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

## Transforming Systems Engineering through a Holistic Approach to Model Centric Engineering

**Presented to: MIT IMCSE 2015**


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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%**)

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# 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)

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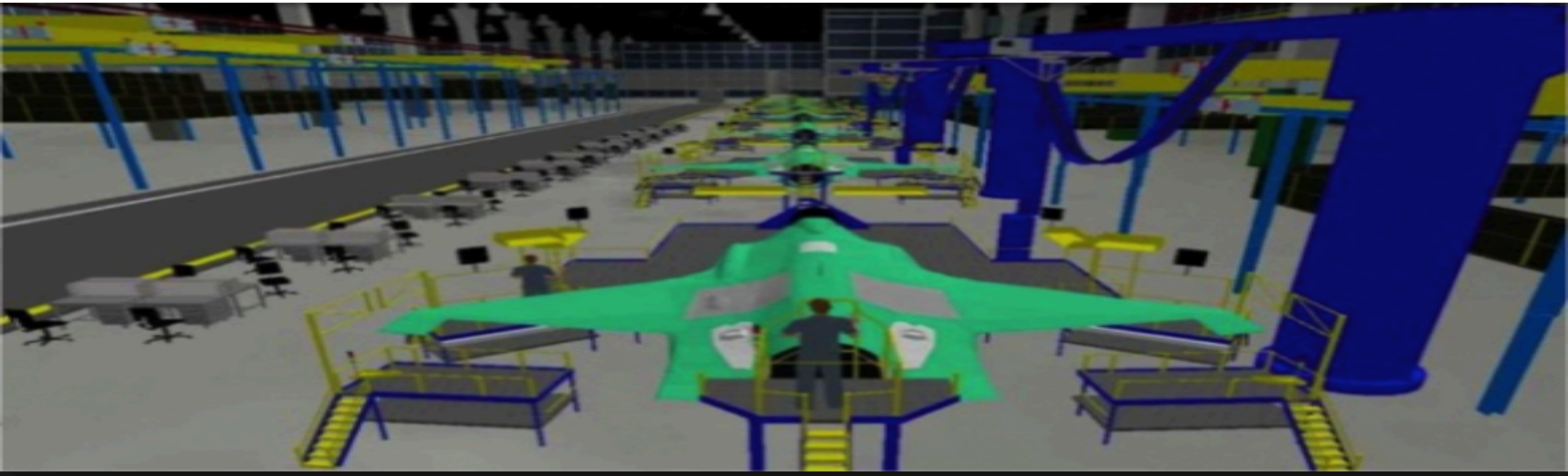
# NAVAIR's Leadership Understands the Problems and Opportunities for a Future State

- 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



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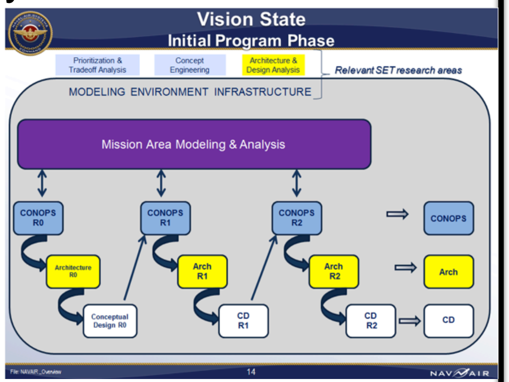
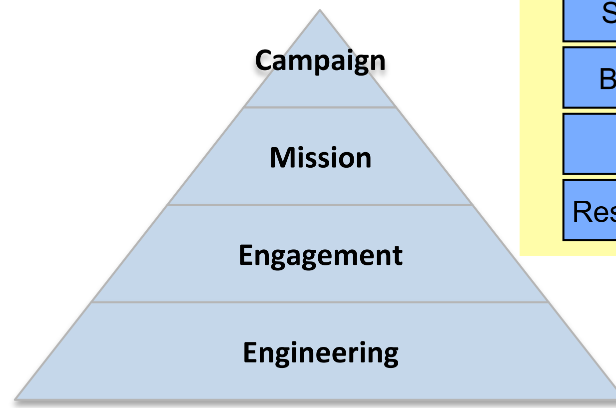
# Four Tasks to Assess Technical Feasibility of *"Doing Everything with Models" (Everything Digital)*

