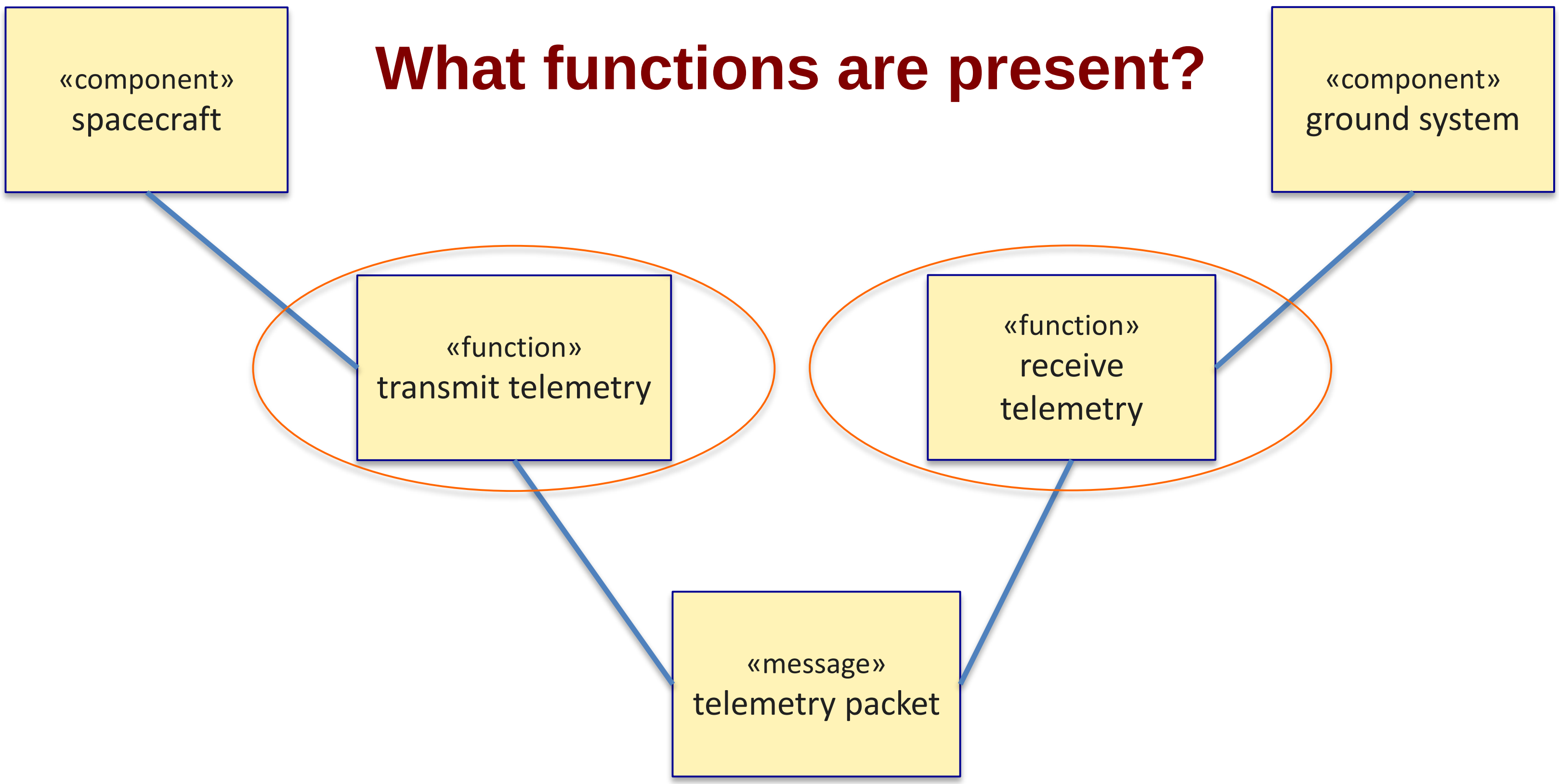

Can be done using
Profiles and Stereotypes with
most SysML-based tools

# Answering Questions

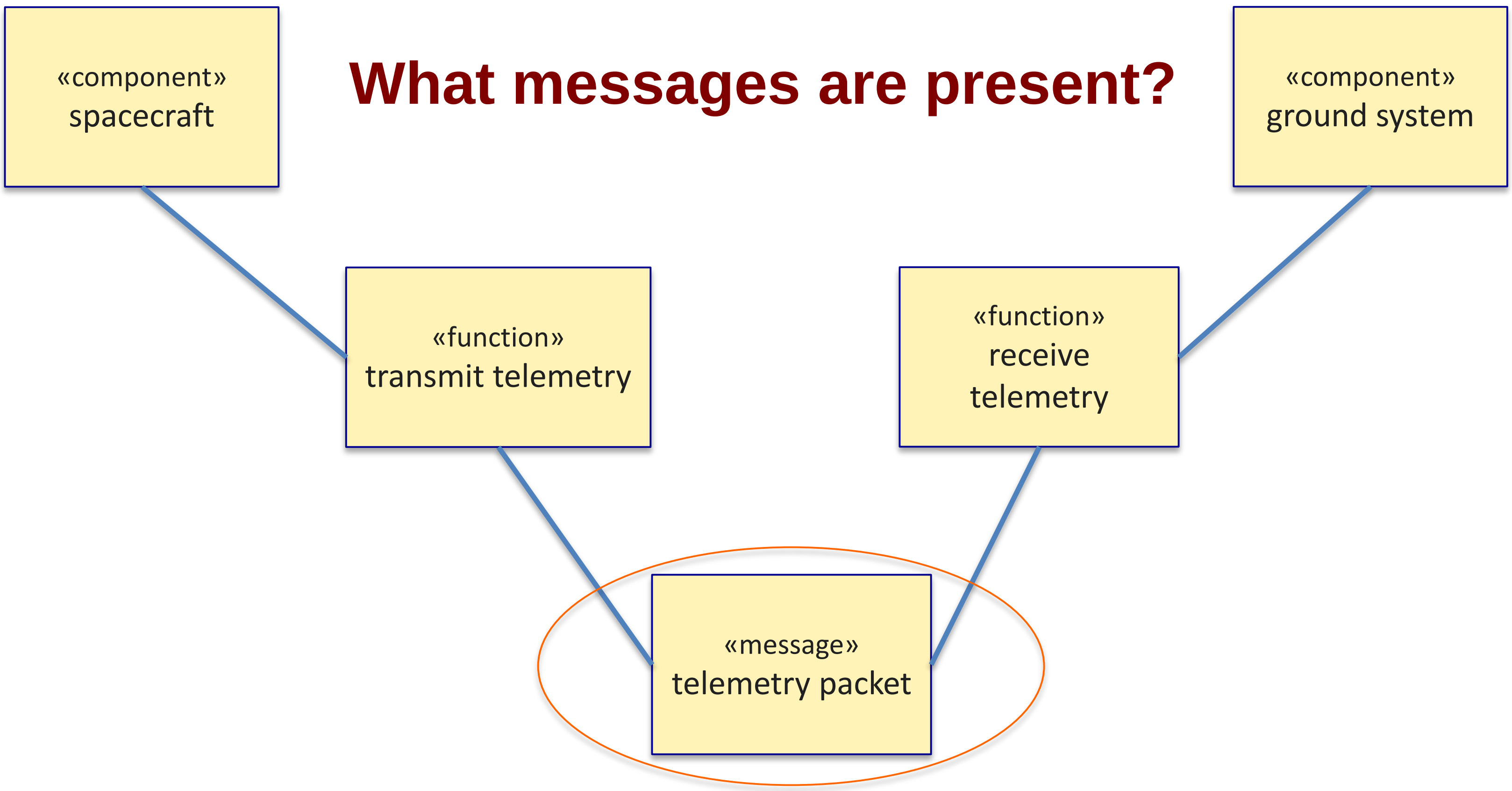
## What components are present?



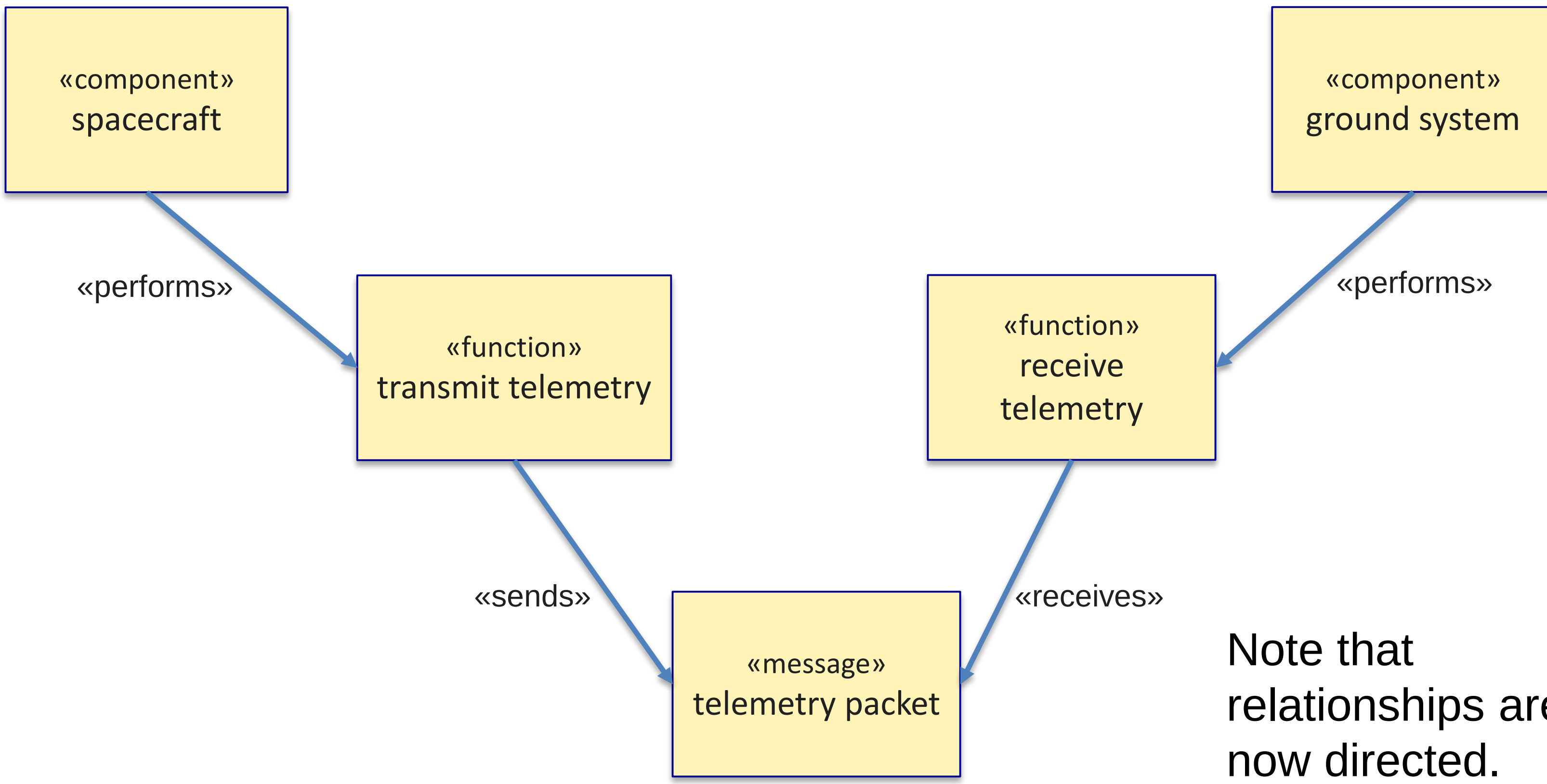
# Answering Questions



# Answering Questions



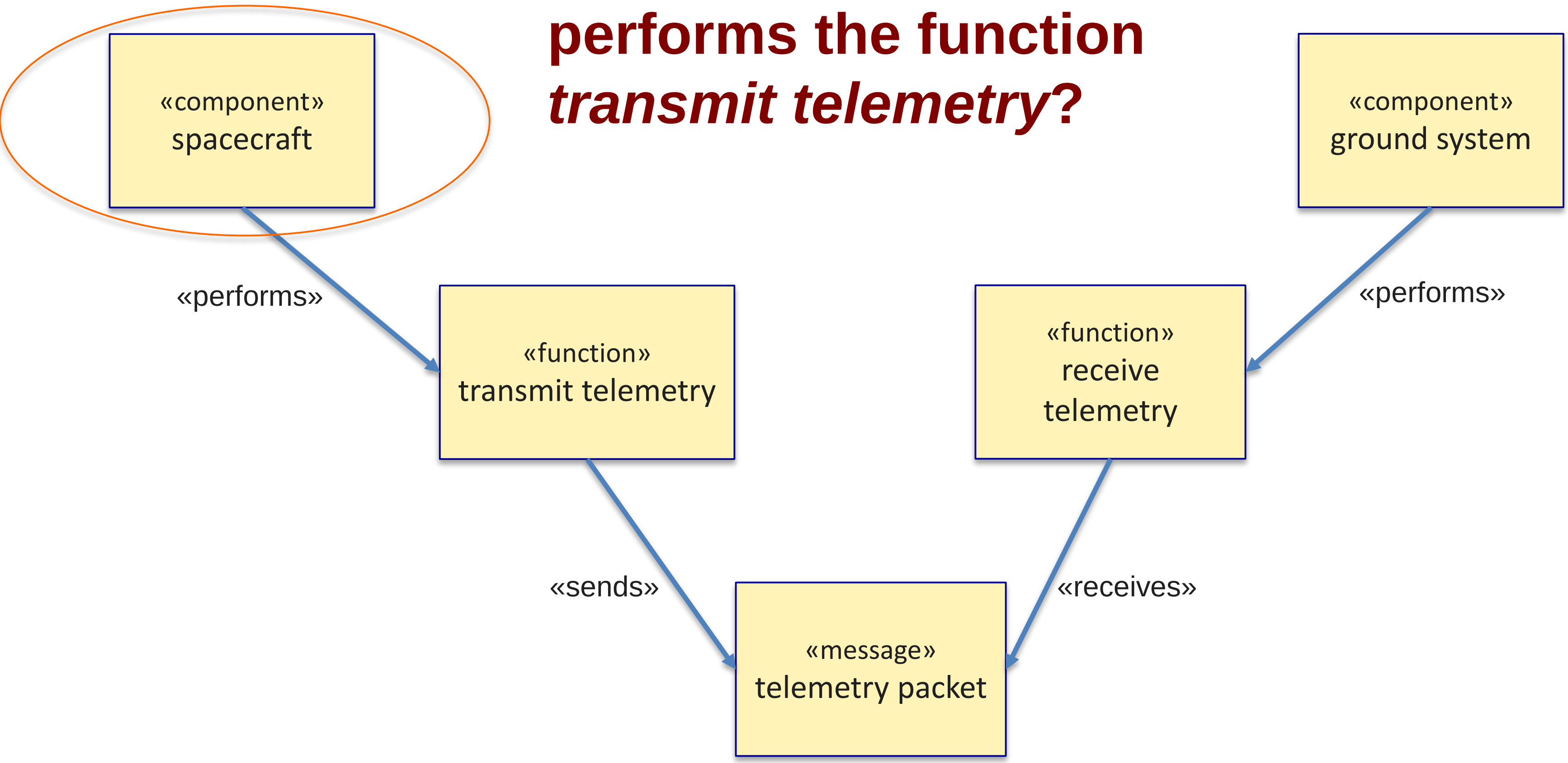
# Add Typed Relationships




Note that relationships are now directed.

