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

Transforming Systems Engineering through a Holistic Approach to Model Centric Engineering
Presented to: NDIA 2014
By:
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Dr. Robert Cloutier
Mr. Eirik Hole
Dr. Gary Witus
Ms. Mary Bone
• Context, Problem and Objectives
• Four Tasks
• Perspectives on findings to date
• Conclusions
• Acknowledgments
• Image credits
Our NAVAIR Sponsor’s Question

Is it Technically Feasible to radically Transform Systems Engineering through Model-Centric Engineering to rapidly deliver the needed capabilities to the Warfighter for Large-Scale Air Vehicle Systems (Reduction of time by at least 25%)
• NAVAIR is partially constrained by their own process
  — Monolithic, serialized, and paper-driven

• NAVAIR fully acknowledges that they have worked hard to put rigorous processes in place over the years (called: the SE Technical Review-SETR)

• Process is “lashed” to the SE “V” (lifecycle Vee)

• NAVAIR needs to deliver capabilities faster as threats are continually changing

• Airworthiness and Safety make the objective more challenging than for other types of systems (of systems)
NAVAIR’s Leadership Understands the Problems and Opportunities for a Future State

- They believe there is a holistic approach to conceiving innovative concepts and solutions enabled through Model-Centric SE coordinating the efforts across multiple disciplines, while managing relationships with all stakeholders.
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

4) Fully integrate model-driven Risk Management and Decision Making
   - Address two classes of risk:
     - Airworthiness and Safety
     - Program Execution
Task 1 – Industry, Government and Academia Visits and Discussions

- Our goals was not to single out specific companies, rather in the aggregate answer the key question
  - Is it technically feasible (for NAVAIR) to have a radical transformation through model-centric engineering and reduce the time to develop a large scale air vehicle system by 25 percent.

- We did not do a survey

- We wanted the discussions to be open ended
  - Tell us about the most advanced and holistic approach to model-centric engineering you use or seen used

- The spectrum of information was very broad; there really is no good way to make a comparison

- We will have a report that summarizes the aggregate of what we heard
Model Based System Engineering (MBSE) versus Model Centric Engineering

- The sponsor’s vision goes beyond MBSE, and discussions with organizations have driven us to use the term model-centric engineer.

- Model-centric better 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.

- Example circa 2008
Use Dynamic Models and Surrogates to Support Continuous “virtual V&V”

- We are approaching a tipping point where integration of computational capabilities, models, software, hardware, platforms, and humans-in-the-loop allows us to assess the system design in the face of changing mission needs.

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

Surrogates, traditional materials, hardware, processes
Base airframe with some advanced materials (composites) hardware (SIL assets)
Final Config: advanced materials (composites/exotics) advanced hardware, final avionics

**Derived from Ernest S. "Turk" Tavares, Jr. and Larry Smith**
Leaders are Embracing Change and Adapting To Use Digital Strategies Faster Than Others

- Enabling digital technologies are changing how companies are doing business using models-centric engineering.

- They use model-centric environments for customer engagements, but also for design engineering analysis and review sessions.

- Use commercial technologies but have developed a significant amount of infrastructure on their own.

- One company called it: “our secret sauce”
There are modeling environments to Create Dynamic Operational Views (OV1)

- Increasing need for integration to better understand and characterize Mission Context for the needed System Capabilities
1D, 2D & 3D Models have Simulation and Analysis Capabilities

- Focused primarily on physics-based design with increasing support for cross-domain analysis
Platform-based Approaches with Virtual Integration Help Automakers Deliver Vehicle Faster

- Refresh and upgrades on periodic schedules are business critical
Modeling and Simulation in the Automotive Domain is Reducing the Physical Crash Testing

- NAVAIR wants to know if it is feasible to assess designs earlier and more continuously by flying virtually
• We heard about mission-level simulations that are being integrated with system simulation, digital assets & products providing a new world of services
• Design optimization and trade study analysis
• Engineering affordability analysis
• Risk modeling and analysis
• Pattern-based modeling based on ontologies with model transformation and analysis
• Domain-specific modeling languages

Not exhaustive. . .
Holistic Model-centric Engineering can Enable, But will Require New Types of Coordination

• Even if technically feasible, there are many changes that will need to be made for NAVAIR to adapt, adopt, transform, and work with contractors in radically different ways
What are the gaps and challenges and road forward?