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

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

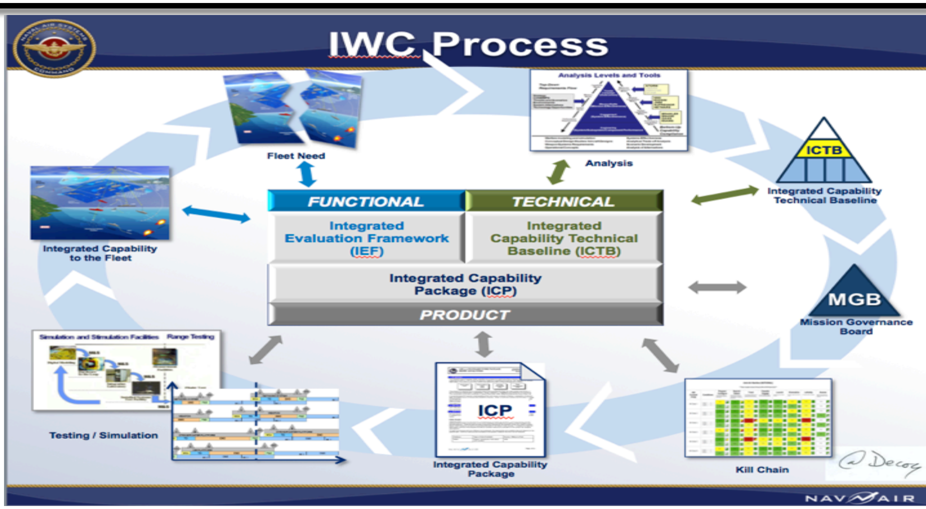



## 2) Develop Common Lexicon for Model Levels, Types, Uses, and Representations

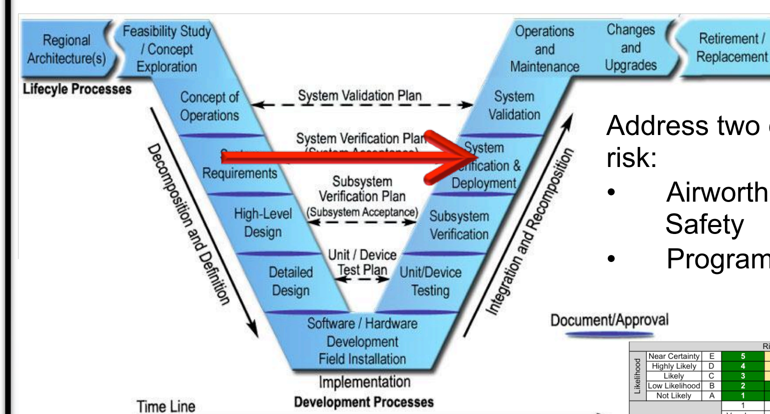



Model Types

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

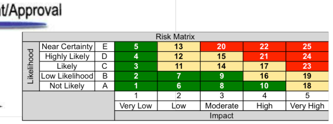



## 3) Model the Vision of Everything Done with Models and Relate to "As Is" process




Address two classes of risk:

- Airworthiness and Safety
- Program Execution




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

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# 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

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# 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

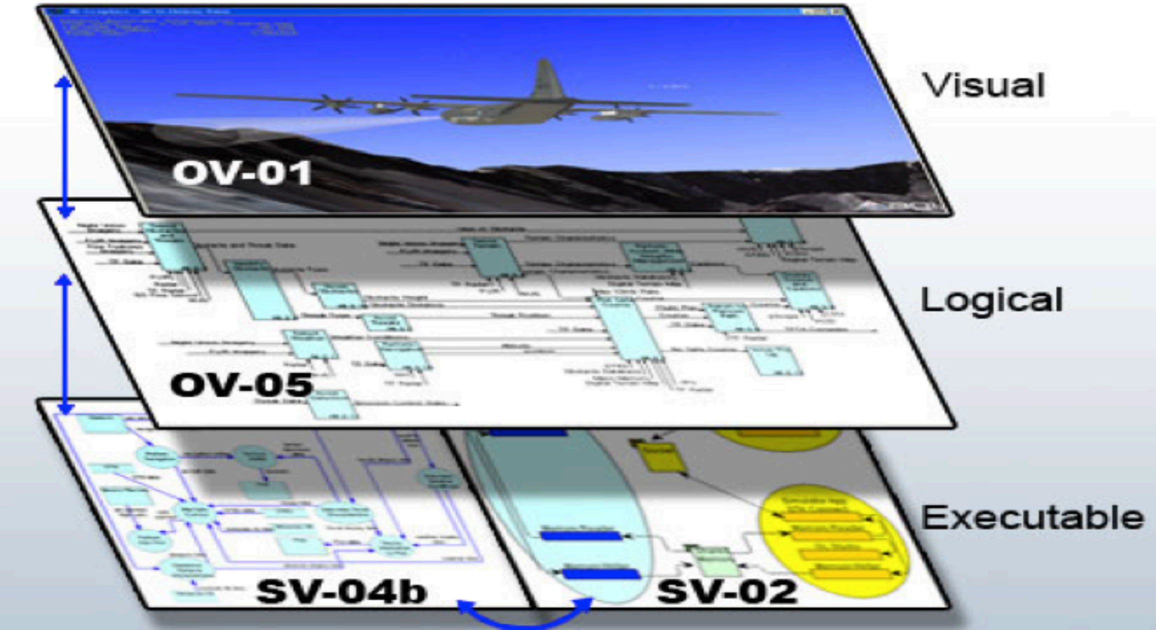
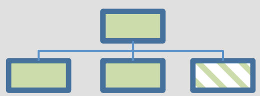
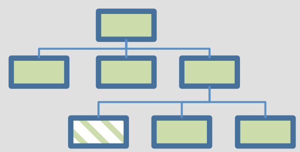
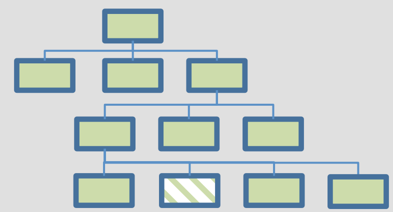
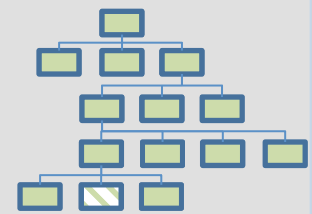