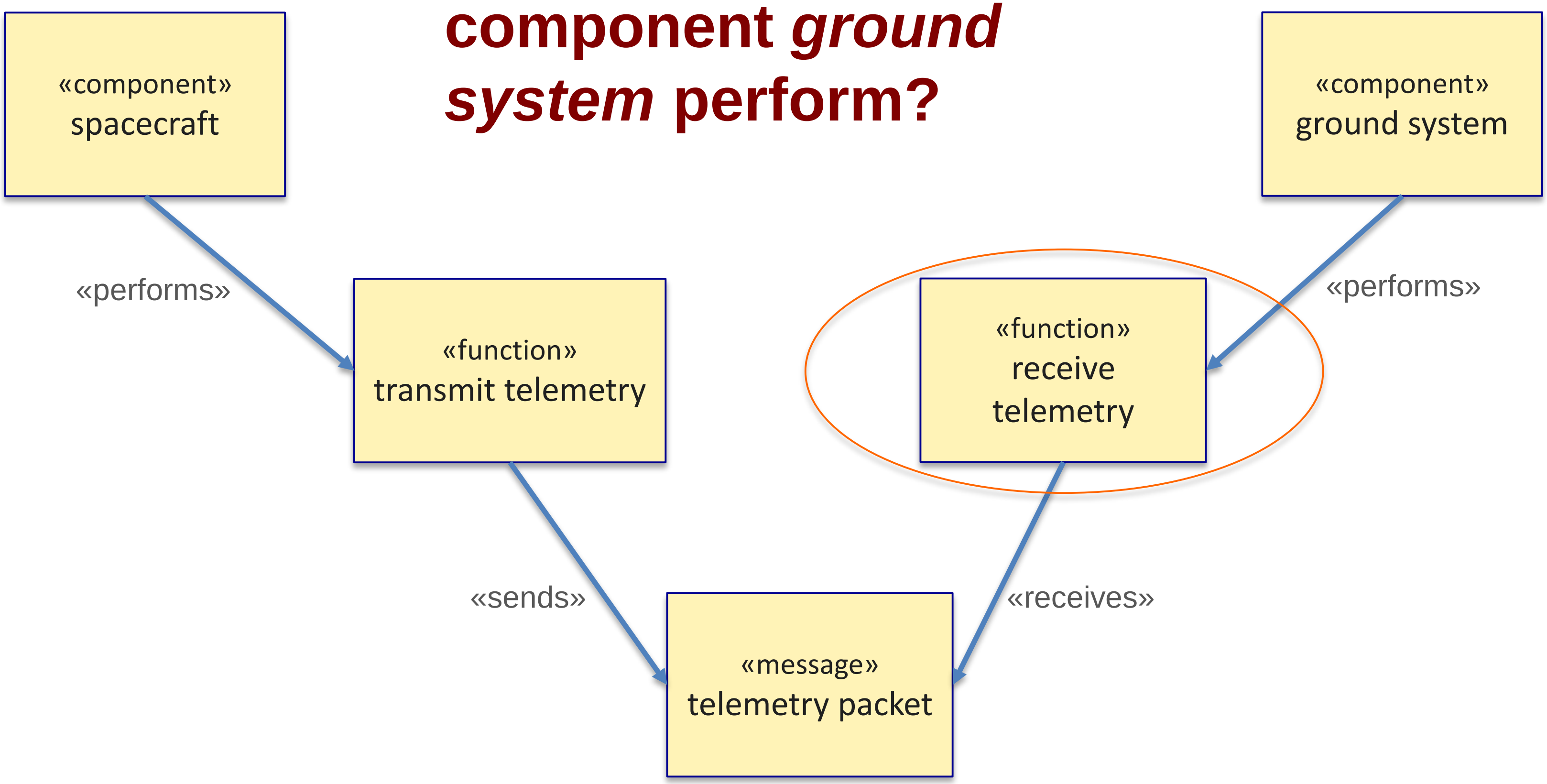
# More Questions and Answers

**What component performs the function *transmit telemetry*?**



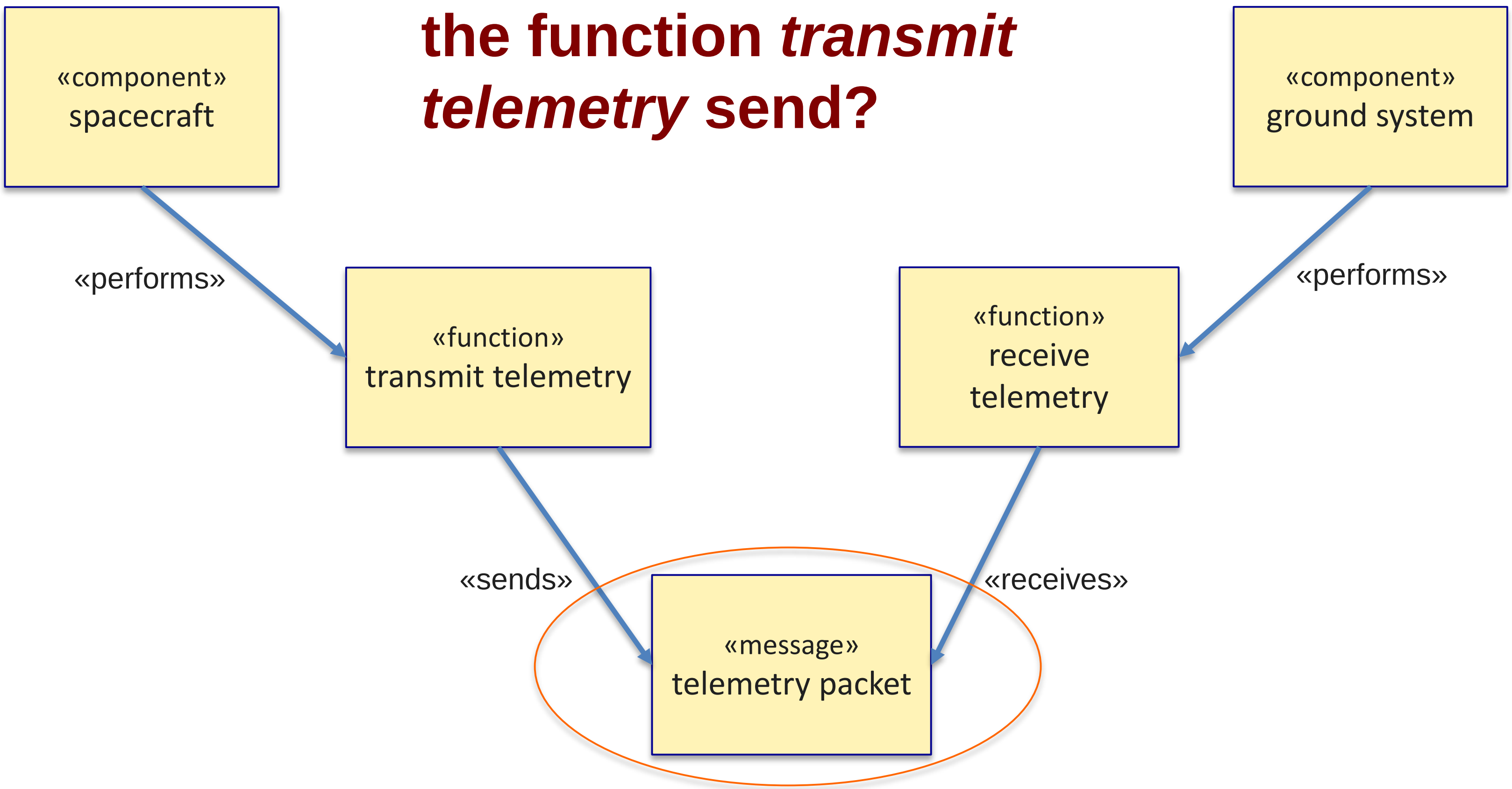
# More Questions and Answers

## What functions does the component *ground system* perform?



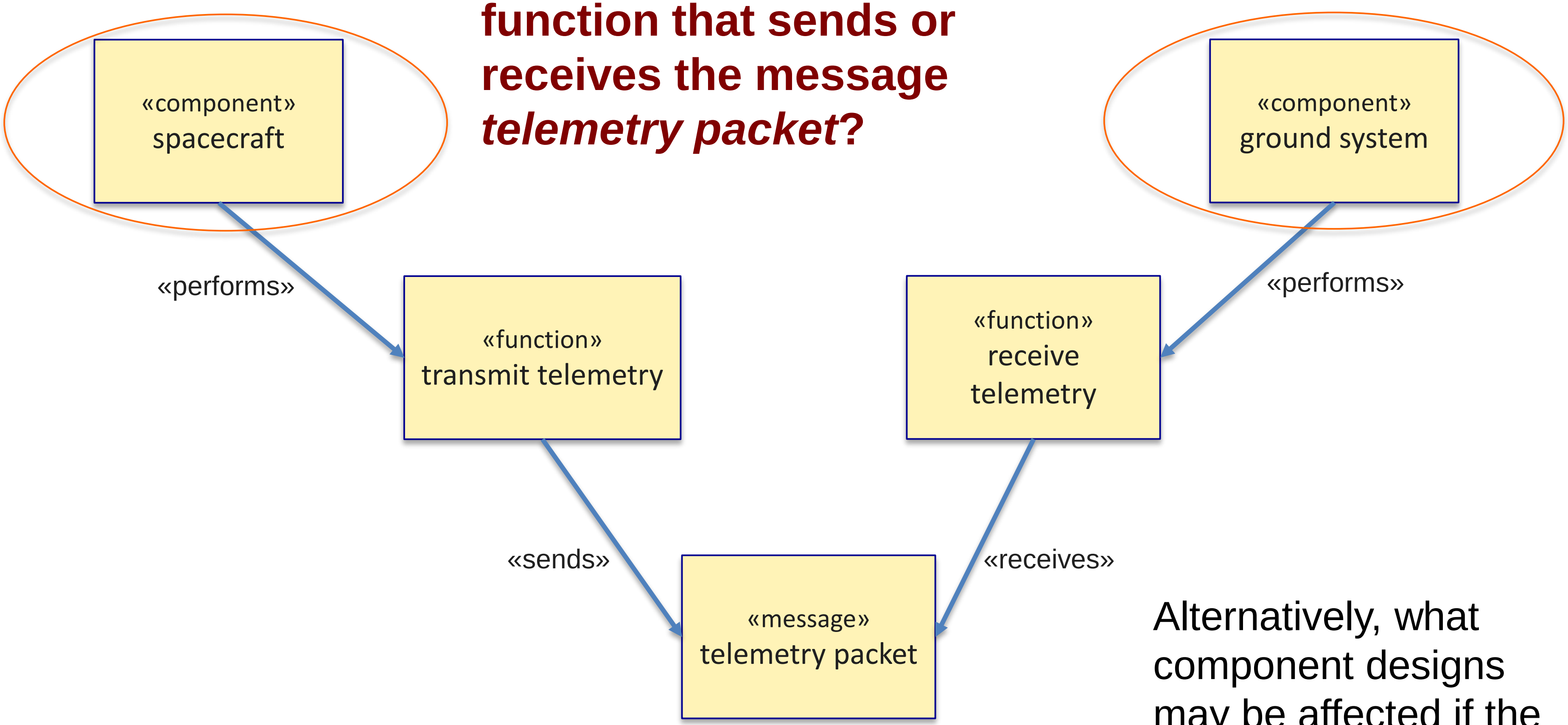
# More Questions and Answers

## 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*?**



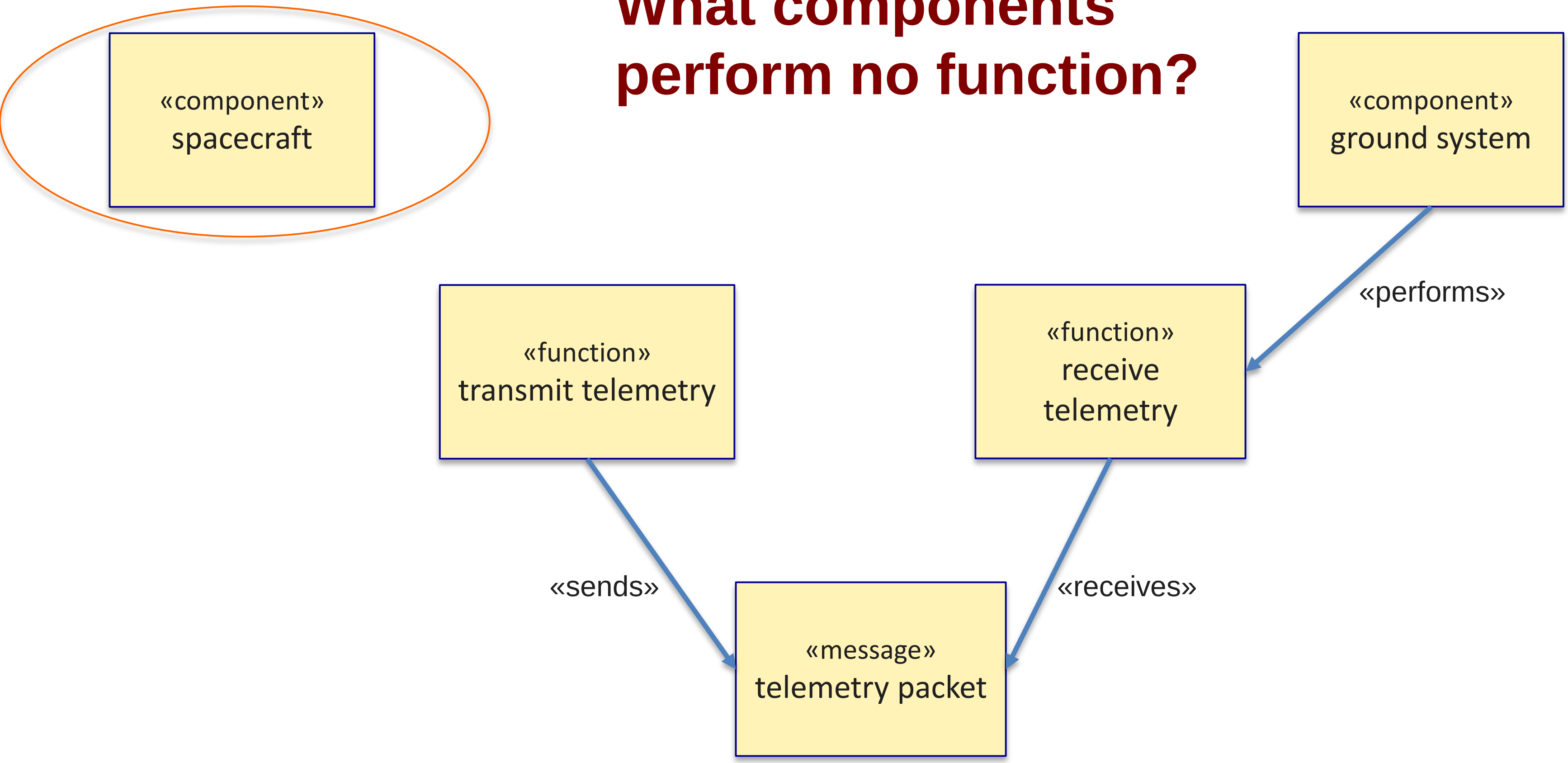

Alternatively, what component designs may be affected if the definition of *telemetry packet* changes?

# Reasoning About Models

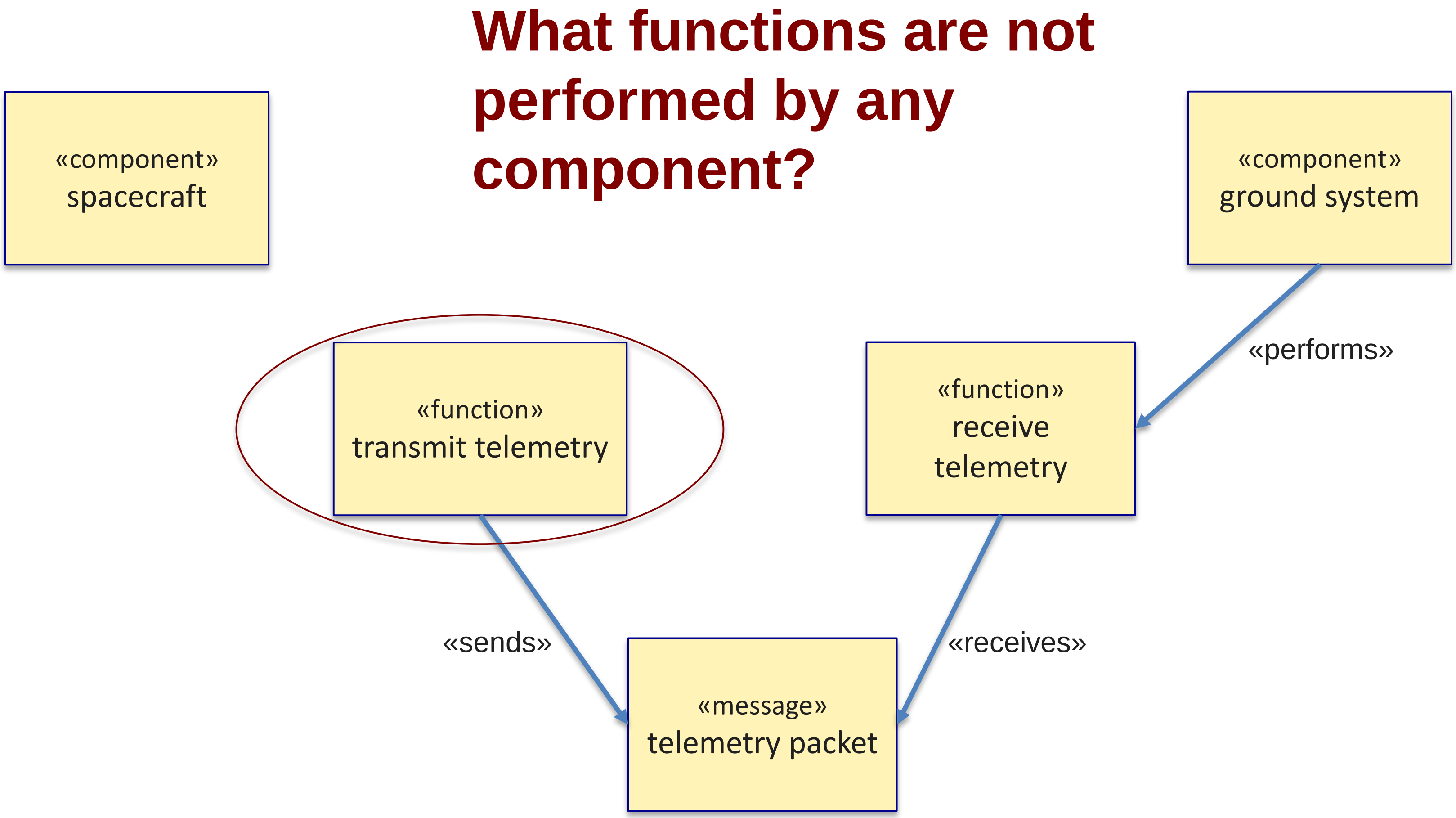
- We can use models to answer questions
- The questions may be about the system itself
  - What is it?
  - How does it work?
  - Is the performance adequate?
  - What happens if something breaks?
- The questions may be about the model
  - Is it complete?
  - Is it consistent?
  - Does it support required 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

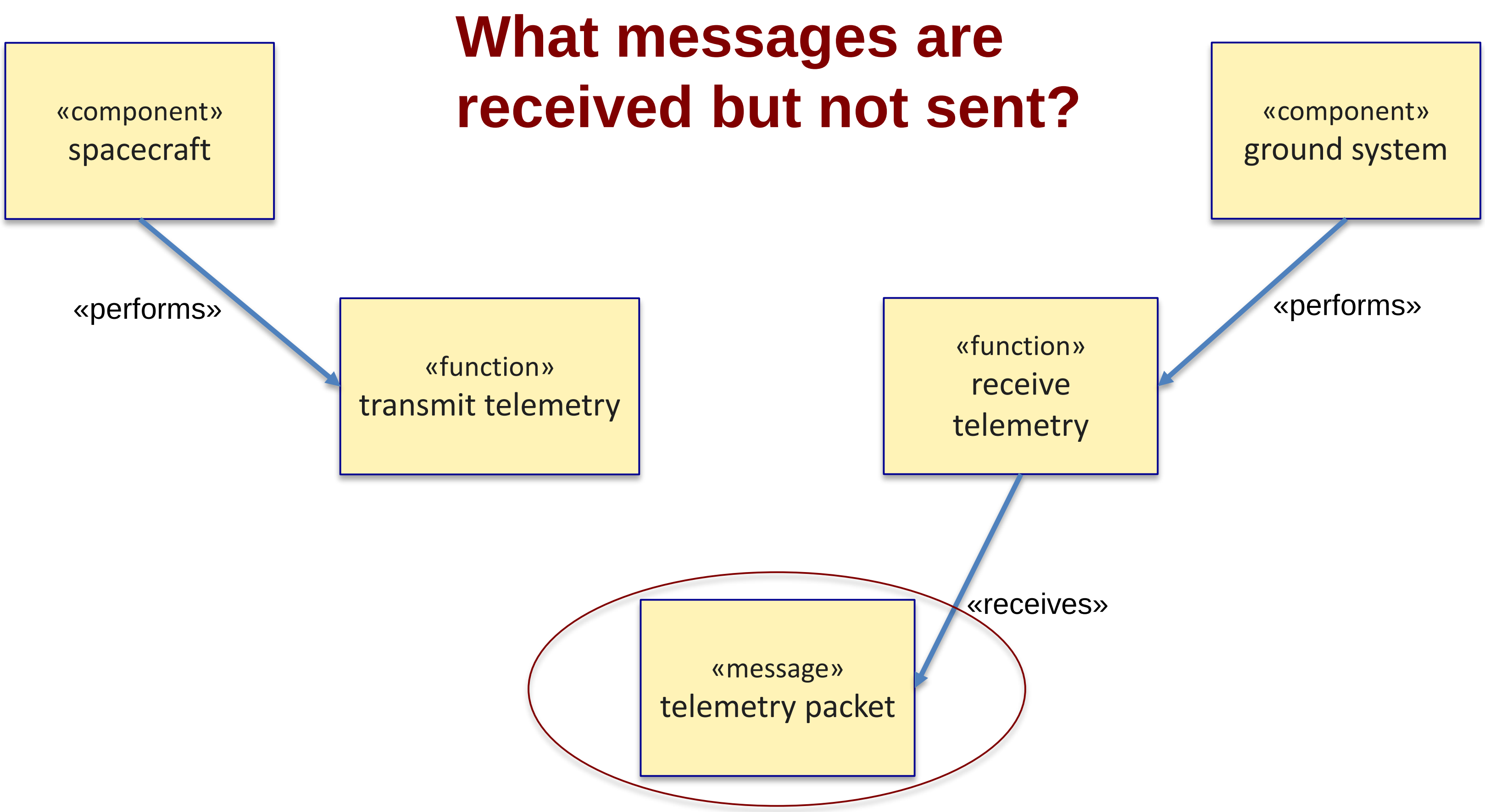
**What components perform no function?**



