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

Transforming Systems Engineering through a Holistic Approach to Model Centric Engineering

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Outline

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

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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%**)

Current State

- 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)*

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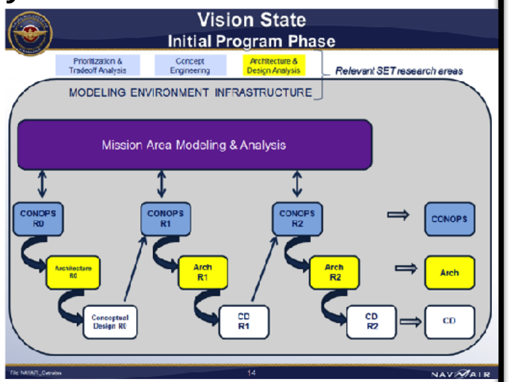
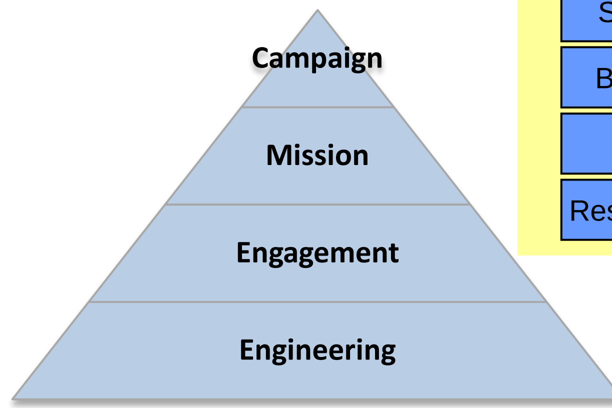
1) Global scan and classification of holistic state-of-the-art MBSE

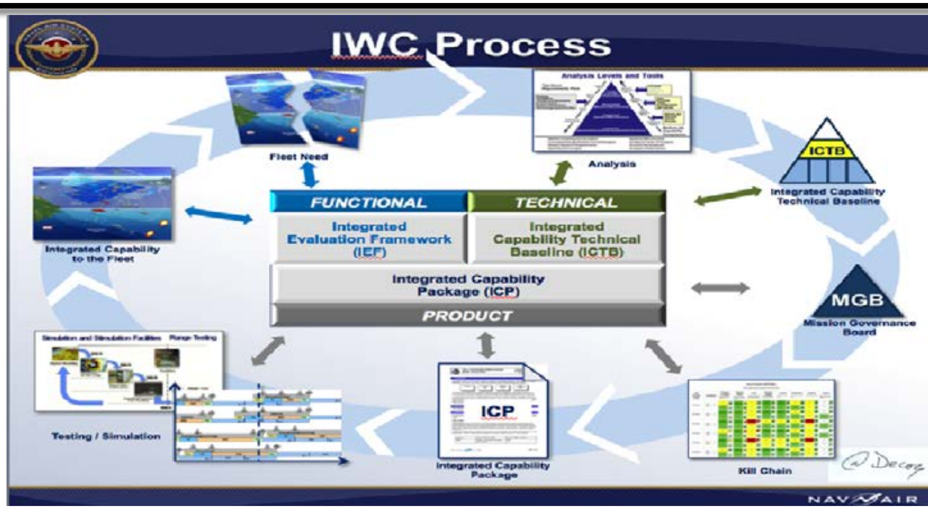
- Use discussion framework to survey government, industry and academia
- Quantify, link and trace realized modeling capabilities to Vision (task 3)



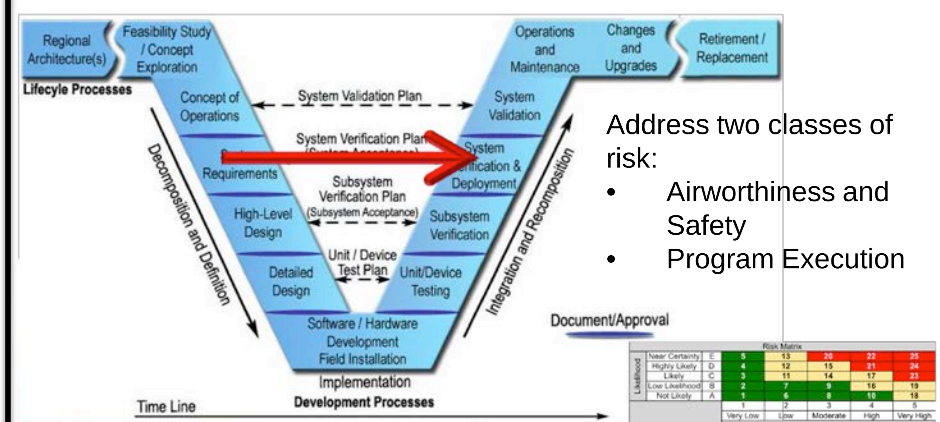
2) Develop Common Lexicon for Model Levels, Types, Uses, and Representations