• Lack of Precise Semantics to support model Integration, interoperability, and transformation is a challenging issue
  — Systems engineering is about integration of disciplines across many domains
  — We have a “sea” of models, simulators, solvers, etc., but we don’t have consistent meaning across or between them
  — Lack of precise semantics especially in both behavior of models and timing/interactions of models
  — This will limit the full spectrum of analyses and simulations needed to provide adequate coverage over a system’s capabilities
  — Some are looking at how to work and integrate a federation of models and digital assets, but that is not an ideal solution

• Many believe we can “engineer” to address this challenge
Producing Software-intensive Systems of the Same Complexity as Hardware is Taking ~5x Longer

- We didn’t put much thought into Software initially, however -

- 90% of the functionality in a 5th Generation Air Vehicle System is in Software, which is increasing in complexity
Augustine’s Law – Growth of Software: Order of Magnitude Every 10 Years

In The Beginning

1960’s

F-4A
1000 LOC

1970’s

F-15A
50,000 LOC

1980’s

F-16C
300K LOC

1990’s

F-22
1.7M LOC

2000+

F-35
>6M LOC

6th Generation

>90M LOC

Image credit: Ken Nidiffer
Number of Source Lines of Code (SLOC) has Exploded in Air Vehicle System Software

- Like it or not, the DoD is now in the software business

### SLOC in thousands

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>LOC (M)</th>
<th>Years</th>
<th>Production Rate</th>
<th>Relative</th>
</tr>
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<tr>
<td>F-22</td>
<td>1.7</td>
<td>6</td>
<td>0.2833</td>
<td>0.5037</td>
</tr>
<tr>
<td>F-35</td>
<td>9</td>
<td>16</td>
<td>0.5625</td>
<td>1.0000</td>
</tr>
<tr>
<td>Next Gen</td>
<td>90</td>
<td>12</td>
<td>7.5000</td>
<td>13.3333</td>
</tr>
</tbody>
</table>

**NOTE:** F-35 SLOC figures are from first test flight and current estimates/sources
Conclusions

• 28 Discussions with Industry, Government and Academia – our summary is not exhaustive

• Explosion of models

• Model-centric versus Model-based?

• There are some gaps and challenges
  —Starting follow-ups to investigate some of the challenge areas more deeply

• Transformations will require changes in the way we work too
  —One participant said, “it’s technically feasible, but people will be the issue...”
  —Another said, key to their success is that they are “staffed with the right-thinking people.”

• We will continue to document our progress and findings
• We wish to acknowledge the great support of the NAVAIR sponsors and stakeholders, including stakeholders from other industry partners that have been very helpful and open about the challenges and opportunities of this promising approach to transform systems engineering.

• We want to specifically thank Dave Cohen who established the vision for this project, and our NAVAIR team, Jaime Guerrero, Eric (Tre´) Johnsen, and Ron Carlson, who has worked closely on a weekly basis in helping to collaboratively research this effort. We thank Howard Owens and Dennis Reed who have joined us in some of the organizational visits. We also thank Larry Smith, and Ernest (Turk) Tavares who worked Phase I with us, but have left the project.

• We have had 28 discussions with organizations from Industry, Government, and Academia, and we want to thank all of those stakeholders, including some from industry that will remain anonymous in recognition of our need to comply with proprietary and confidentiality agreements associated with Task 1.
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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>CDR</td>
<td>Critical Design Review</td>
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<tr>
<td>DoD</td>
<td>Department of Defense</td>
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<tr>
<td>MBSE</td>
<td>Model-based System Engineering</td>
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<tr>
<td>MBE</td>
<td>Model-Based Engineering</td>
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<tr>
<td>NAVAIR</td>
<td>Naval Air Systems Command</td>
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<tr>
<td>OV</td>
<td>Operational View</td>
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<tr>
<td>P&amp;FQ</td>
<td>Performance and Flight Quality</td>
</tr>
<tr>
<td>PDR</td>
<td>Preliminary Design Review</td>
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<tr>
<td>SLOC</td>
<td>Software Lines Of Code</td>
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<tr>
<td>SE</td>
<td>Systems Engineering</td>
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<tr>
<td>SETR</td>
<td>Systems Engineering Technical Review</td>
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<td>SFR</td>
<td>System Functional Review</td>
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<tr>
<td>SRR</td>
<td>System Requirements Review</td>
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<tr>
<td>SoS</td>
<td>System of Systems</td>
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<tr>
<td>SV</td>
<td>System View</td>
</tr>
<tr>
<td>V&amp;V</td>
<td>Verification and Validation</td>
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