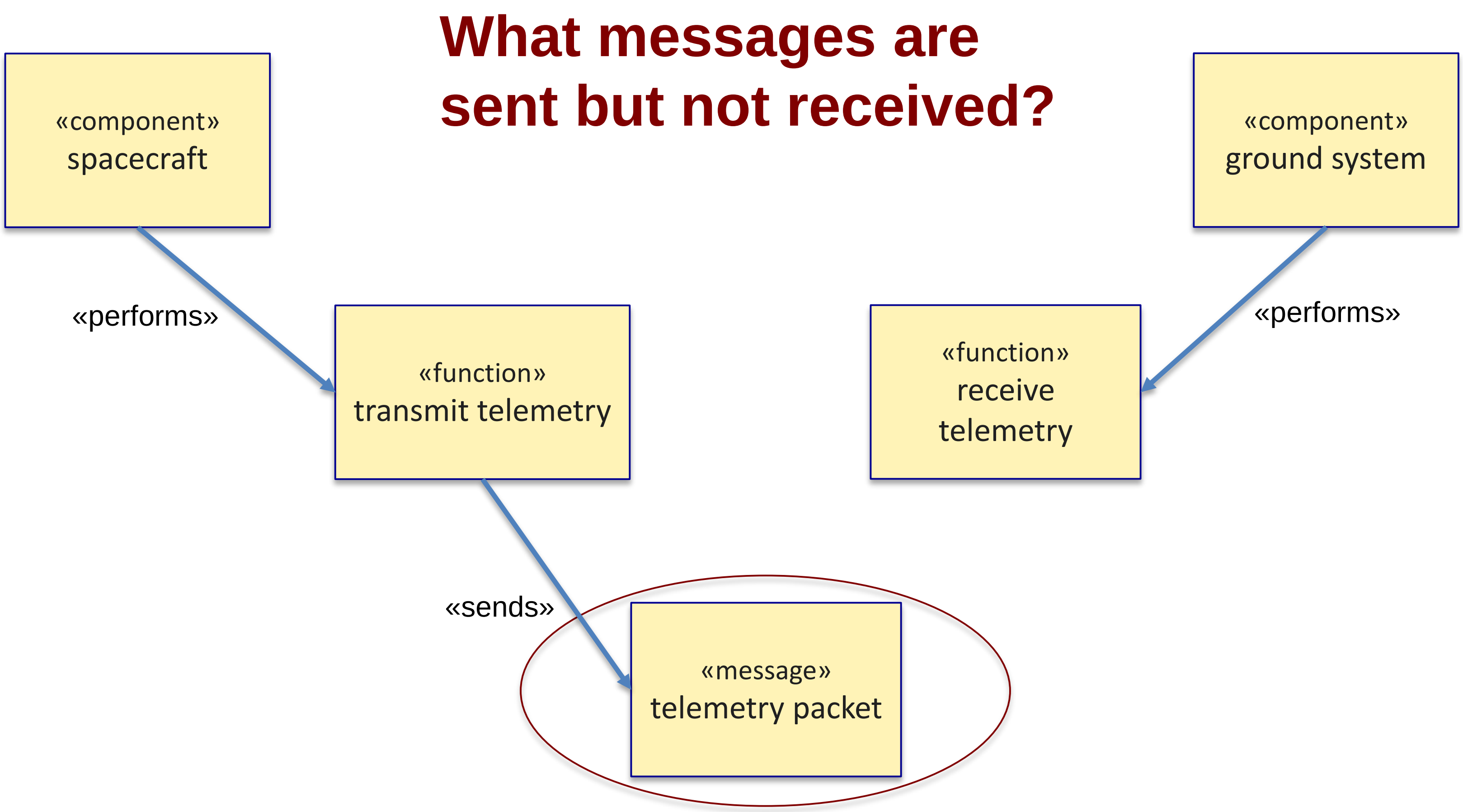
# Reasoning About Completeness



# Reasoning About Completeness

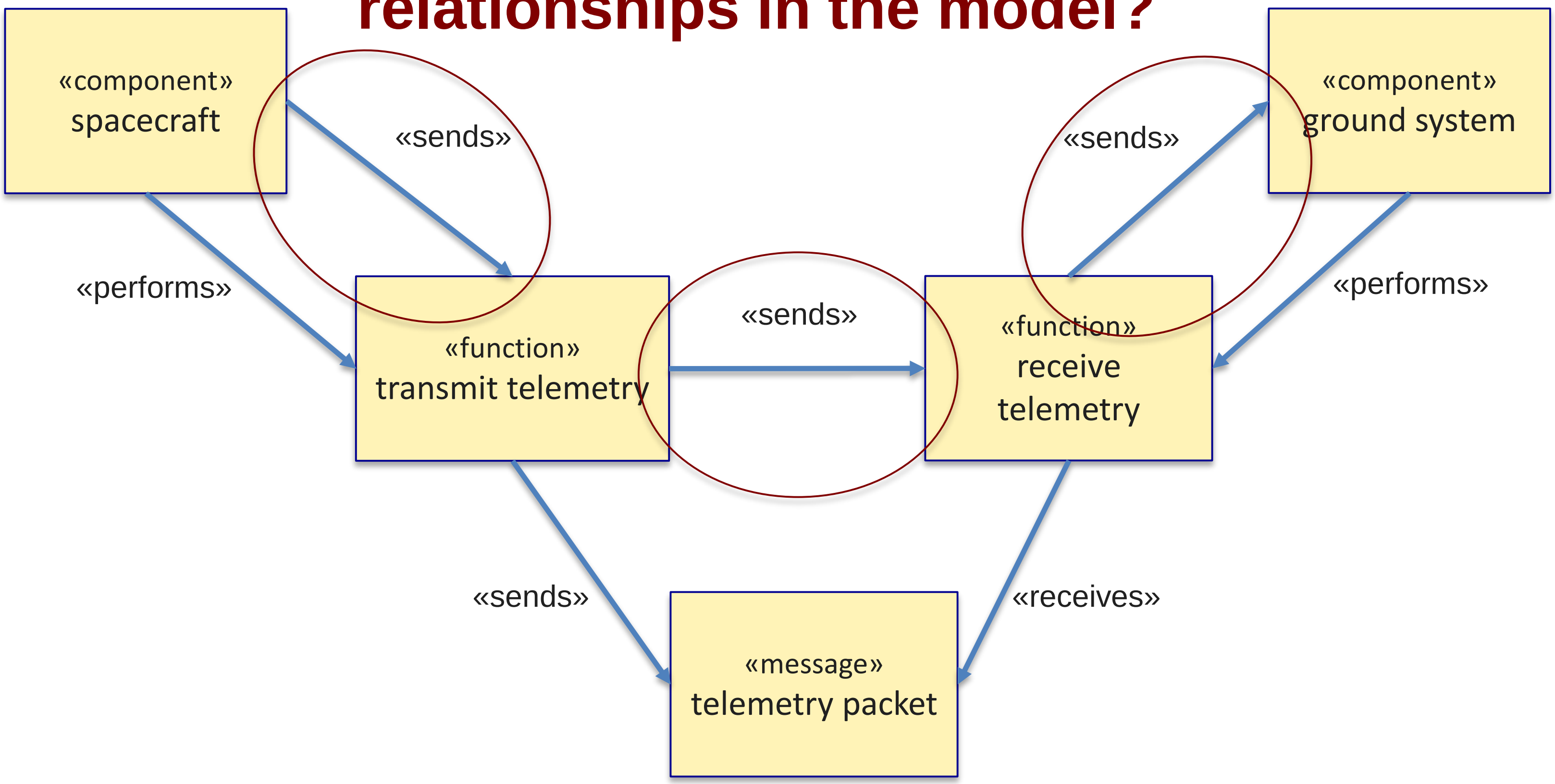


# Reasoning About Completeness



# Reasoning About Consistency

## Are there illegal or meaningless relationships in the model?



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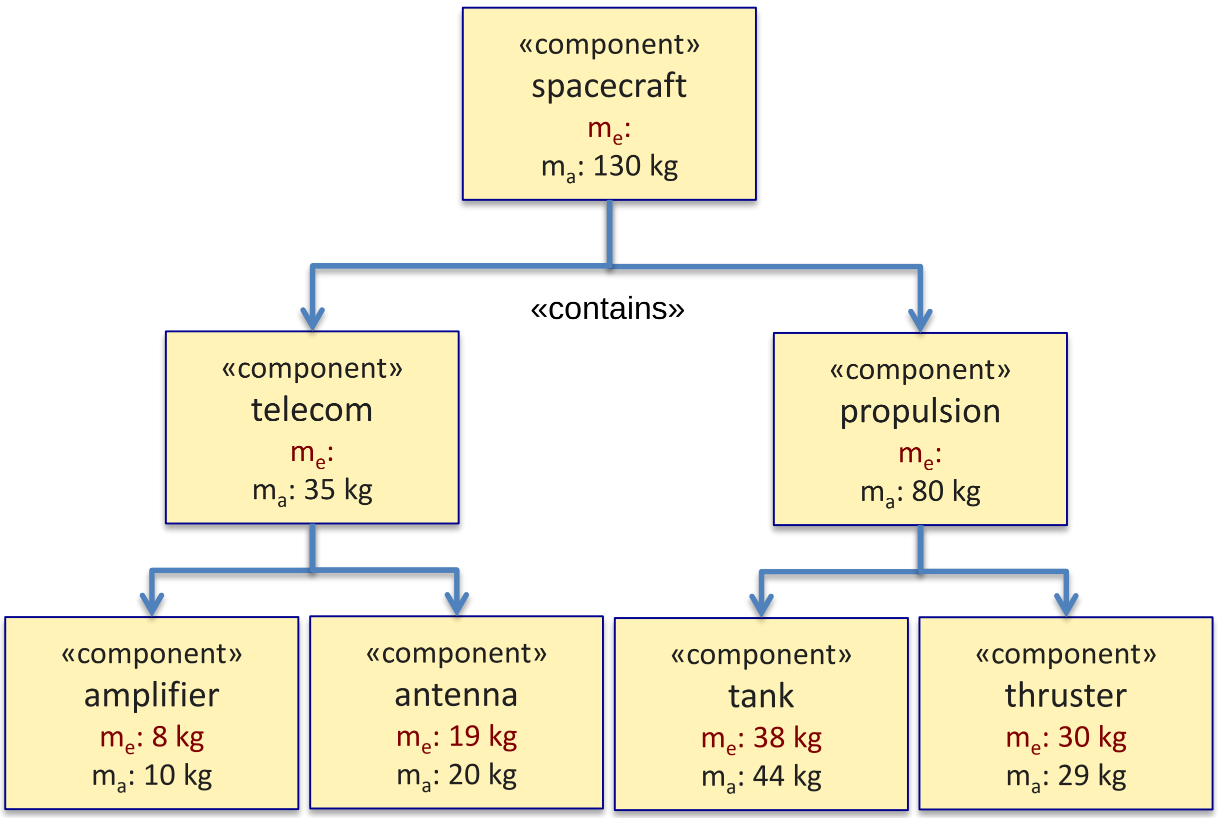
# Reasoning About Design

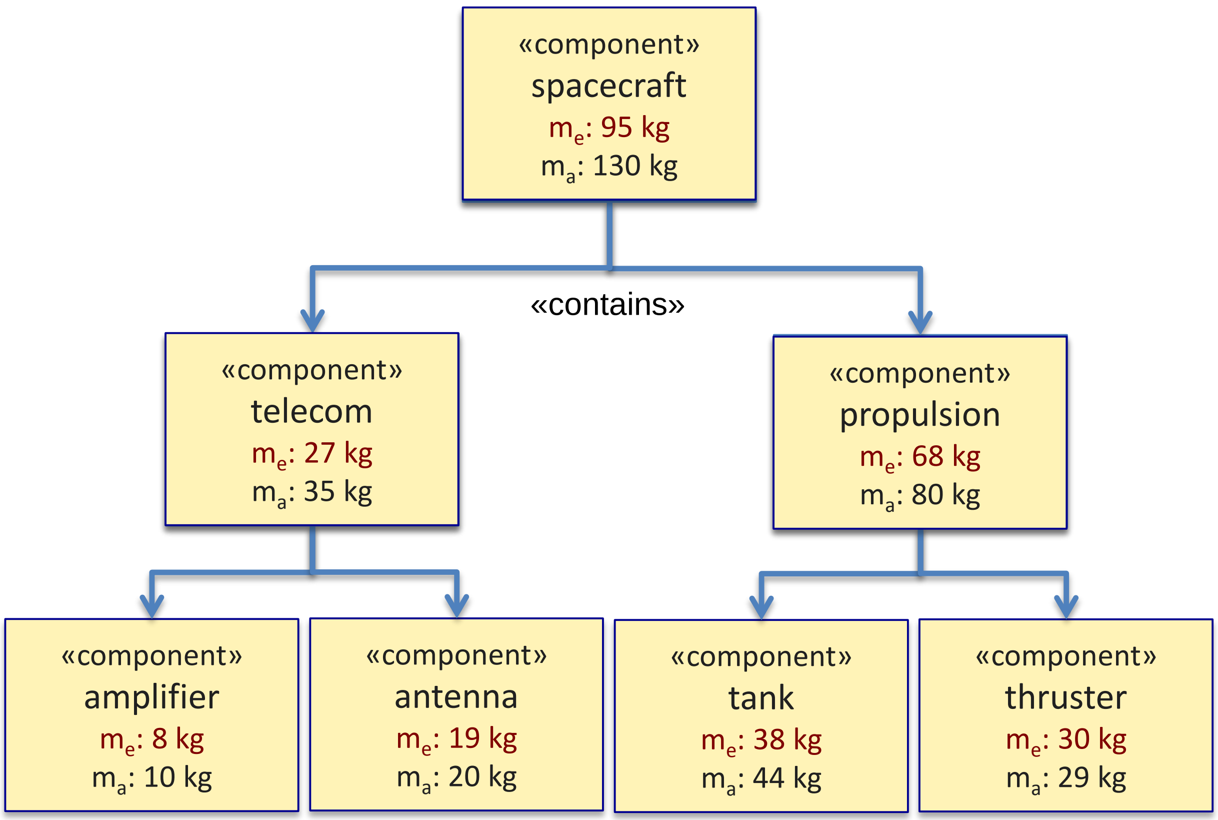



Each component has:

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

$m_e$: estimated mass
$m_a$: allocated mass

# Reasoning About Design



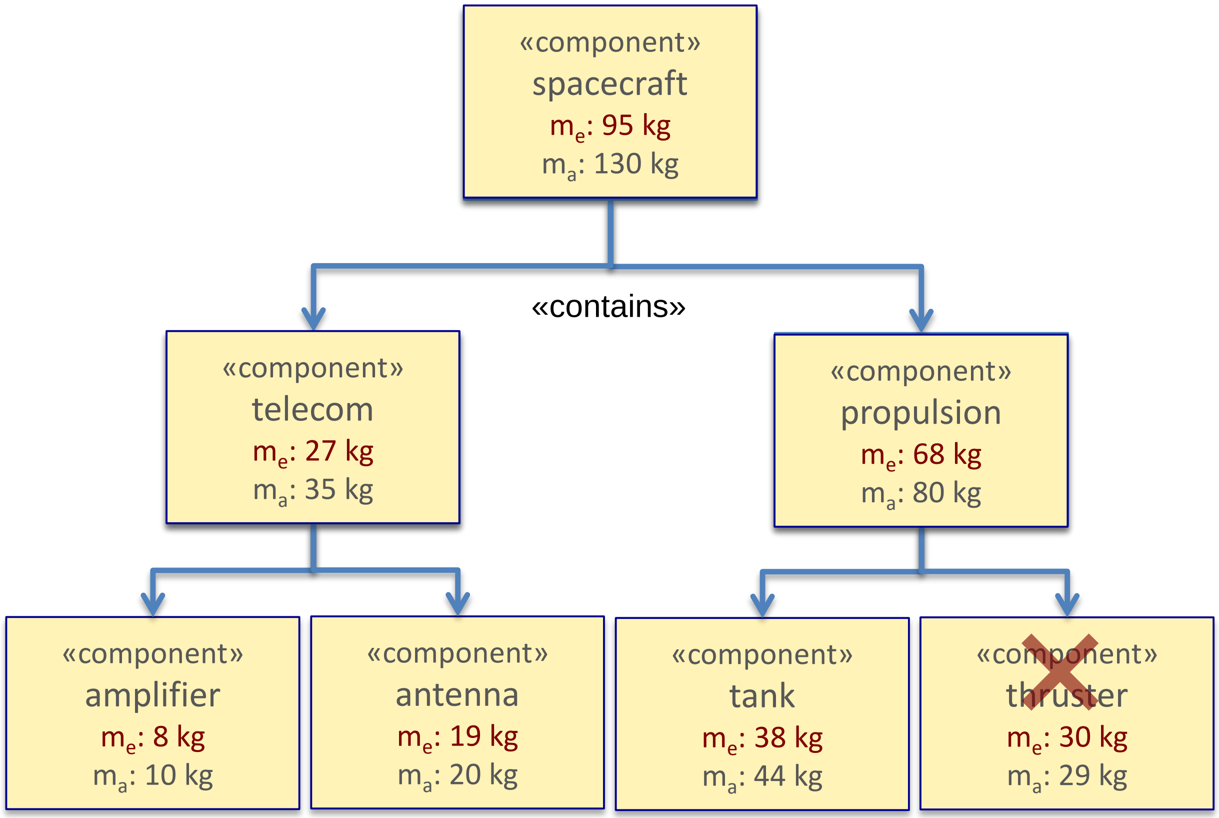

Each component has:

- 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

# 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

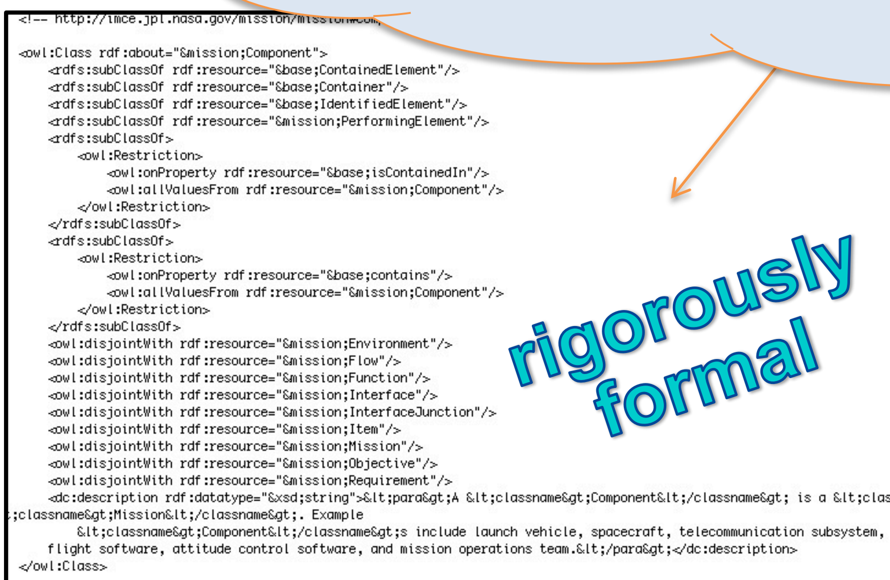
$m_e$: estimated mass
$m_a$: allocated mass

# 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/missionCom

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    <rdfs:subClassOf rdf:resource="&base;Container"/>
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    <rdfs:subClassOf rdf:resource="&mission;PerformingElement"/>
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        <owl:Restriction>
            <owl:onProperty rdf:resource="&base;isContainedIn"/>
            <owl:allValuesFrom rdf:resource="&mission;Component"/>
        </owl:Restriction>
    </rdfs:subClassOf>
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&base;contains"/>
            <owl:allValuesFrom rdf:resource="&mission;Component"/>
        </owl:Restriction>
    </rdfs:subClassOf>
    <owl:disjointWith rdf:resource="&mission;Environment"/>
    <owl:disjointWith rdf:resource="&mission;Flow"/>
    <owl:disjointWith rdf:resource="&mission;Function"/>
    <owl:disjointWith rdf:resource="&mission;Interface"/>
    <owl:disjointWith rdf:resource="&mission;InterfaceJunction"/>
    <owl:disjointWith rdf:resource="&mission;Item"/>
    <owl:disjointWith rdf:resource="&mission;Mission"/>
    <owl:disjointWith rdf:resource="&mission;Objective"/>
    <owl:disjointWith rdf:resource="&mission;Requirement"/>
    <dc:description rdf:datatype="&xsd;string">&lt;para&gt;A &lt;classname&gt;Component&lt;/classname&gt; is a &lt;clas
;classname&gt;Mission&lt;/classname&gt;. Example
        &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>
</owl:Class>
```
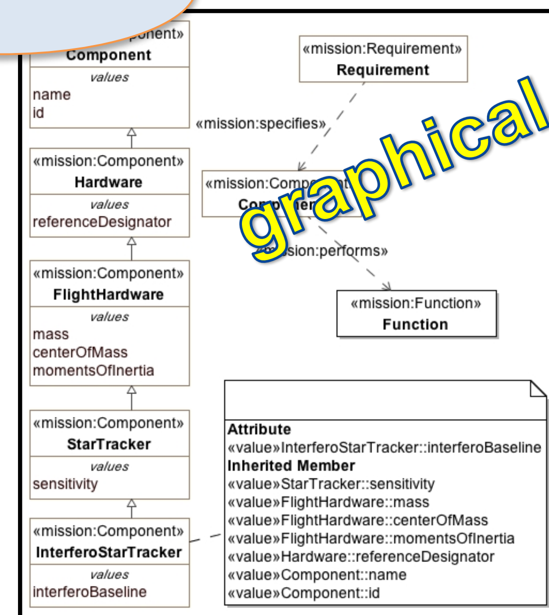



Logical Automatic Processing

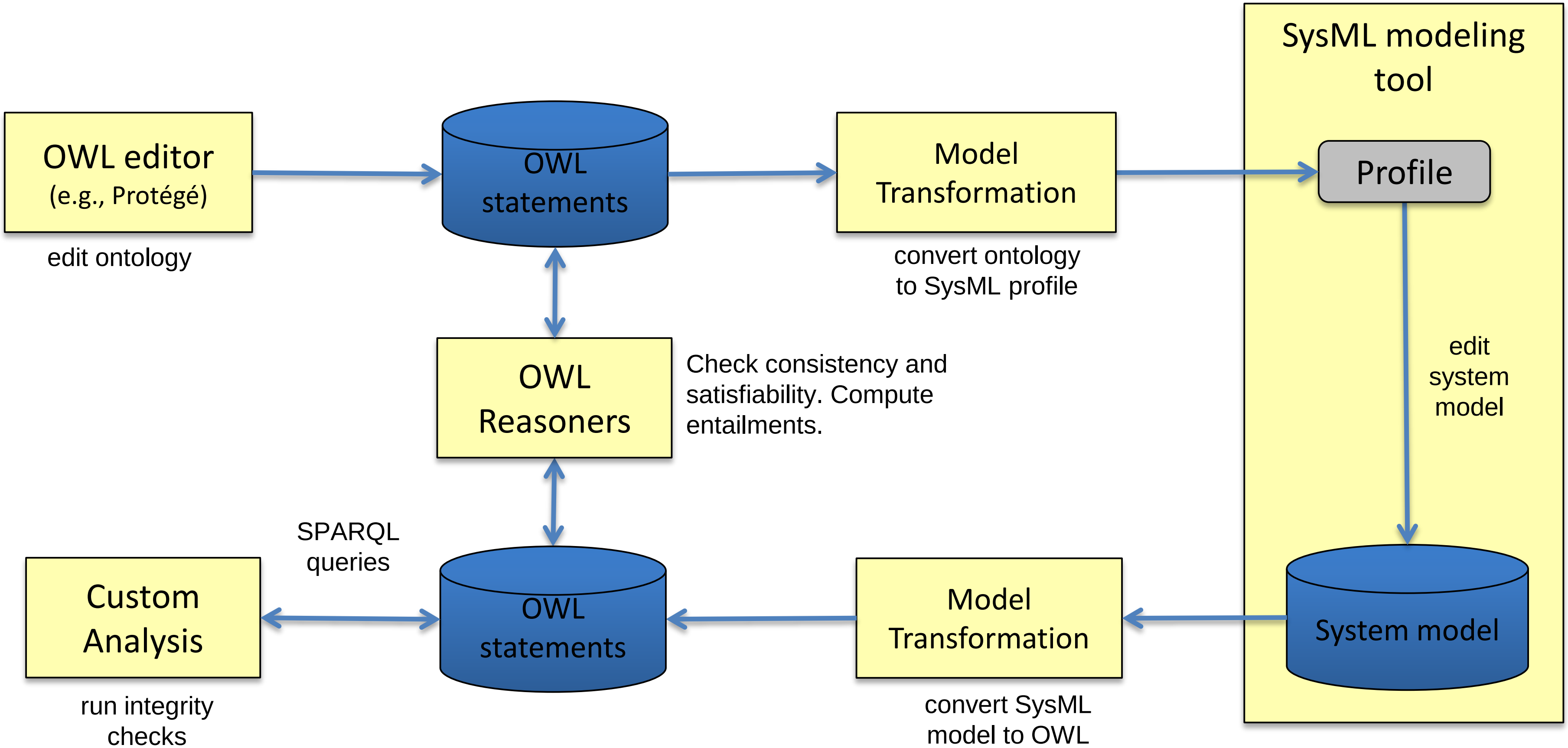
## SysML




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

(animated)

# English → OWL → SysML Profile → Usage

1

**English**: “Component performs Function”

2

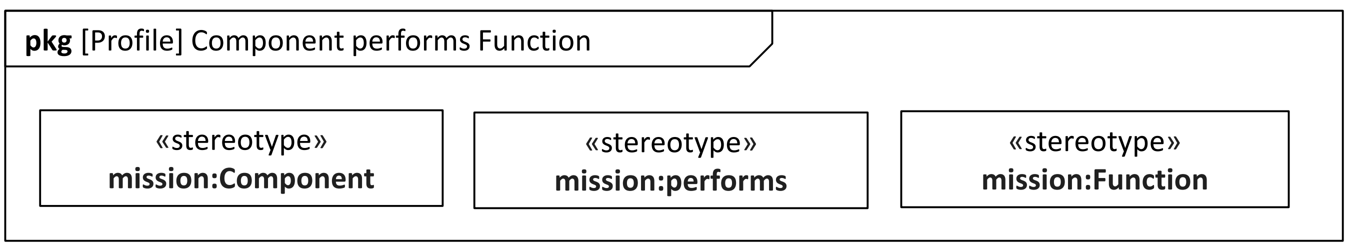
**OWL (RDF)**