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



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



Address two classes of risk:
- Airworthiness and Safety
- Program Execution

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

Task 1 – Industry, Government and Academia Visits and Discussions

- 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

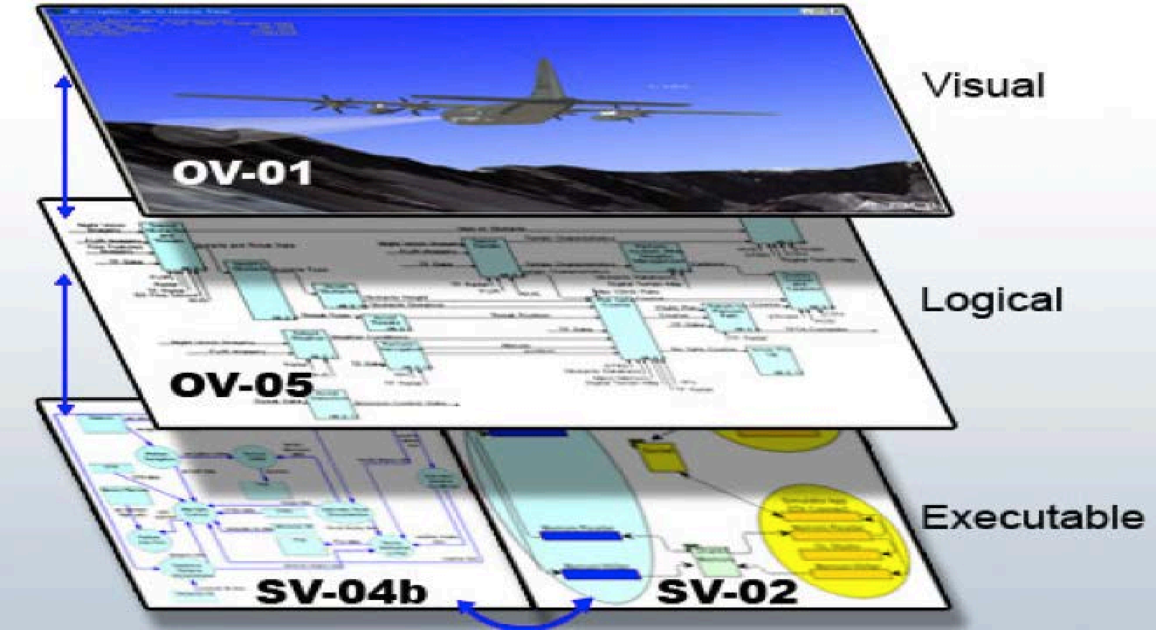
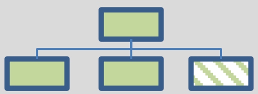
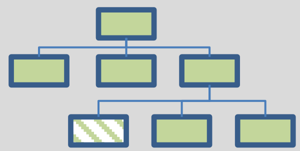
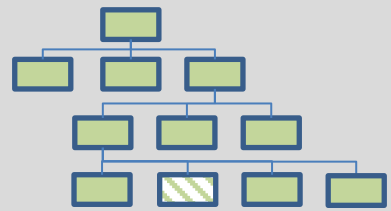
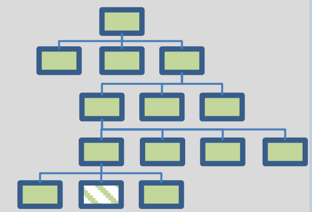


Image credit: Henson Graves

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

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

Surrogates, traditional materials, hardware, processes

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

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

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

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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

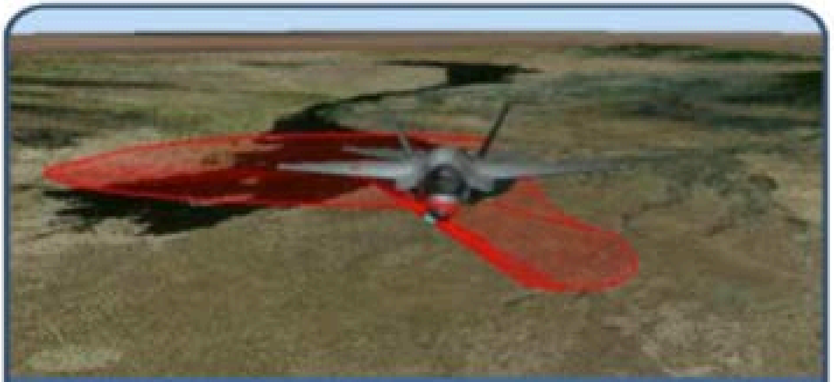
- Use commercial technologies but have developed a significant amount of infrastructure on their own

- One company called it:
  “our secret sauce”

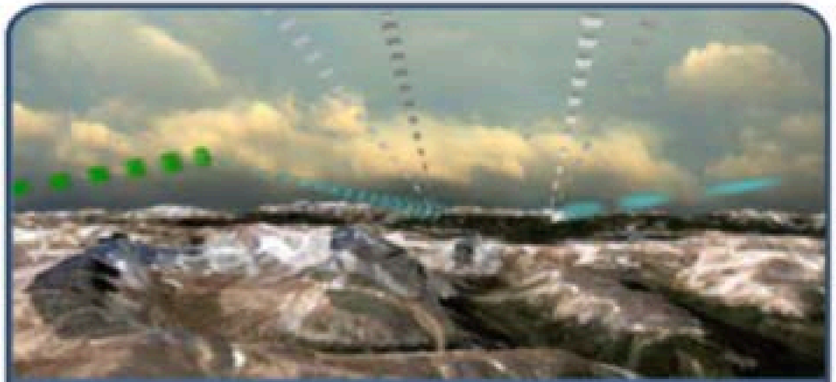
There are modeling environments to Create Dynamic Operational Views (OV1)

- Increasing need for integration to better understand and characterize Mission Context for the needed System Capabilities

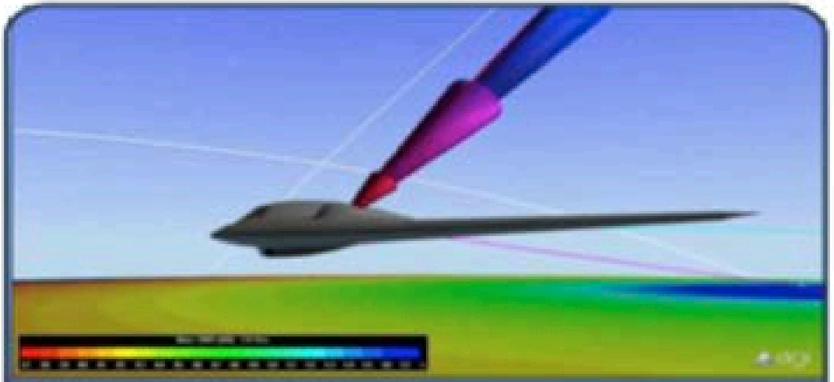
Vehicle Motion Models
Model vehicle position and attitude