```
<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>
```

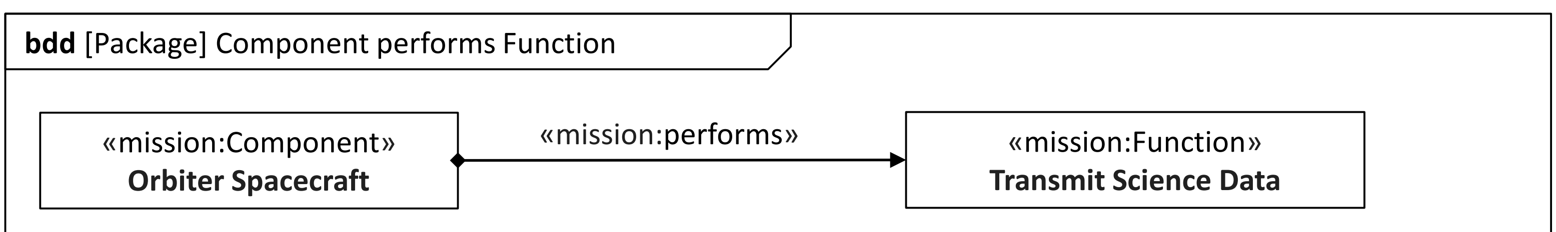
3

**SysML profile**




4

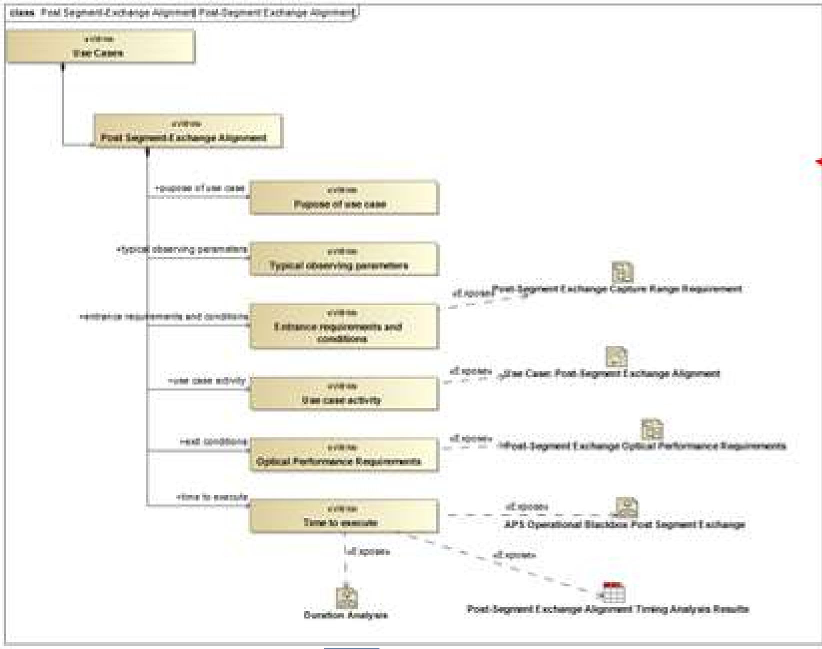
**Usage**



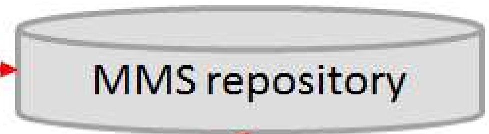
# Semantic Web Technologies >
# Integrated Modeling Environment >
# Modeling Method Alternatives >
# MDAO (Time Permitting)

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

Model Development Kit/DocGen
View and Viewpoint Hierarchy

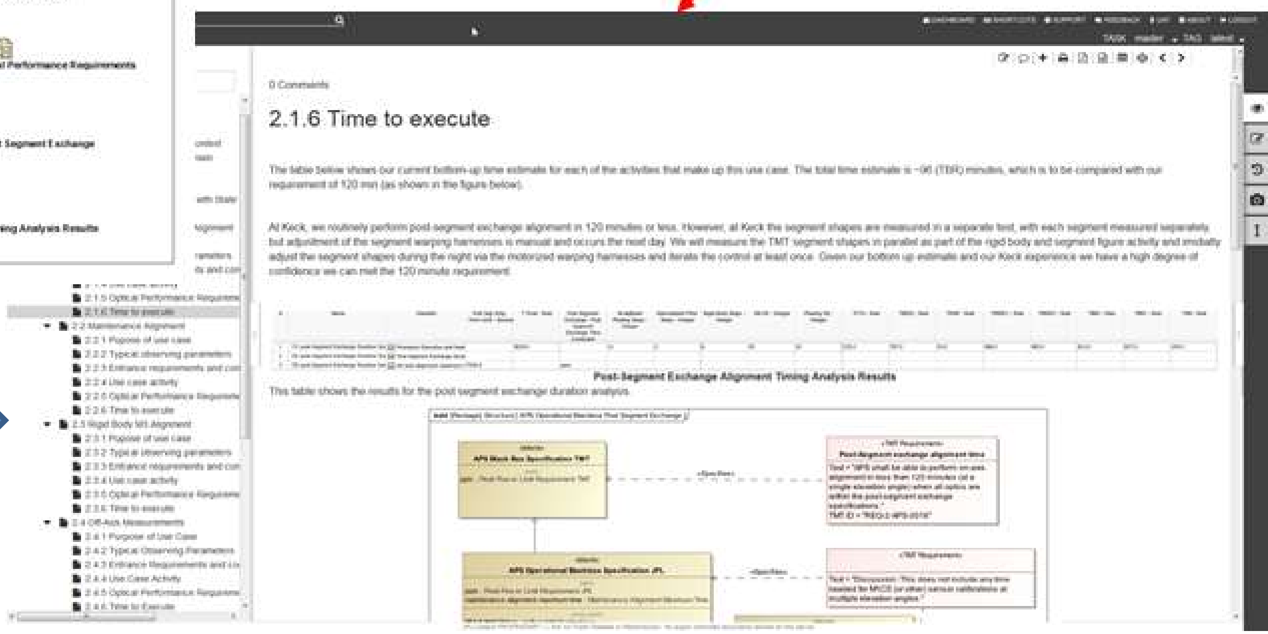



Model Management System

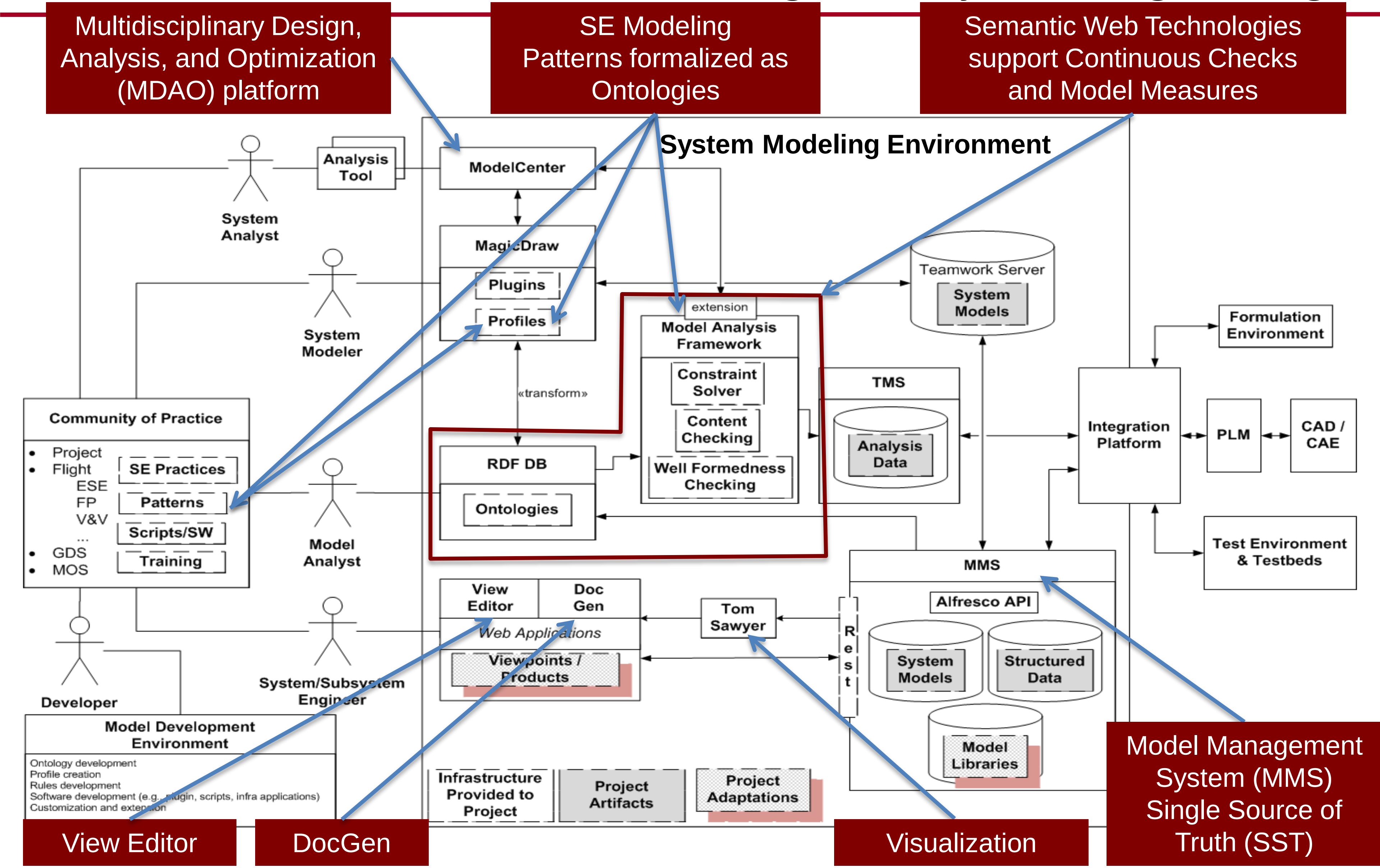



View Editor

Visualization in View Editor



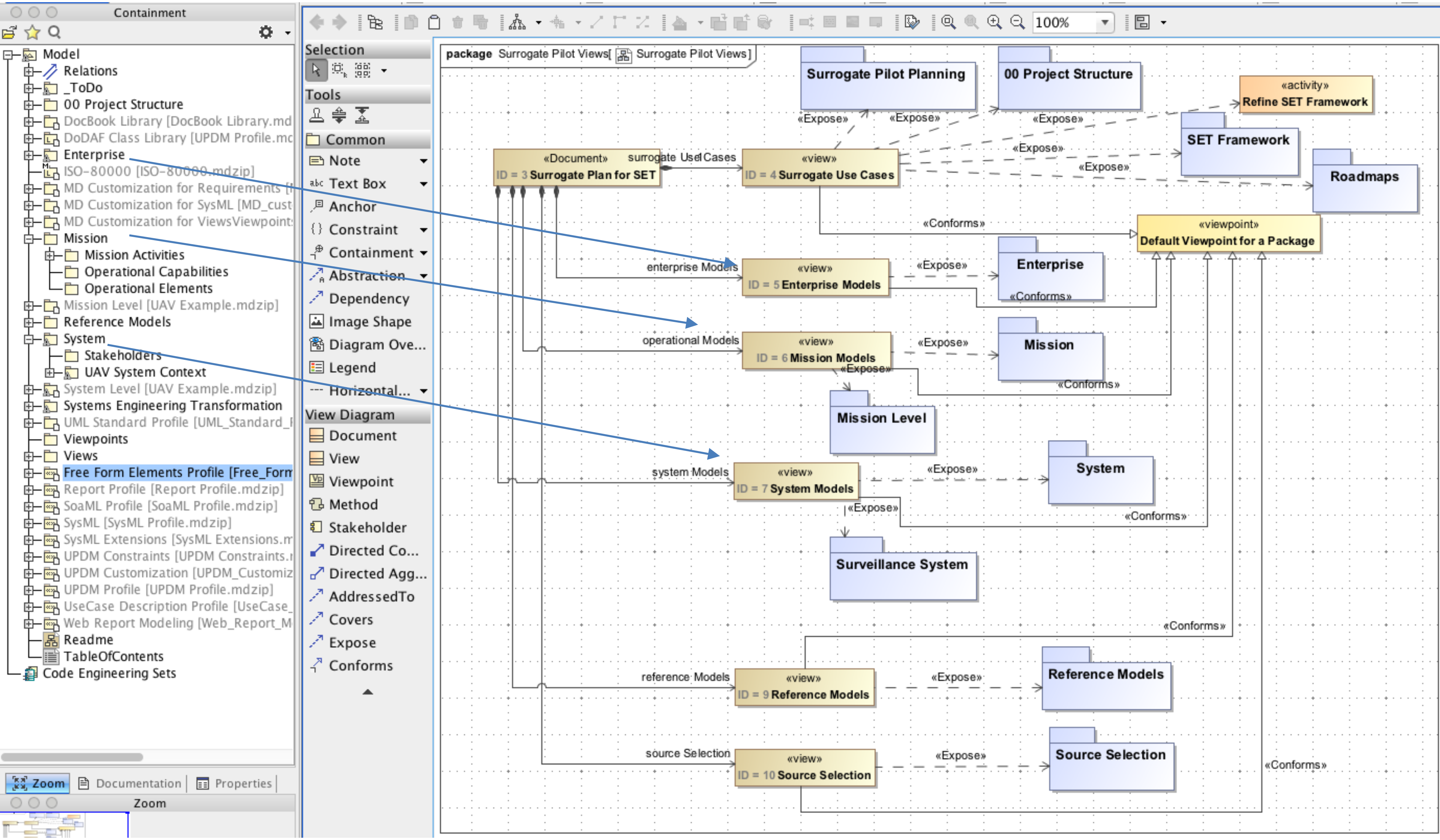
# Using OpenMBEE and Look to Adopt Semantic Technologies for Systems Engineering



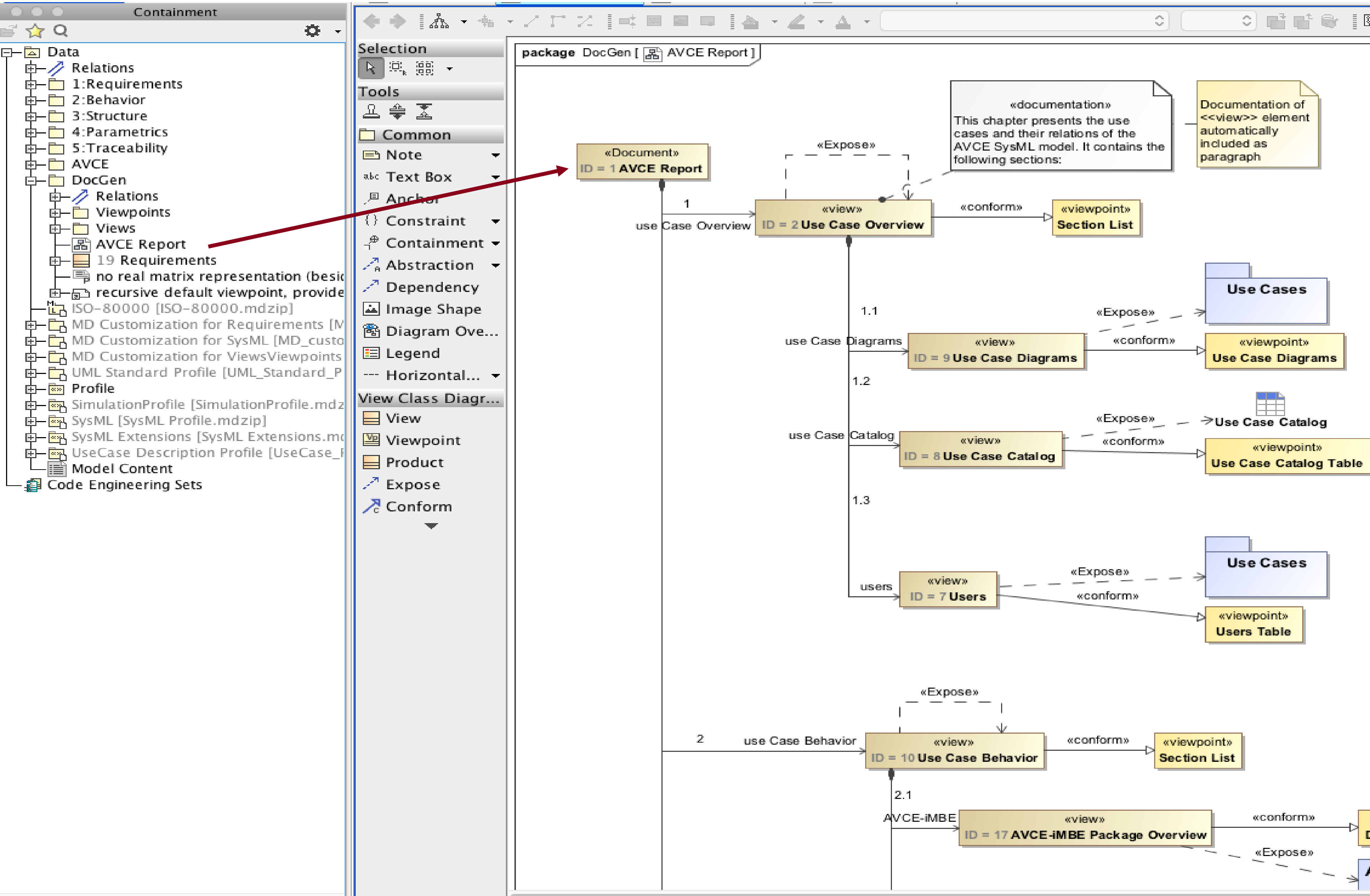

*An Integrated Model Centric Engineering (IMCE) Reference Architecture for a Model Based Engineering Environment (MBEE), NASA/JPL, Sept, 2014.

SERC 168/170.

# Modeling Enterprise and Model for Systems Engineering Transformation Pilot



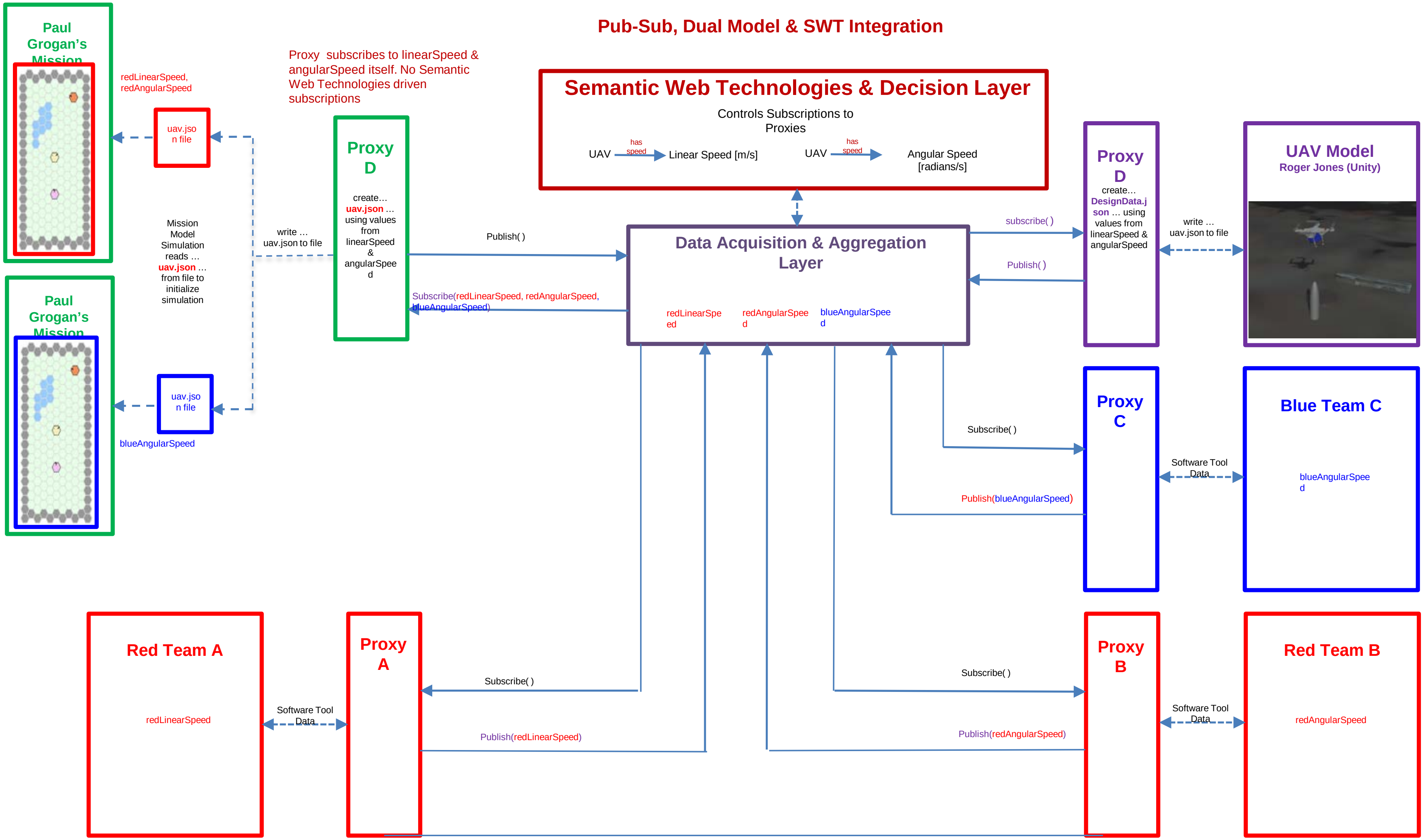
# View and Viewpoint Hierarchy for AVCE Model



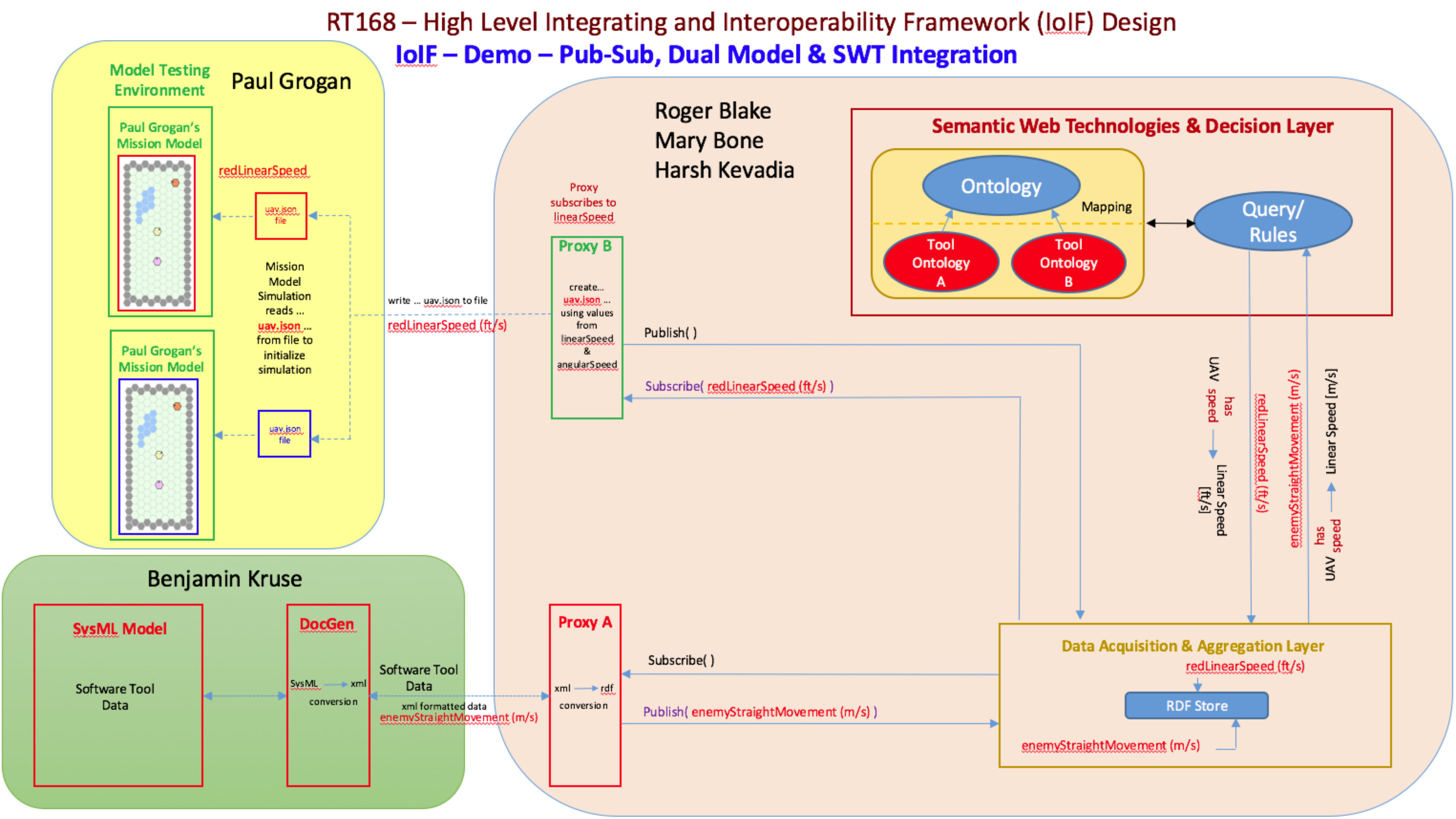
# RT168 – High Level Integrating and Interoperability Framework (IoIF) Design

## IoIF - Prototype 5

### Pub-Sub, Dual Model & SWT Integration



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

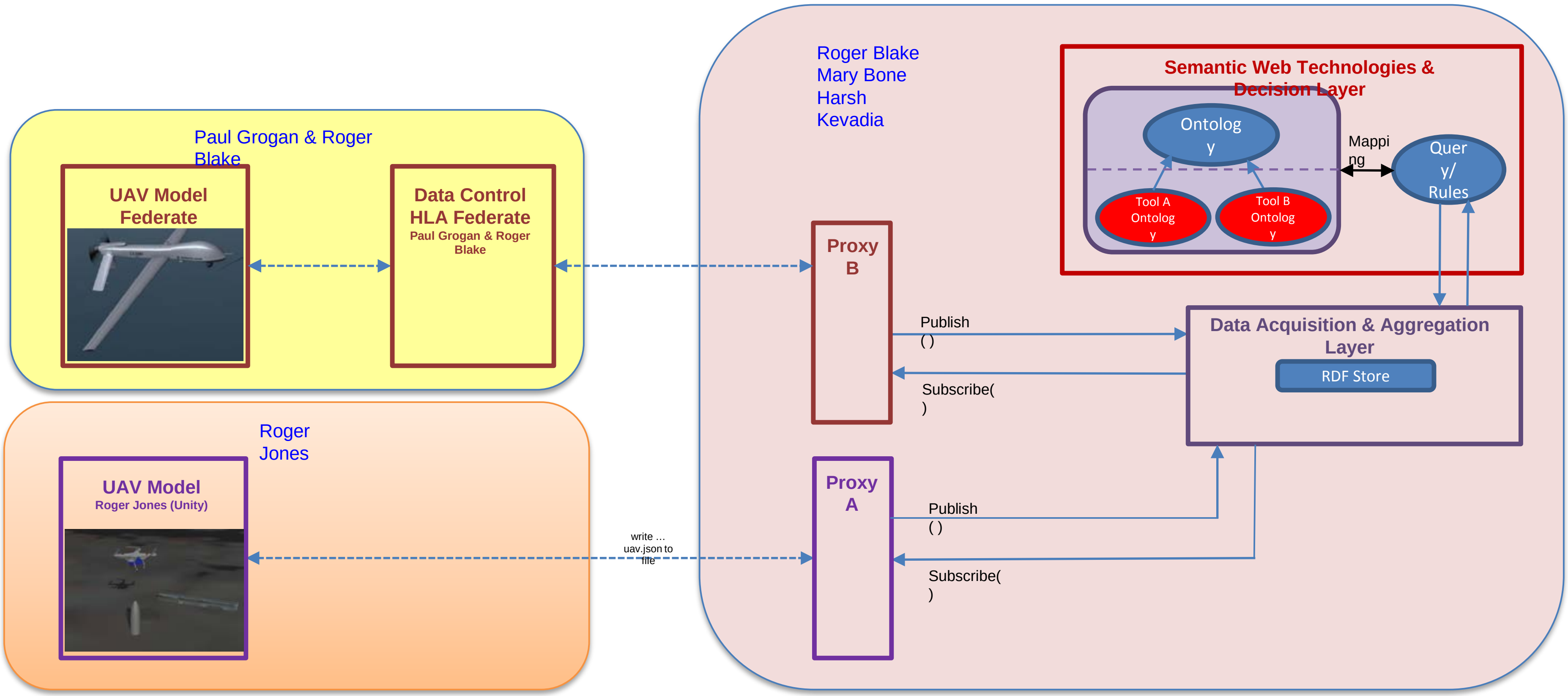


# IoIF Integrating High-End Mission and Simulation with Graphical CONOPS

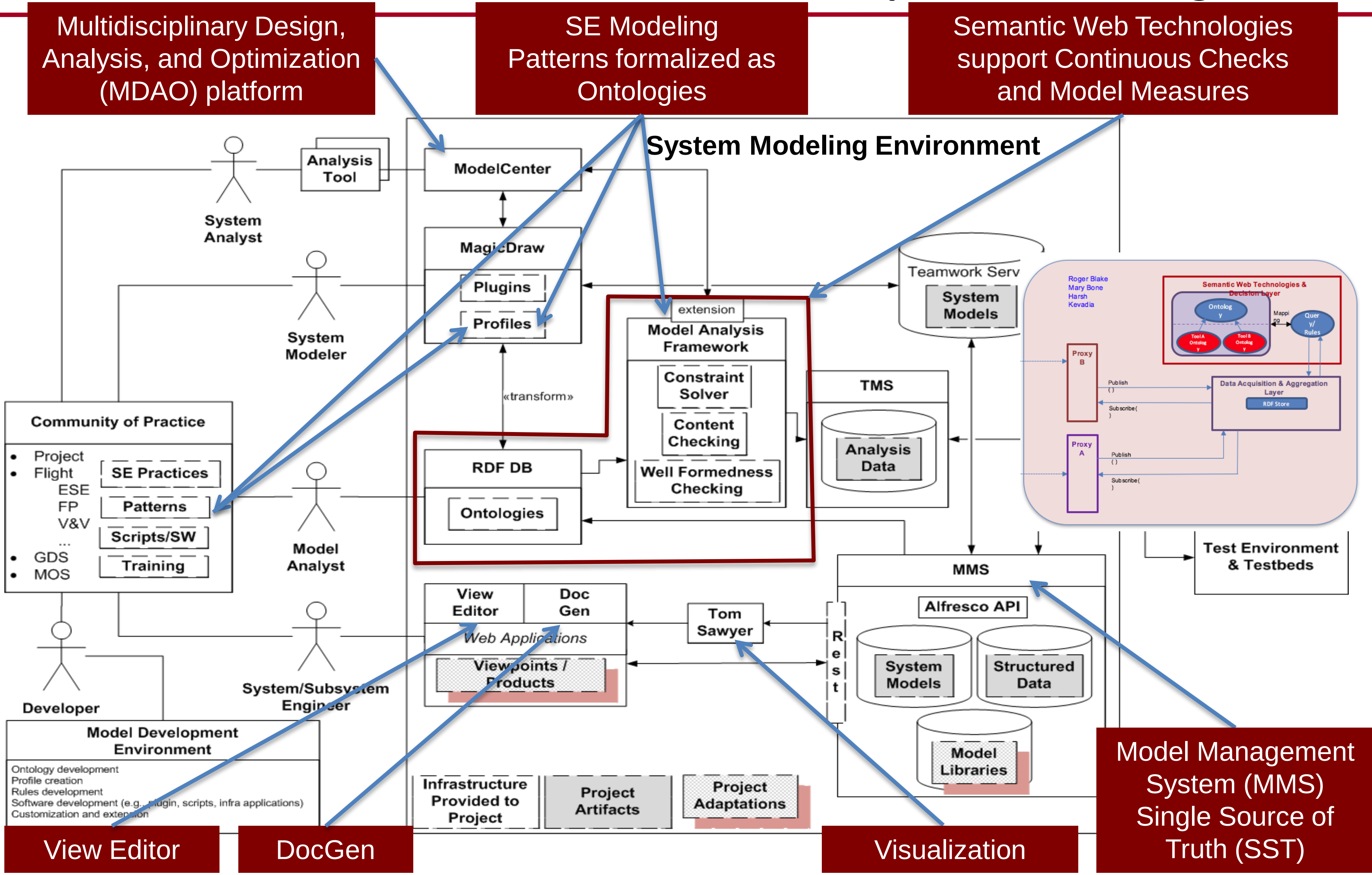
RT168 – High Level Integrating and Interoperability Framework (IoIF) Design

**IoIF - Prototype 7**

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