Sensor Models
Model sensor geometry & pointing



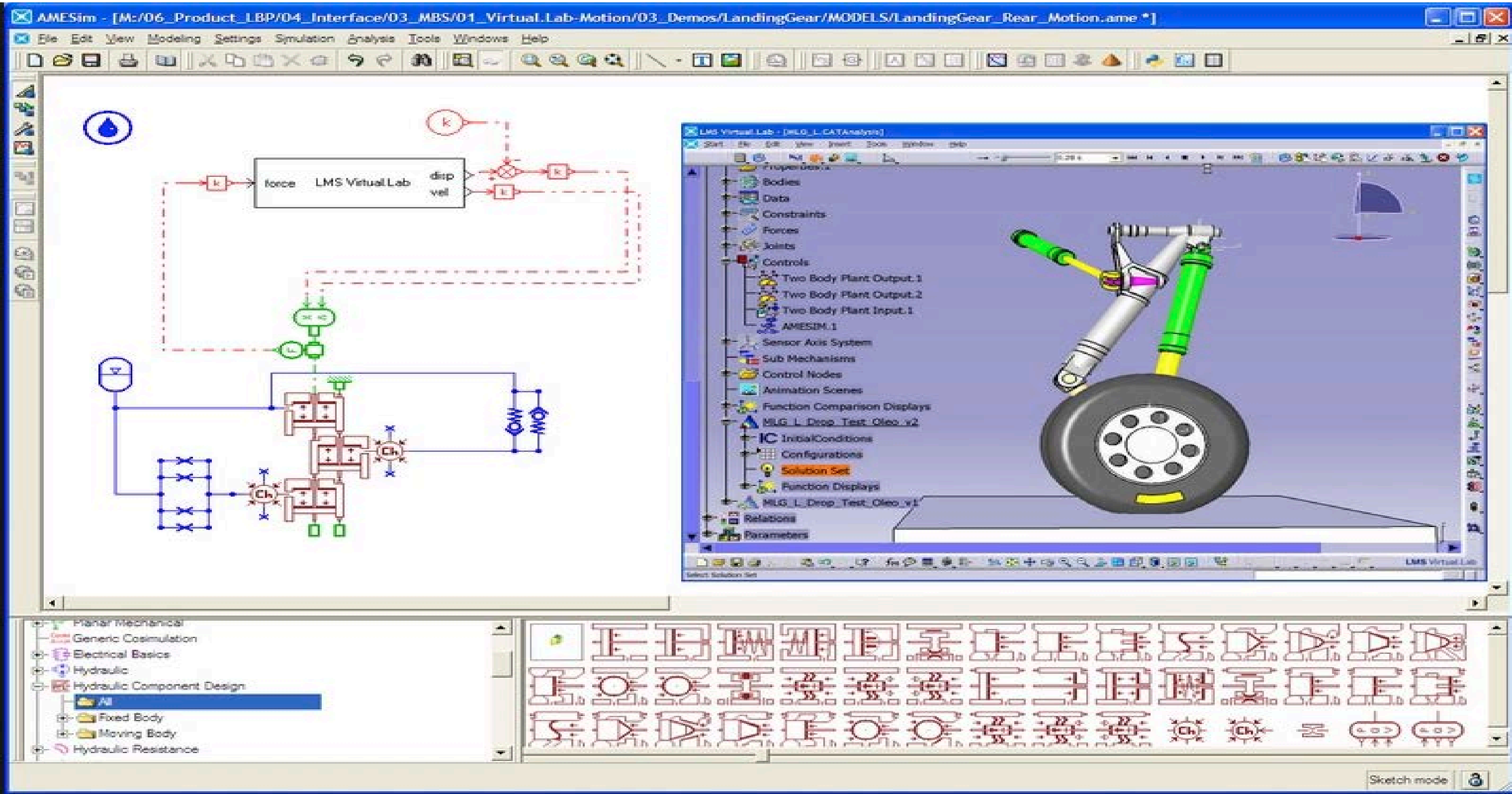
Environment Models
Model terrain, atmosphere & space



Comms & Radar Models
Model RF propagation & interference

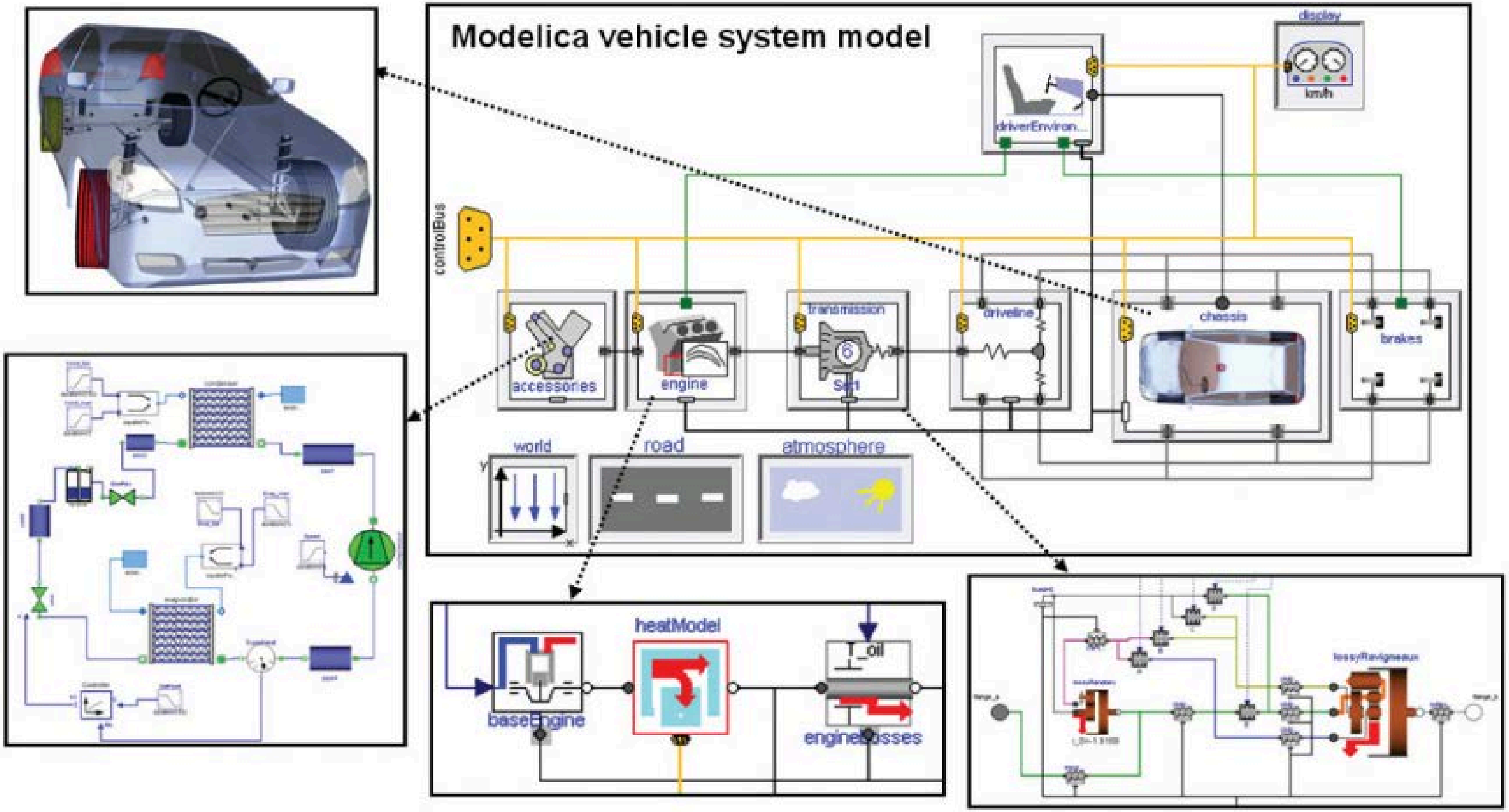
1D, 2D & 3D Models have Simulation and Analysis Capabilities