# 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.

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# 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.

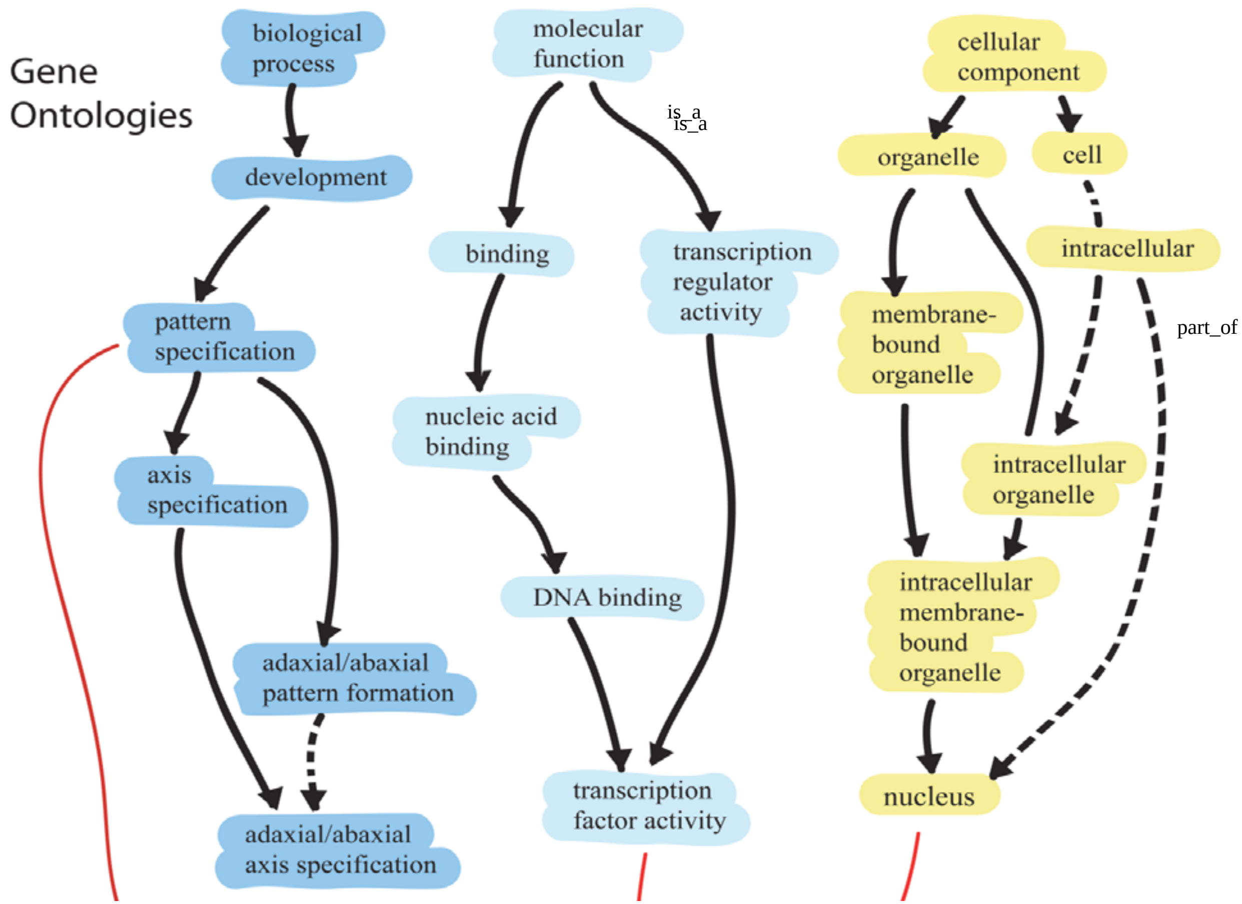
# Open Biomedical Ontologies (OBO) Successful Results from Interoperable Ontologies

- 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



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

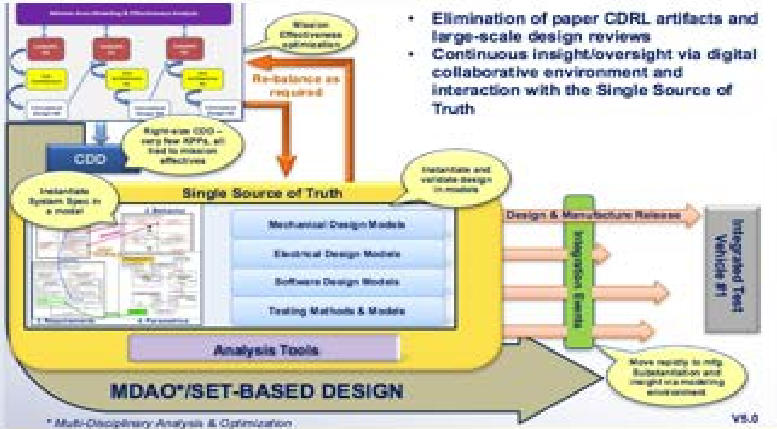
- Resulted in coordination to solve Genome
- Are there parallels to Systems Engineering?

| RELATION TO TIME / GRANULARITY | CONTINUANT | | | | OCCURRENT |
|---|---|---|---|---|---|
| | INDEPENDENT | | DEPENDENT | | |
| ORGAN AND ORGANISM | Organism (NCBI Taxonomy) | Anatomical Entity (FMA, CARO) | Organ Function (FMP, CPRO) | Phenotypic Quality (PaTO) | **Biological Process** (GO) |
| CELL AND CELLULAR COMPONENT | Cell (CL) | **Cellular Component** (FMA, GO) | Cellular Function (GO) | | |
| MOLECULE | Molecule (ChEBI, SO, RnaO, PrO) | | **Molecular Function** (GO) | | Molecular Process (GO) |

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

# Surrogate Pilot Modeling Concept for NAVAIR SE Transformation

## Update: 7/31/2017



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

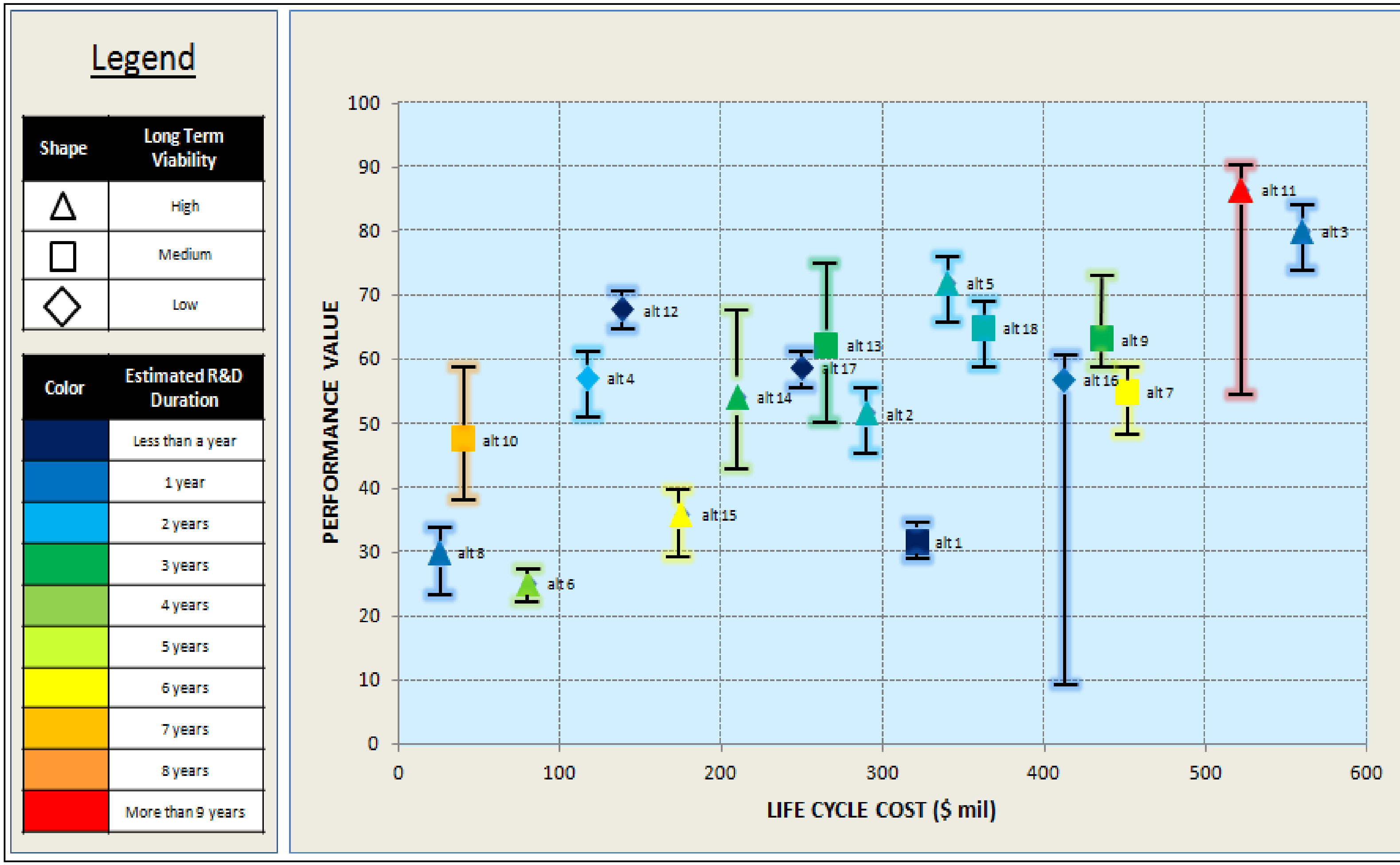
Dr. Matt Cilli

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

Dr. George Ball

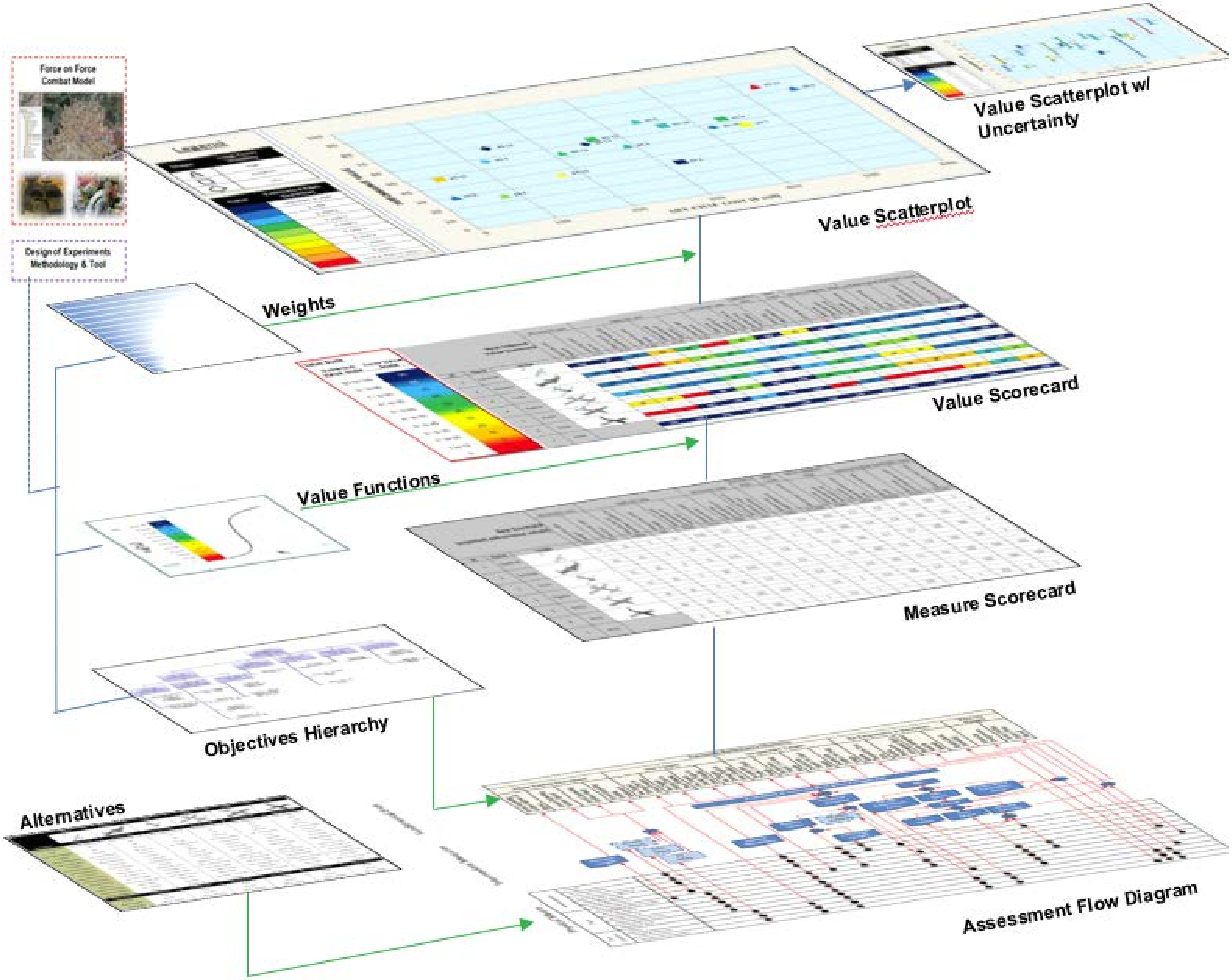
# Semantic Web Technologies >
# Integrated Modeling Environment >
# Modeling Method Alternatives >
# MDAO (Time Permitting)

# 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.

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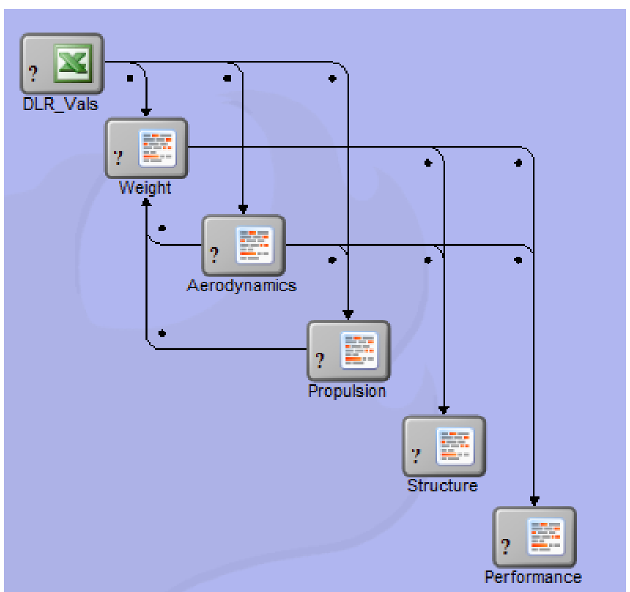
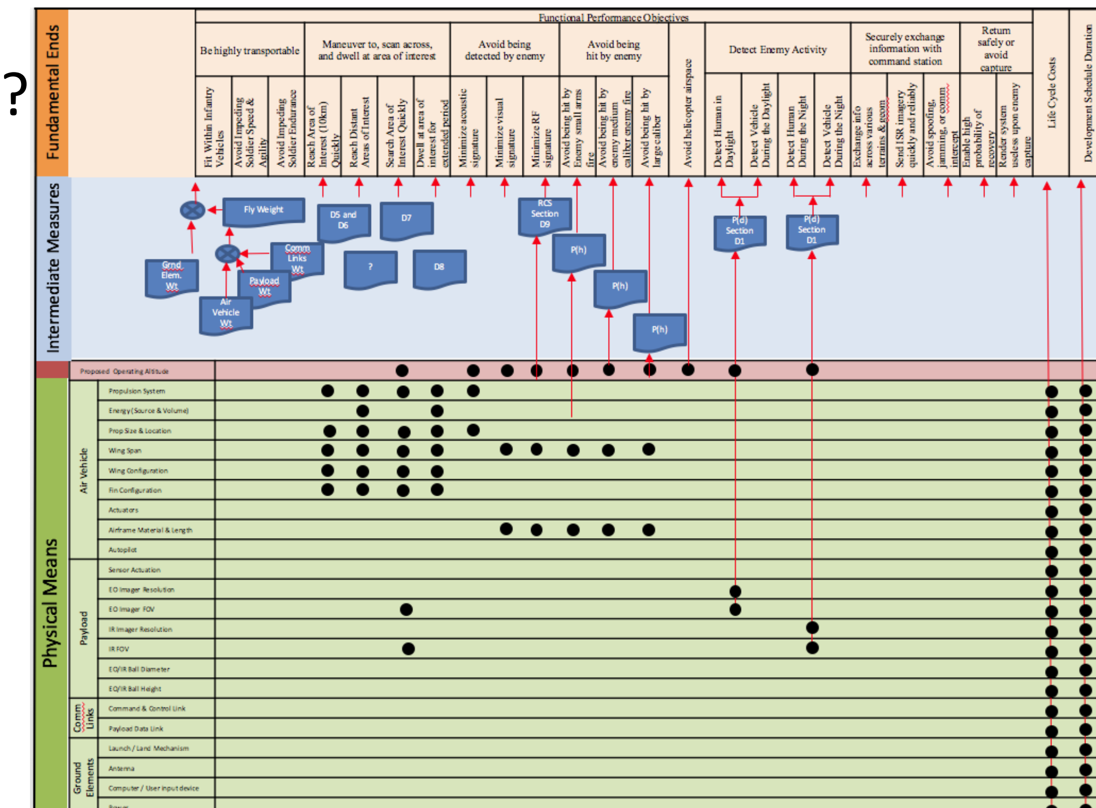
# Decision Framework

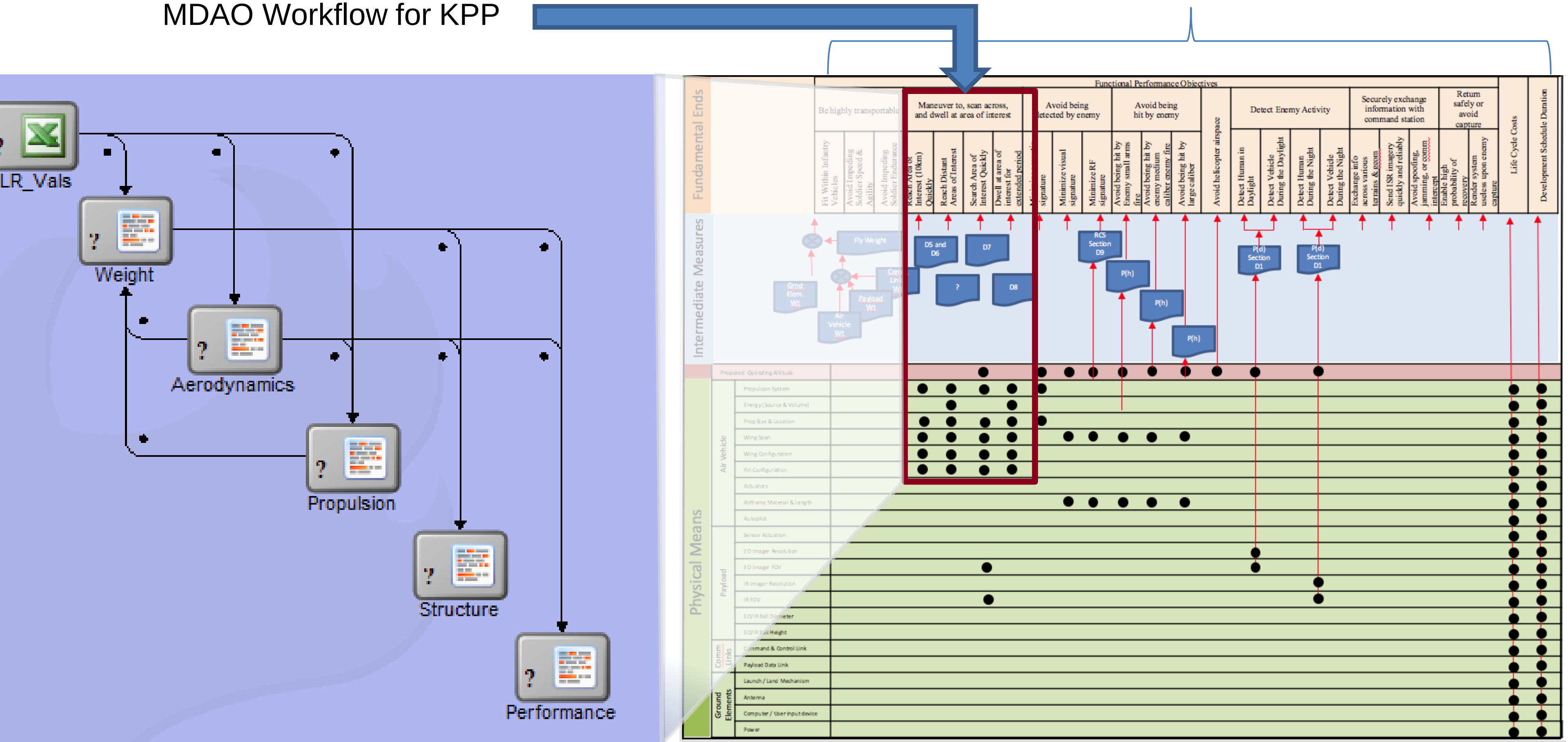
- SWT application to AAMODAT