- 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



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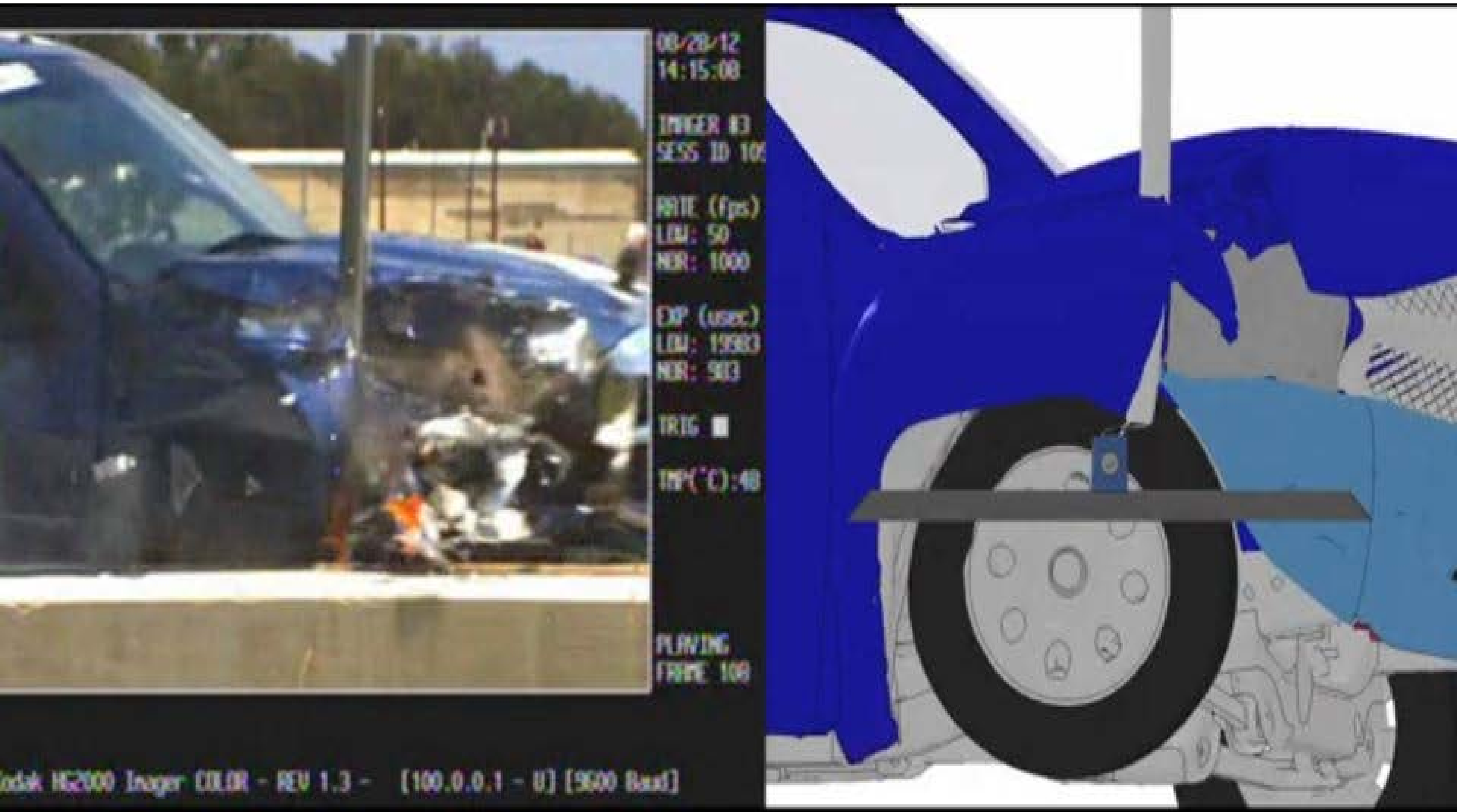
Modeling and Simulation in the Automotive Domain is Reducing the Physical Crash Testing

- NAVAIR wants to know if it is feasible to assess designs earlier and more continuously by flying virtually



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

- We heard about mission-level simulations that are being integrated with system simulation, digital assets & products providing a new world of services

More – Technical Areas

- 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

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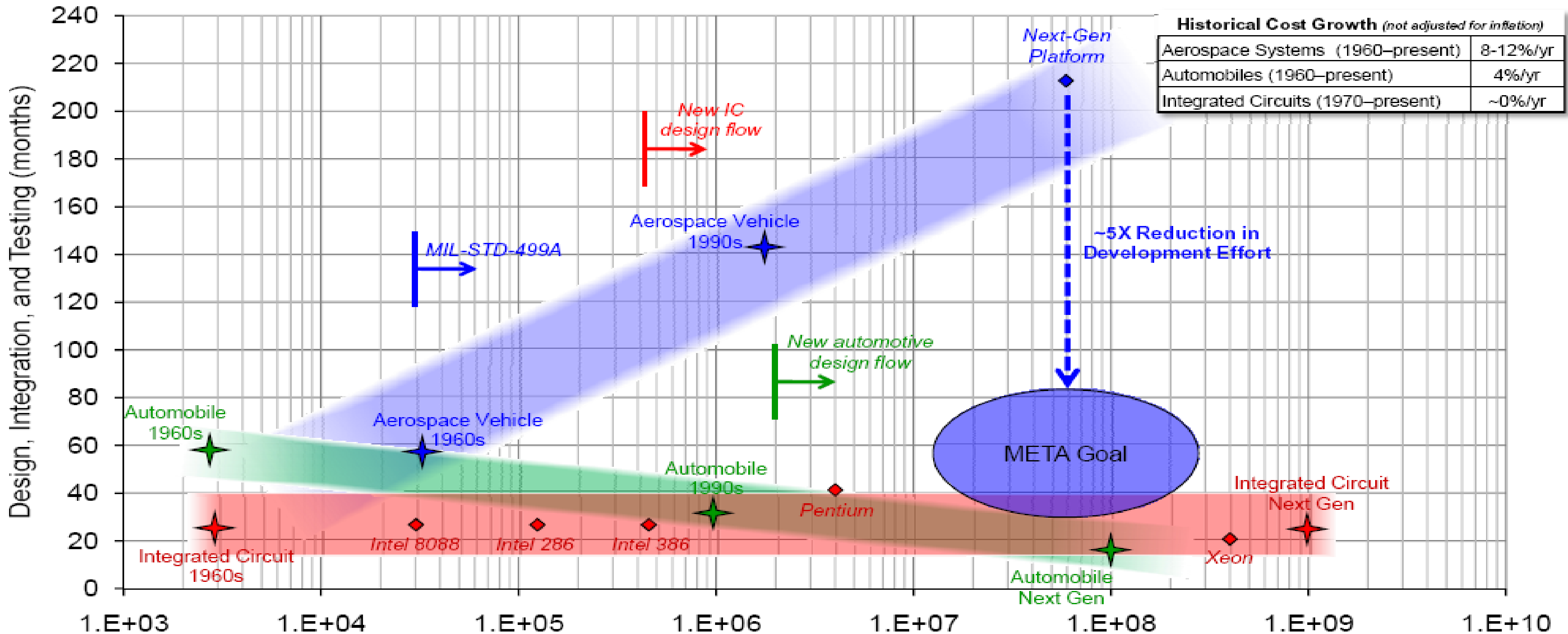
What are the gaps and challenges and road forward?