- Templates for objective hierarchies
- Can MDAO represent Assessment Flow Diagram?
- Does AFD characterize needed MDAO workflows?



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)

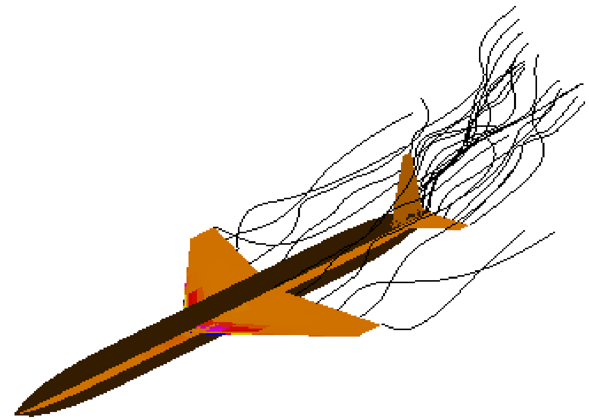
**Management**
(e.g. representing, documenting and coordinating existing information)

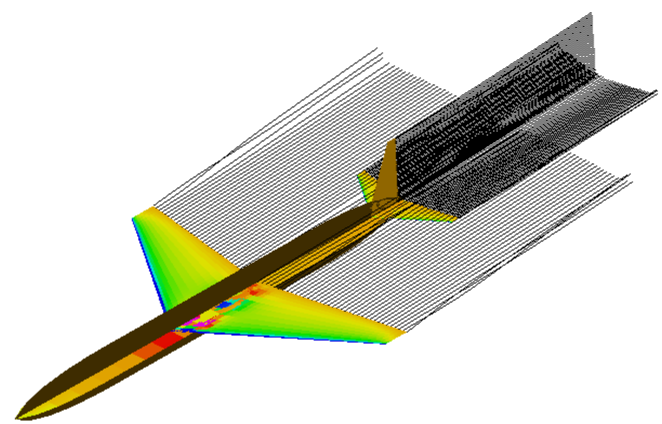
**Reasoning**
(e.g. interpreting results, choosing options)

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

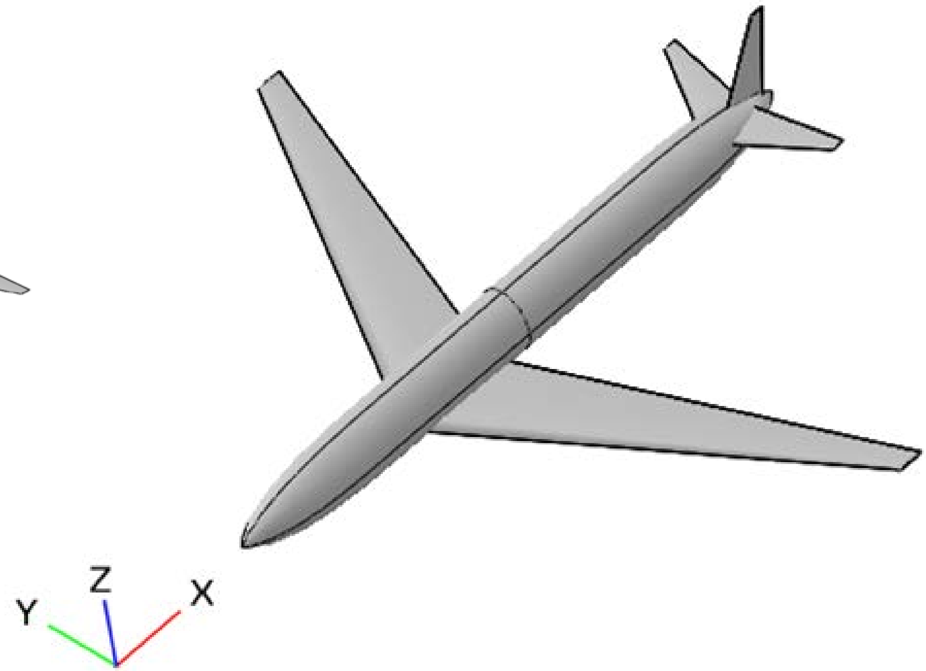
- Equation-based Models
  - —Fixed-wing
  - —Quadcopter
- Simulation-based Model
  - —OpenVSP geometry and VSPAero CFD tool wrapped into ModelCenter
  - —Extensive debugging completed
  - —Suitable CFD mesh found balancing results and computational cost



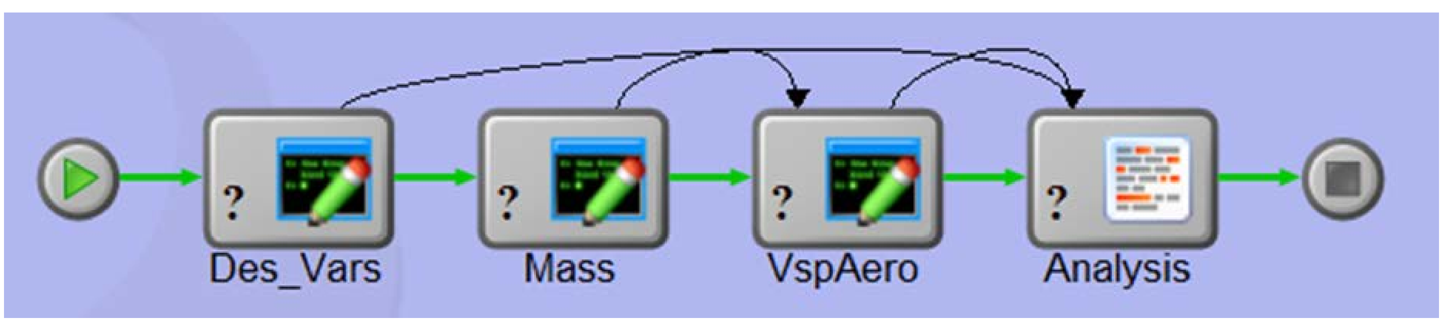


# Current Model Status

- UAV Geometry
  - —Easy to change

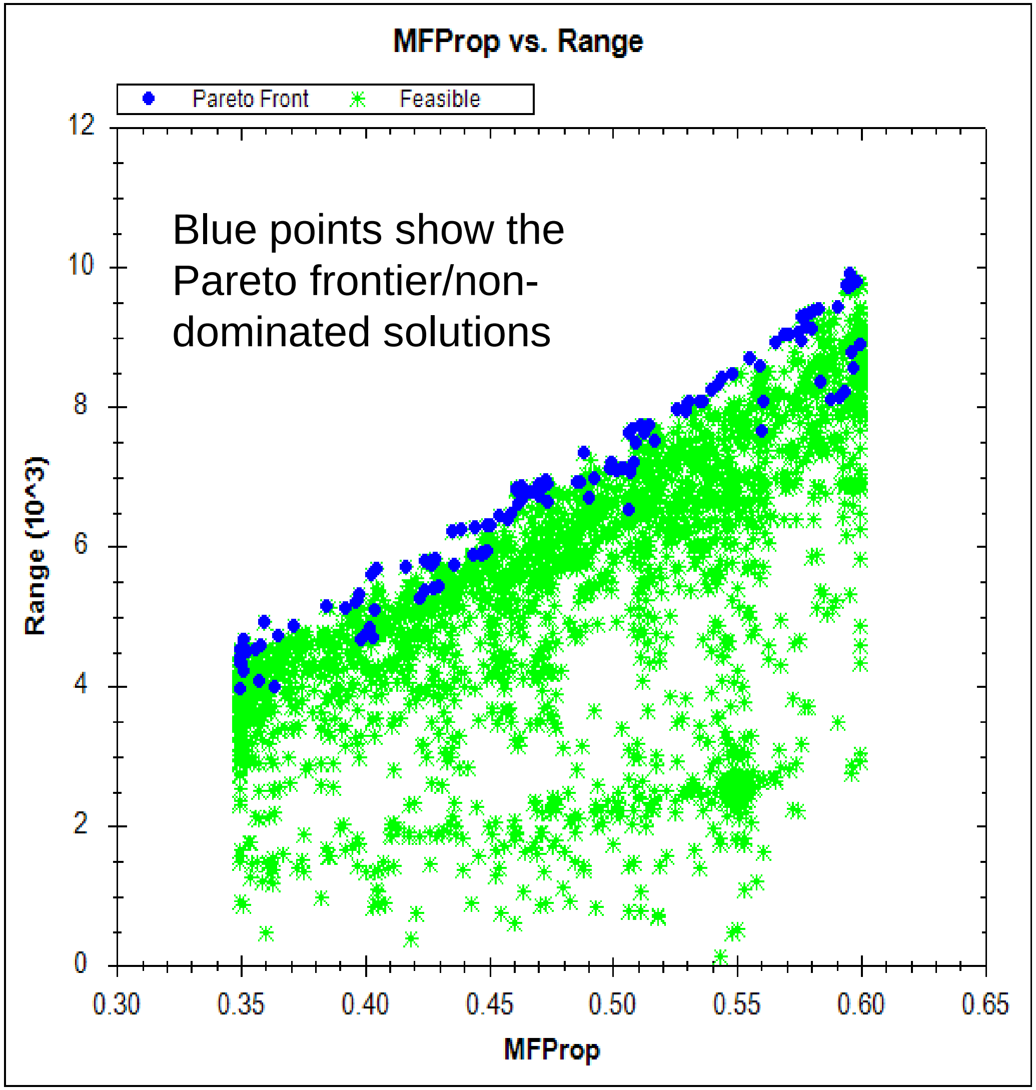



- ModelCenter Workflow
  - —Adjusts geometry and flight conditions for MDAO
  - —About 1 minute per run



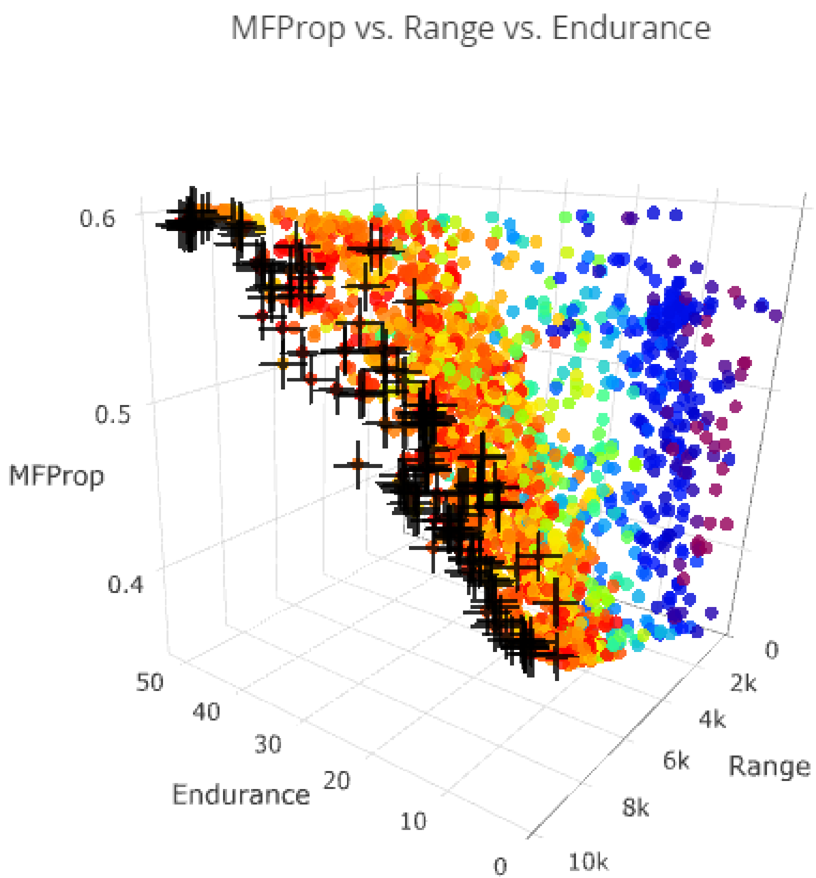
# Optimization

- 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

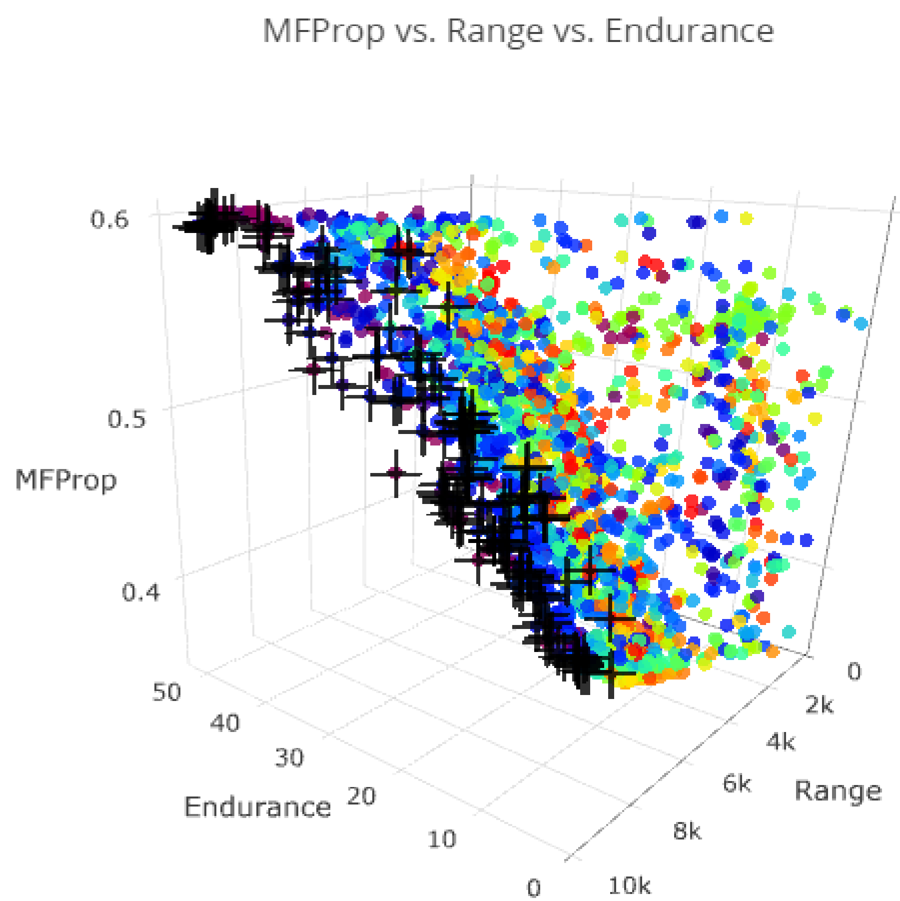



**Range (mi) vs. Fuel Mass Fraction**

# Optimization Visualizations



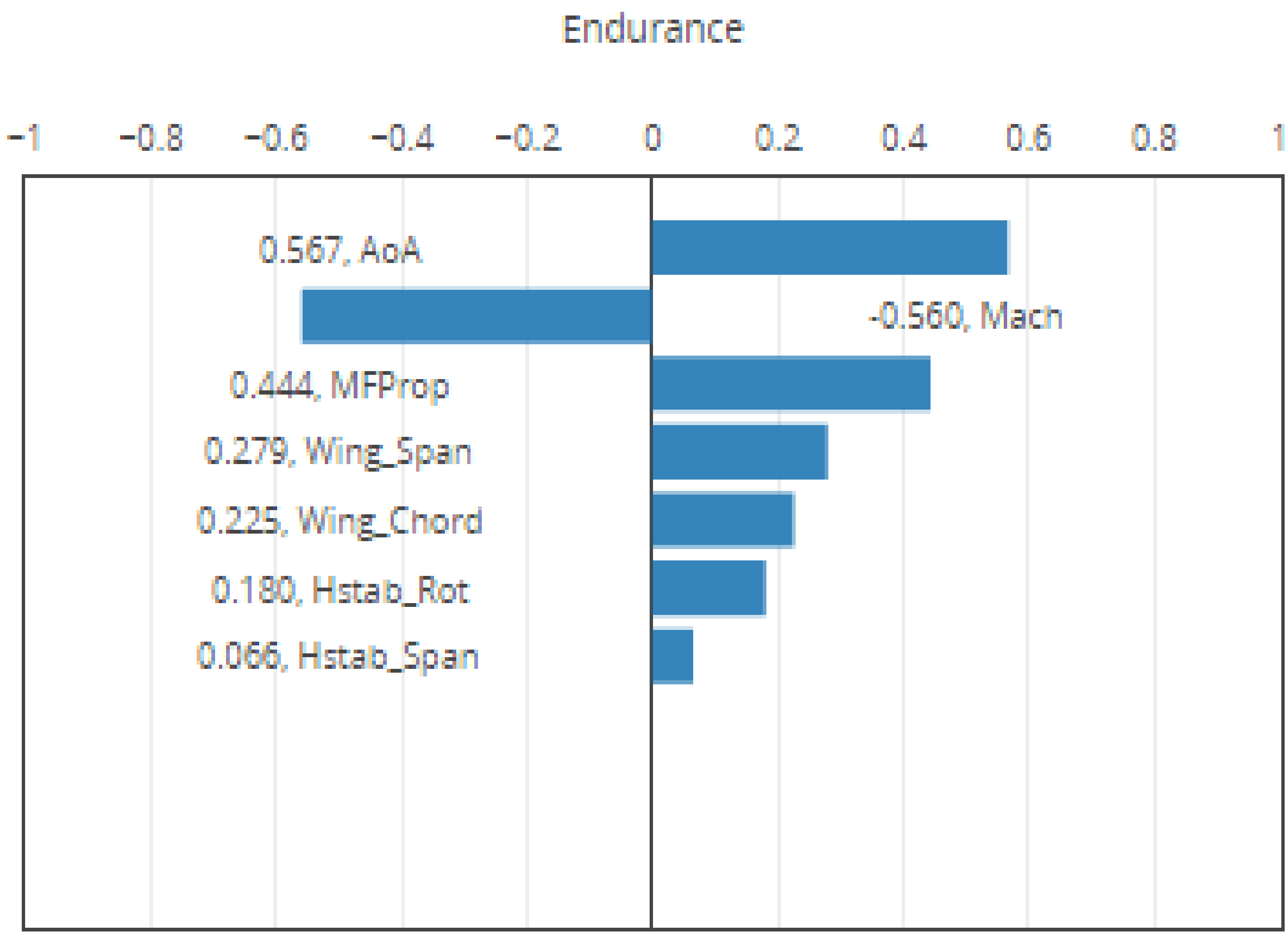

Colors Represent Angle of Attack



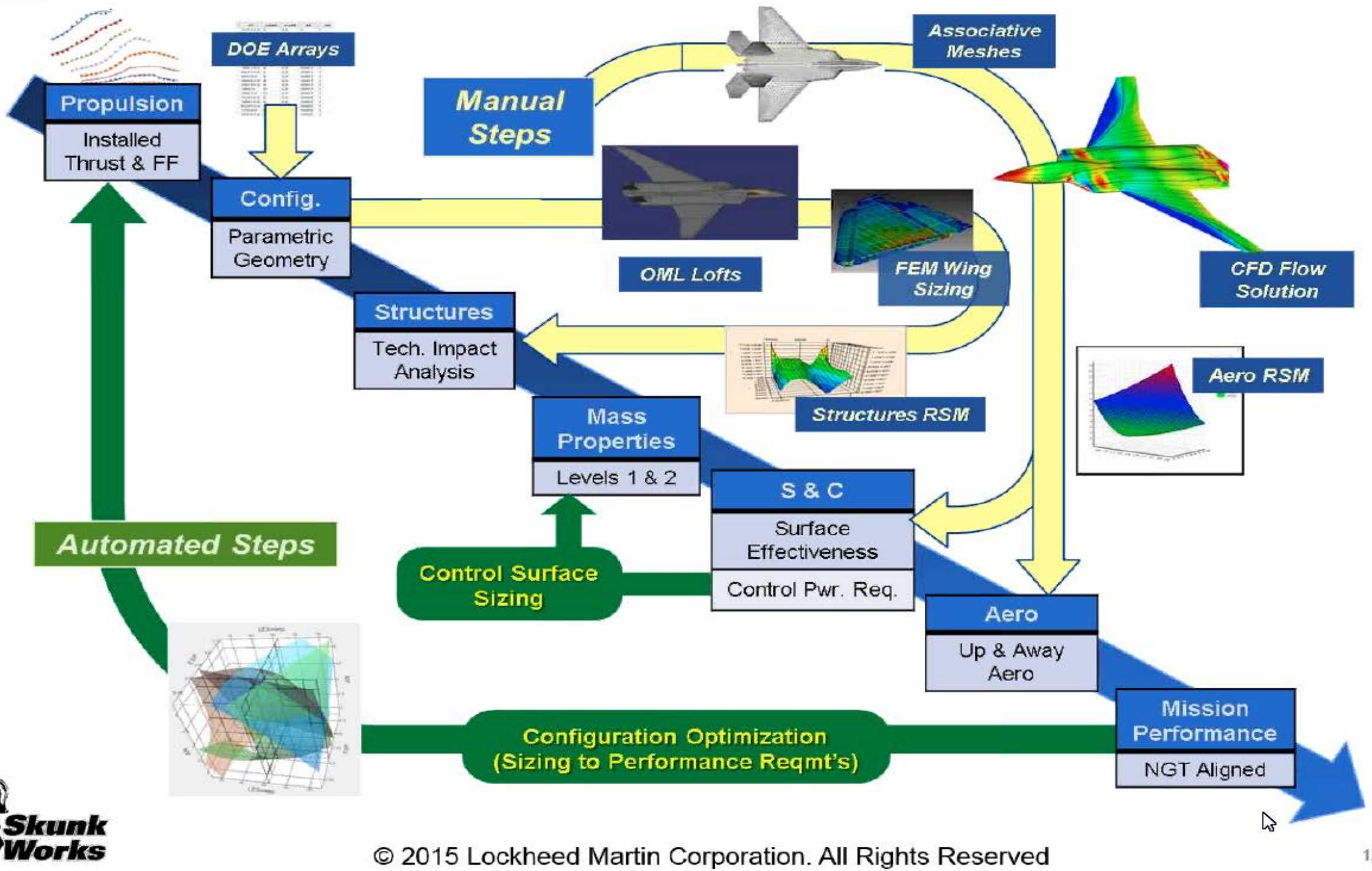

Colors Represent Mach # (airspeed)

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

# Sensitivity Analysis



# Modelcenter Process Changes – ESAVE Program

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# 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

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


*SERC RT170 MCE Project for NAVAIR*