- 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



Historical Cost Growth (not adjusted for inflation)	
Aerospace Systems (1960–present)	8-12%/yr
Automobiles (1960–present)	4%/yr
Integrated Circuits (1970–present)	~0%/yr

DARPA TTO

Note (*): Not a great metric. But that's what we have today. META will come up with better metrics.

Augustine's Law – Growth of Software: Order of Magnitude Every 10 Years

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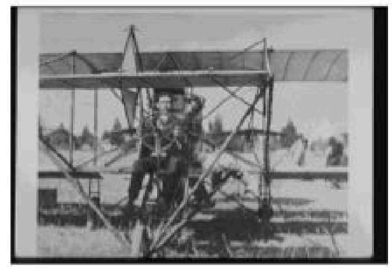
In The Beginning



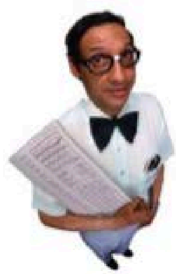
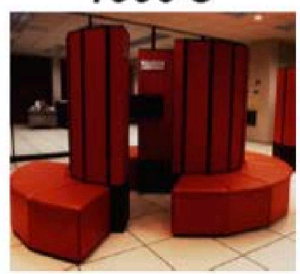
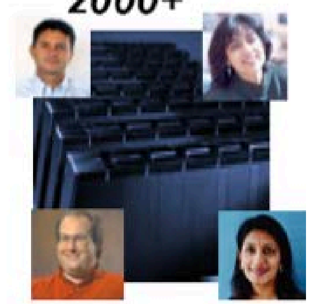
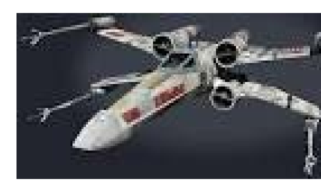
1960's	1970's	1980's	1990's	2000+	
					?
F-4A 1000 LOC	F-15A 50,000 LOC	F-16C 300K LOC	F-22 1.7M LOC	F-35 ~~>6M~~ >9M LOC	6th Generation >90M *LOC*
					