*ASDL Contact:* Russell.Peak@gatech.edu (PI)

*GT-ASDL Subtask:*

## Model-Centric Engineering (MCE) Techniques & Demos

POC: Russell.Peak@gatech.edu

SE Transformation Working Session #26
Wed Nov 9, 2016 • Lexington Park MD

Not for distribution outside of project team and its partners without prior review.
May contain project proprietary information or other sensitive information.

Georgia Tech | Aerospace Systems Design Laboratory

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# RT-157/170 – Support Tasks Related to Model Integration and Single Source of Truth

Drivers | Education | Problem Solving | Semantic Web | RDF | Ontologies | Behavior Modeling | NLP and Ontologies | CPS

## Semantic-driven Modeling and Reasoning for Systems Engineering Transformation

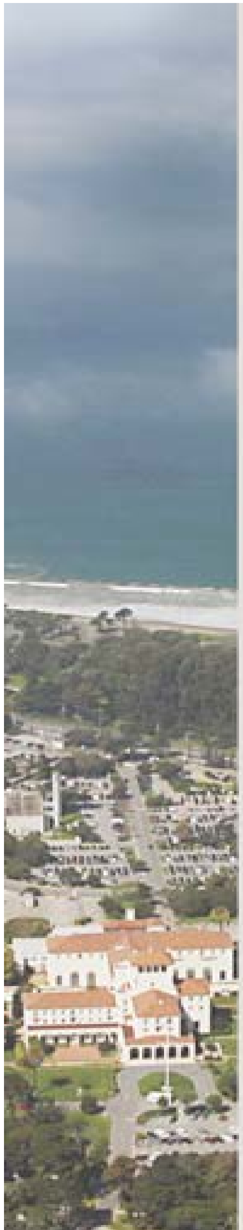

Mark Austin

University of Maryland

*austin@isr.umd.edu NAVAIR Presentation*


November 8, 2016

# 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.

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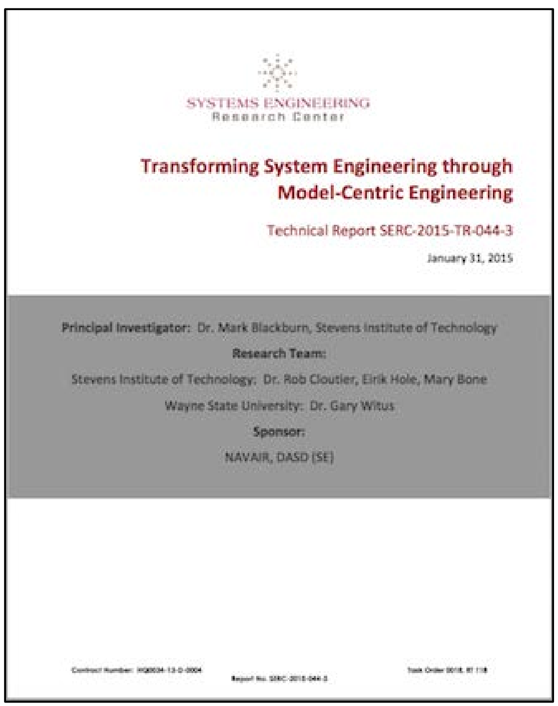
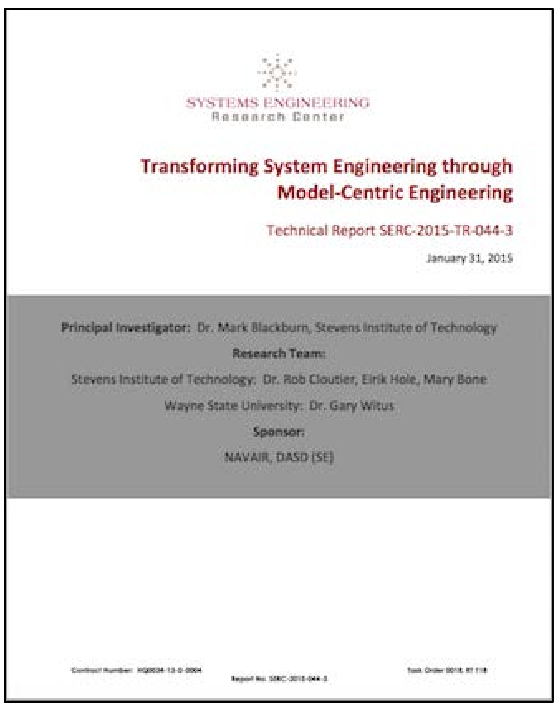
# Collaborations

- 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/


SYSTEMS ENGINEERING
Research Center
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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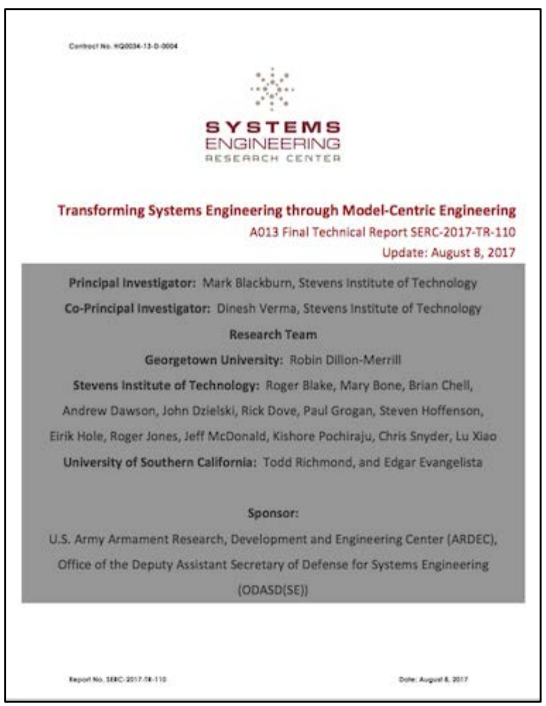
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RESEARCH CENTER
Transforming Systems Engineering through Model-Centric Engineering
A013 Final Technical Report SERC-2017-TR-110
Update: August 8, 2017
Principal Investigator: Mark Blackburn, Stevens Institute of Technology
Co-Principal Investigator: 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 |