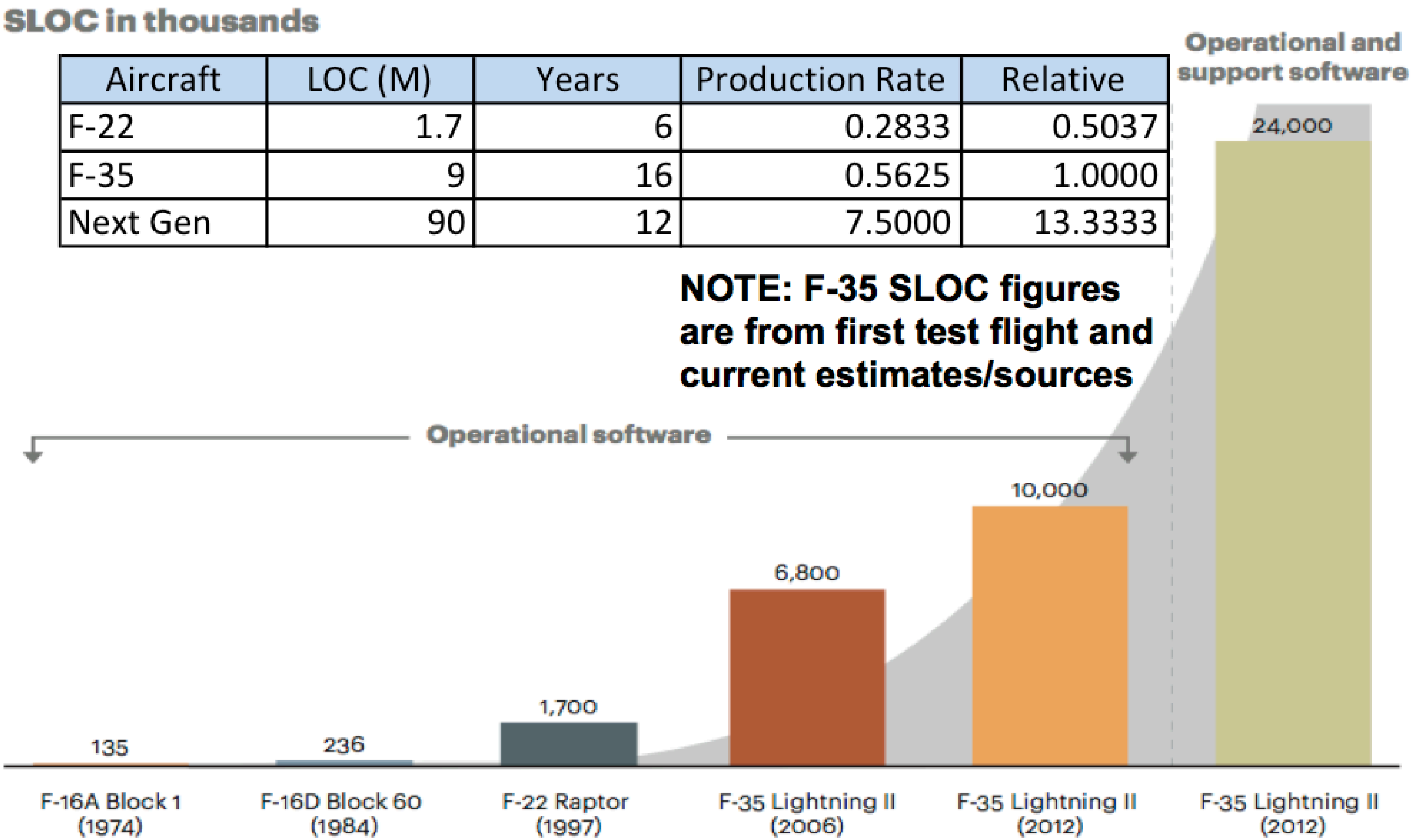
Image credit: Ken Nidiffer

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

Aircraft	LOC (M)	Years	Production Rate	Relative
F-22	1.7	6	0.2833	0.5037
F-35	9	16	0.5625	1.0000
Next Gen	90	12	7.5000	13.3333

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



AT Kearney, Software: The Brains Behind U.S. Defense Systems

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

Acknowledgment

- We wish to acknowledge the great support of the NAVAIR sponsors and stakeholders, including stakeholders from other industry partners that have been very helpful and open about the challenges and opportunities of this promising approach to transform systems engineering.
- We want to specifically thank Dave Cohen who established the vision for this project, and our NAVAIR team, Jaime Guerrero, 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.

Thank You

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Acronyms

CDR	Critical Design Review
DoD	Department of Defense
MBSE	Model-based System Engineering
MBE	Model-Based Engineering
NAVAIR	Naval Air Systems Command
OV	Operational View
P&FQ	Performance and Flight Quality
PDR	Preliminary Design Review
SLOC	Software Lines Of Code
SE	Systems Engineering
SETR	Systems Engineering Technical Review
SFR	System Functional Review
SRR	System Requirements Review
SoS	System of Systems
SV	System View
V&V	Verification and Validation

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