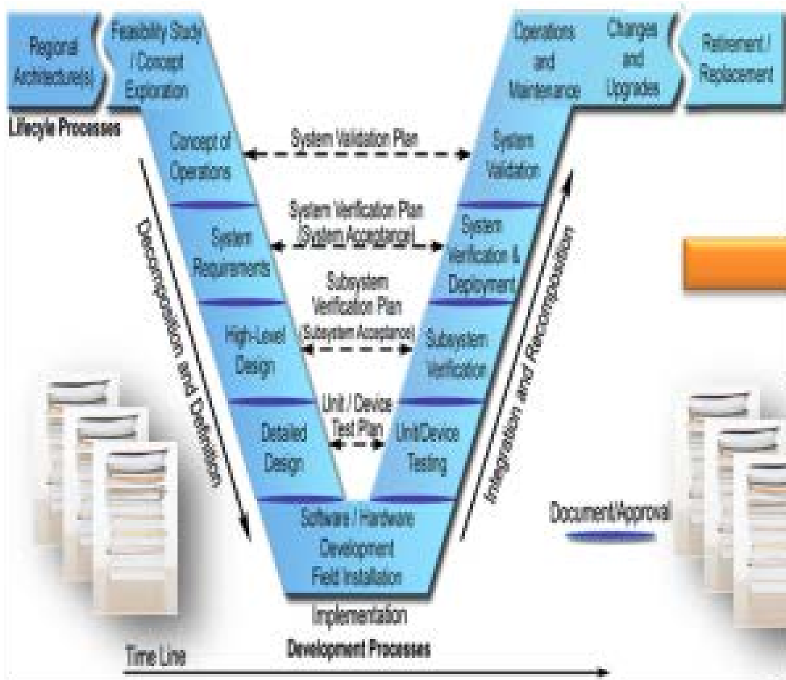
# Model-Centric Systems Engineering Methodology

**Growing System Complexity**

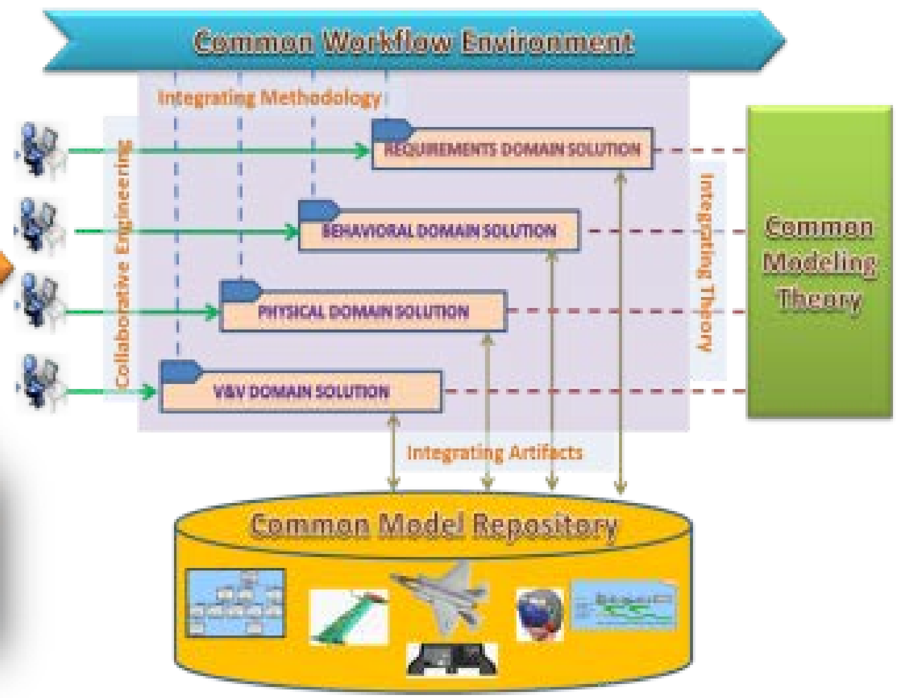
4th Gen Fighter ~
20 sub-sys
$10^3$ interfaces
40% functions in SW

5th 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

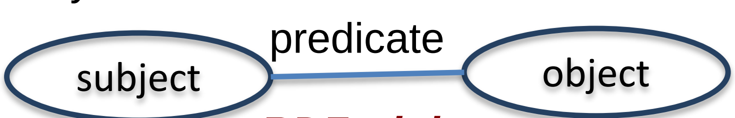
# Semantic Web Technology Stack Supports Different Levels of Abstraction

## Layers of Abstraction

Ontology and reasoning layers

***Analytical Knowledge***

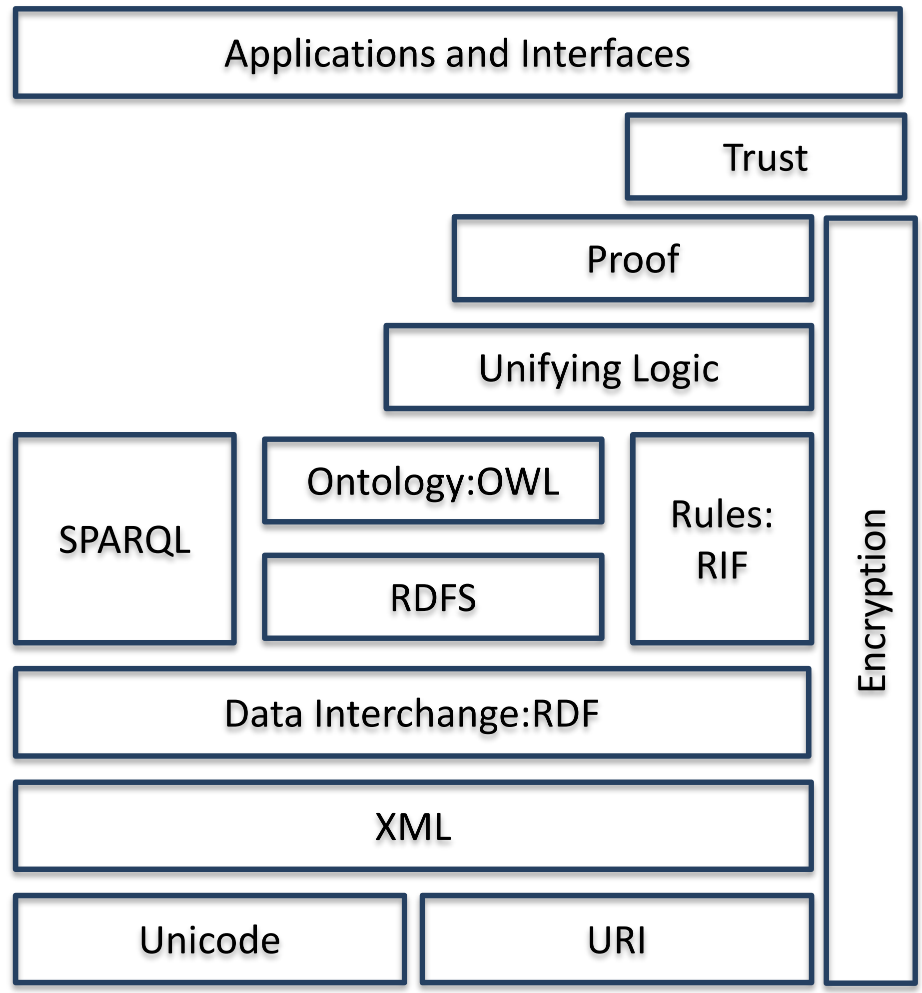
Data layers



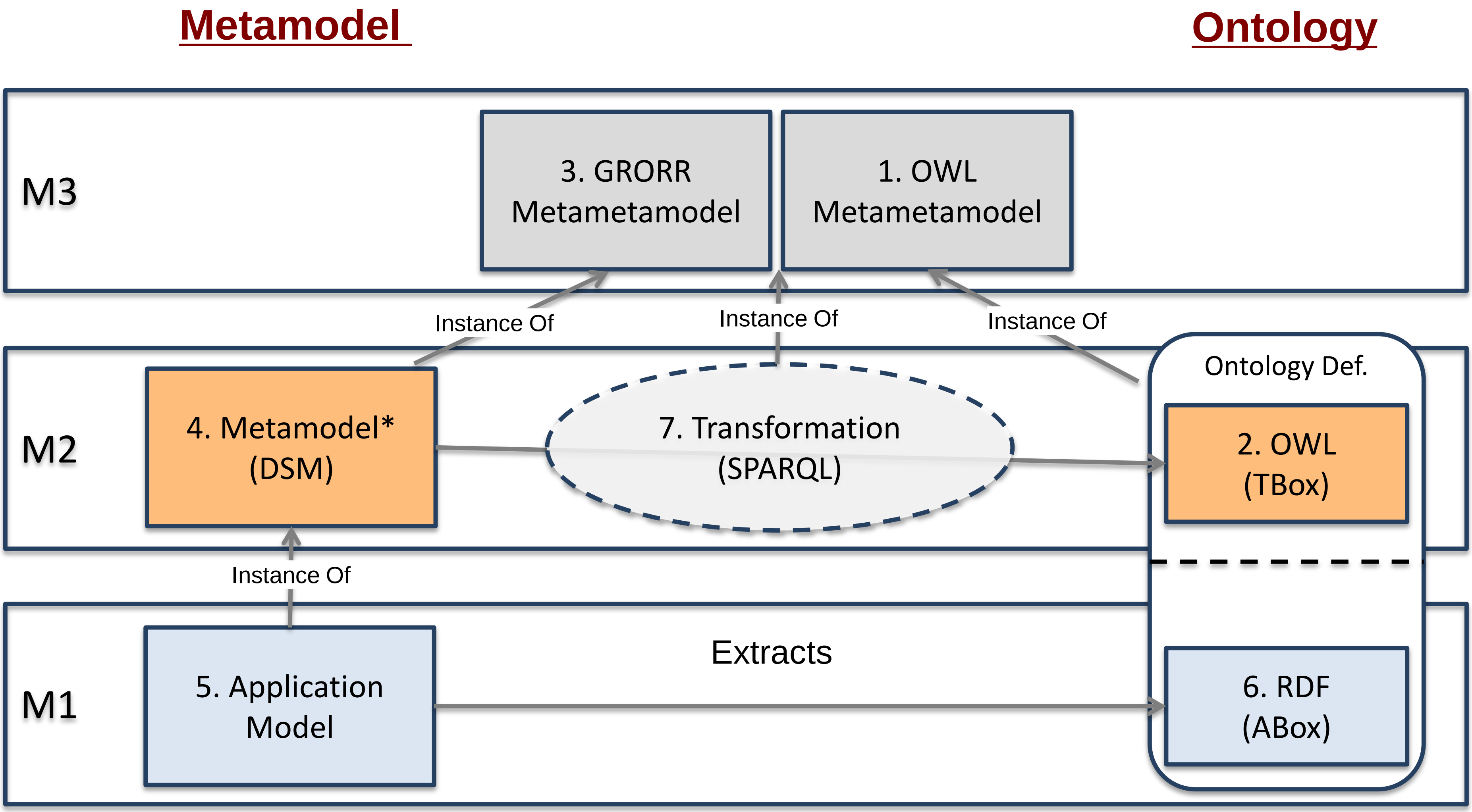

***RDF triple***

Representation / syntax layers

## Semantic Web Technology Stack



# Formalizing Viewpoint Semantics for Integration of Modeling & Analysis

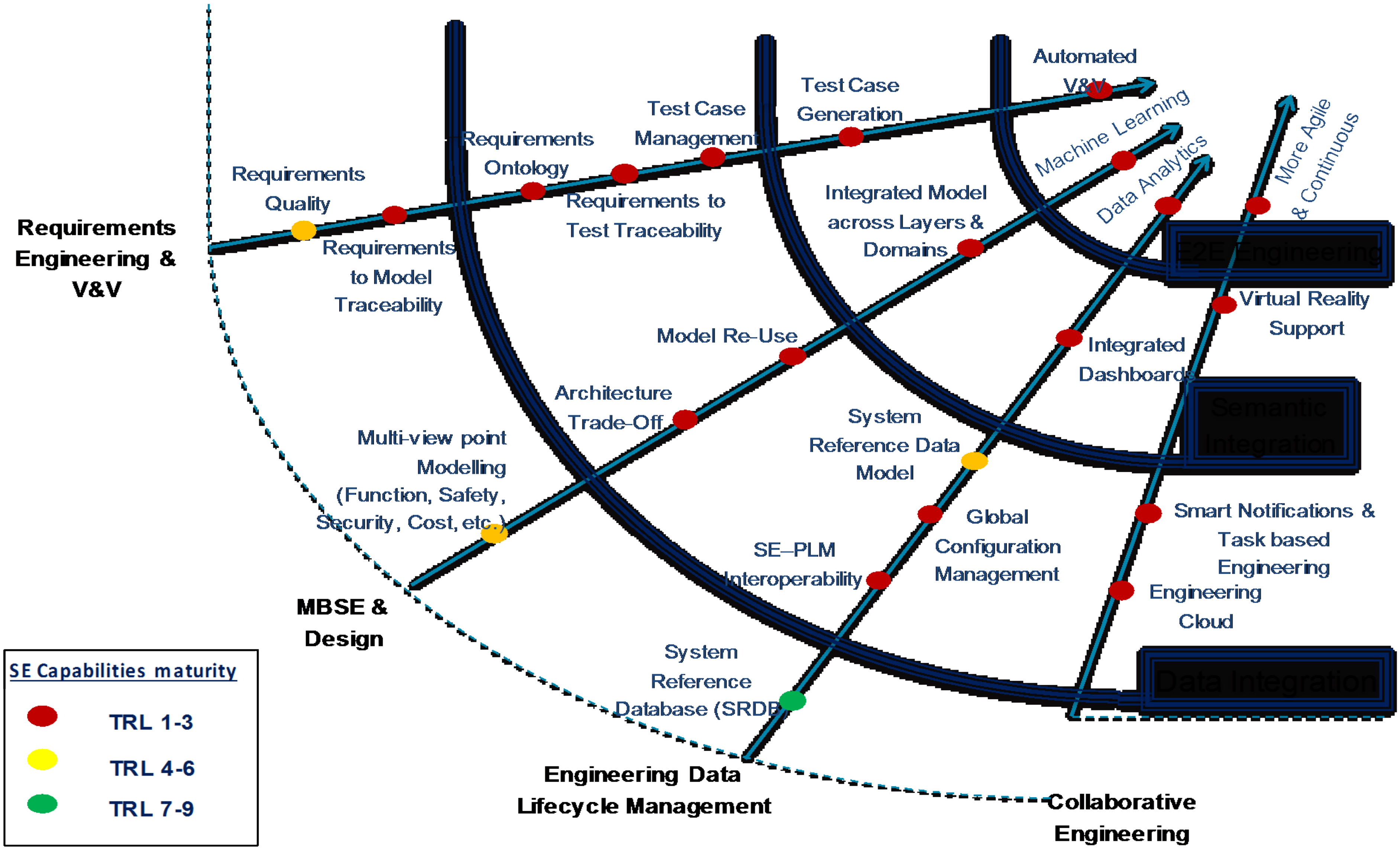



*Simulink, Modelica, Excel, BNF, SQL, SPARQL, and maybe some General Modeling Languages too etc.

MOF, KM3, GRORR, etc.

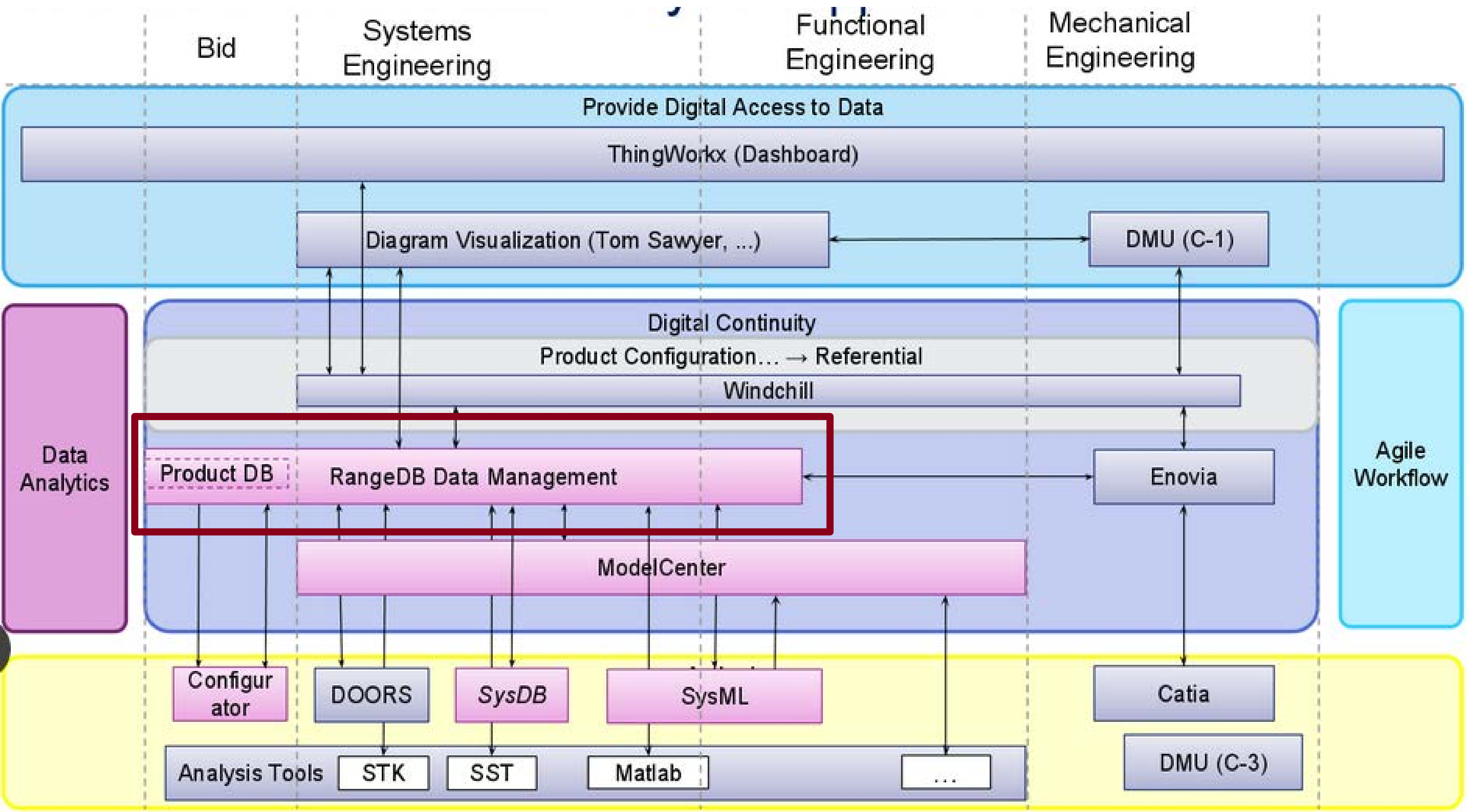
SERC 168/170.

# Multiple Dimensions of Airbus Technology Roadmap: Perspective of Information Model



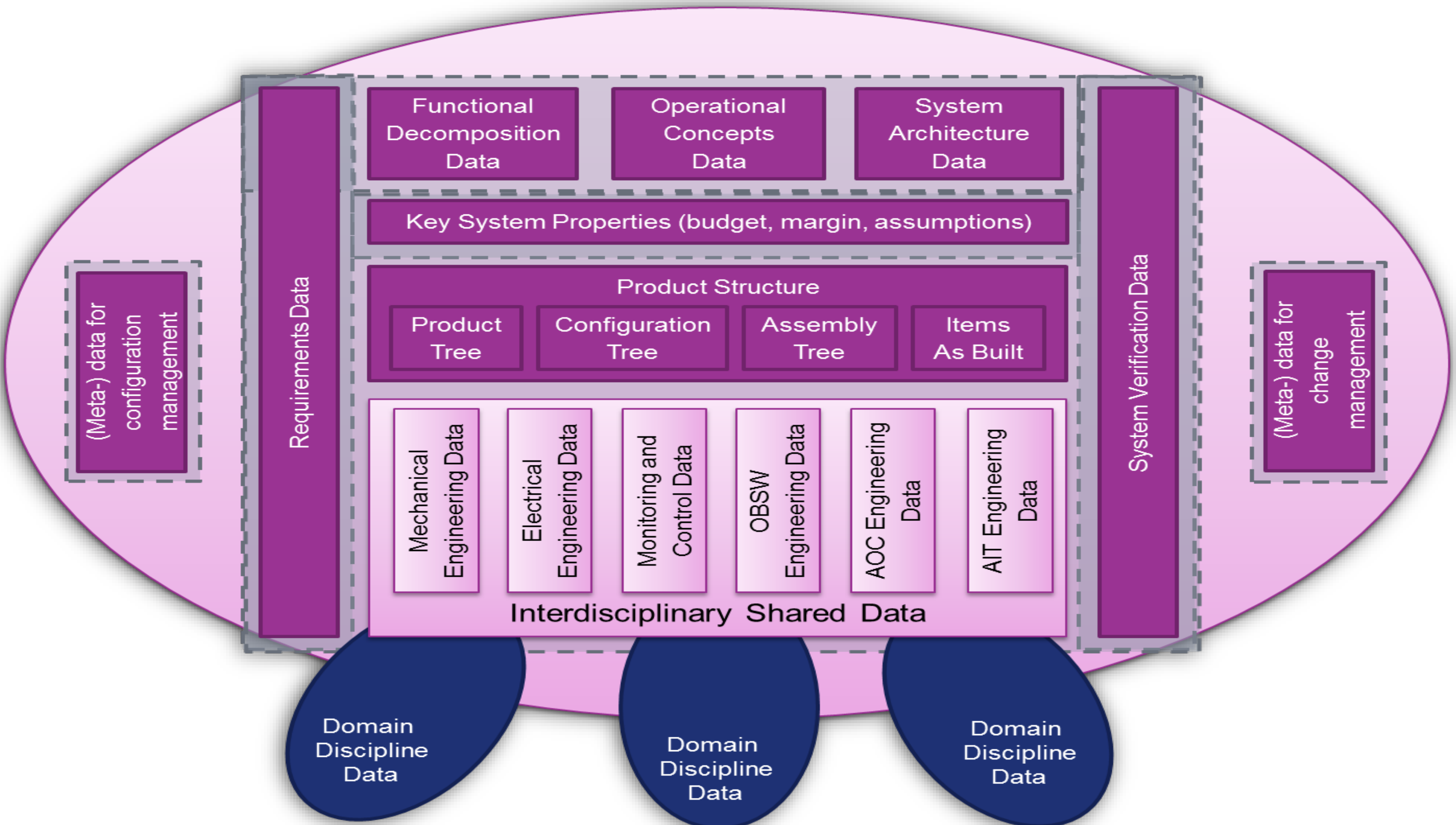

Hartmann, R., Digital Environment and MBSE Progress at Airbus Space, NASA JPL Symposium and Workshop on Model Based Systems Engineering, January 2017.

# 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.

SYSTEMS ENGINEERING Research Center

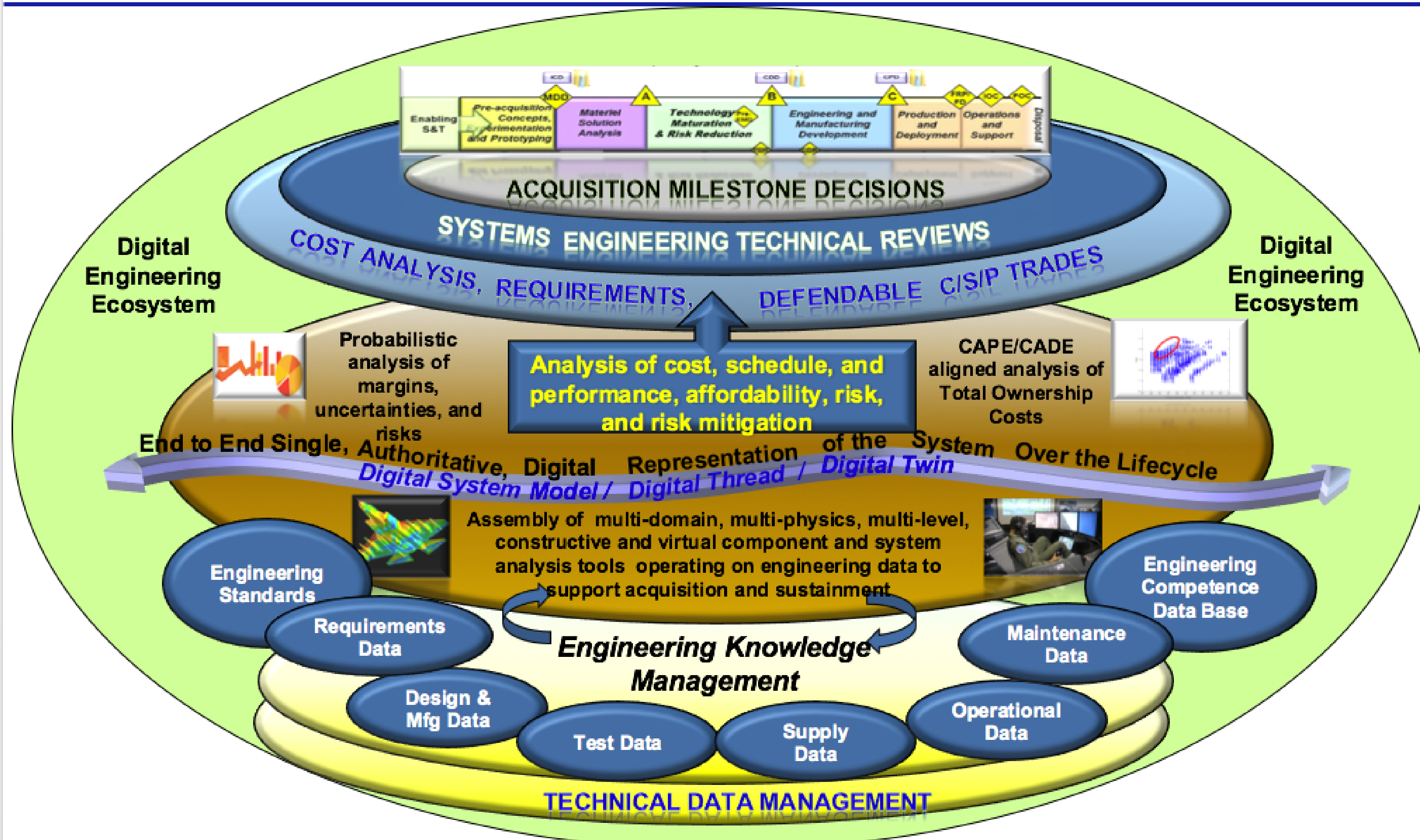
# Uses Cases for Multi-Disciplinary Engineering (Systems Engineering)

| 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 | + | + | ++ | | | ++ | + |

Semantic Web Technologies for Intelligent Engineering Applications

# A Holistic View of Digital Engineering Support to DoD Acquisition






Distribution Statement A –. Distribution is unlimited.

# Graphical CONOPS with Unity