Image credit: Henson Graves

# Use Dynamic Models and Surrogates to Support Continuous "virtual V&V"



- We seem to be 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"**

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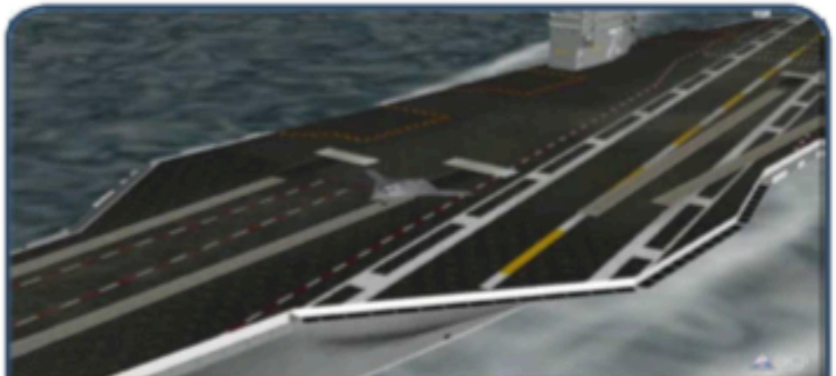
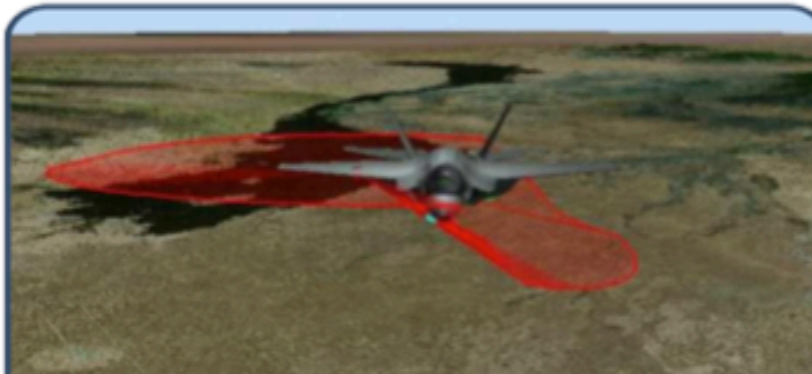
# There are modeling environments to Create Dynamic Operational Views (OV1)

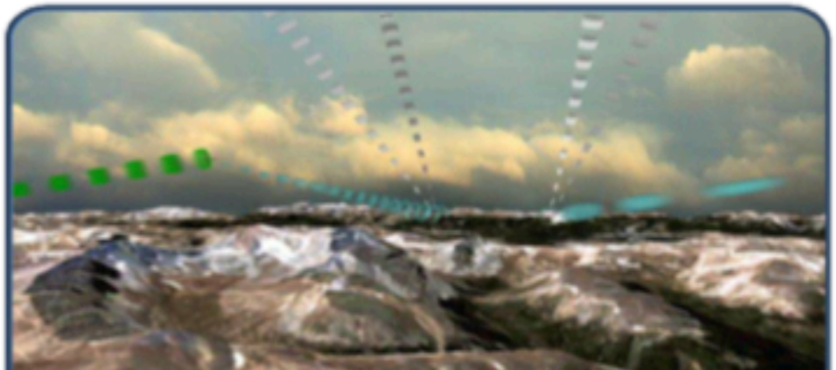
- Increasing need for integration to better understand and characterize Mission Context for the needed System Capabilities



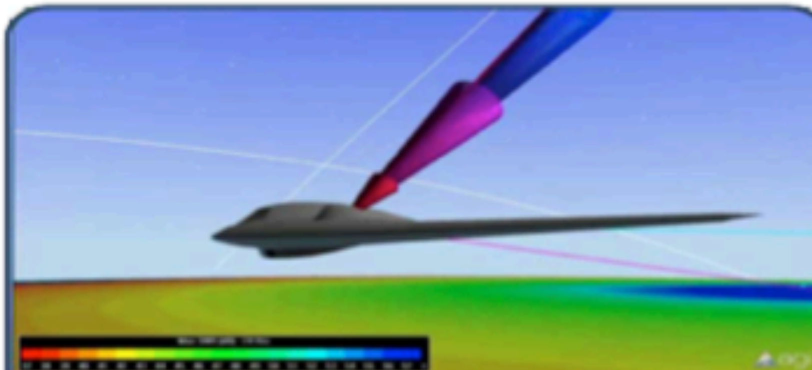
**Vehicle Motion Models**
*Model vehicle position and attitude*



**Sensor Models**
*Model sensor geometry & pointing*



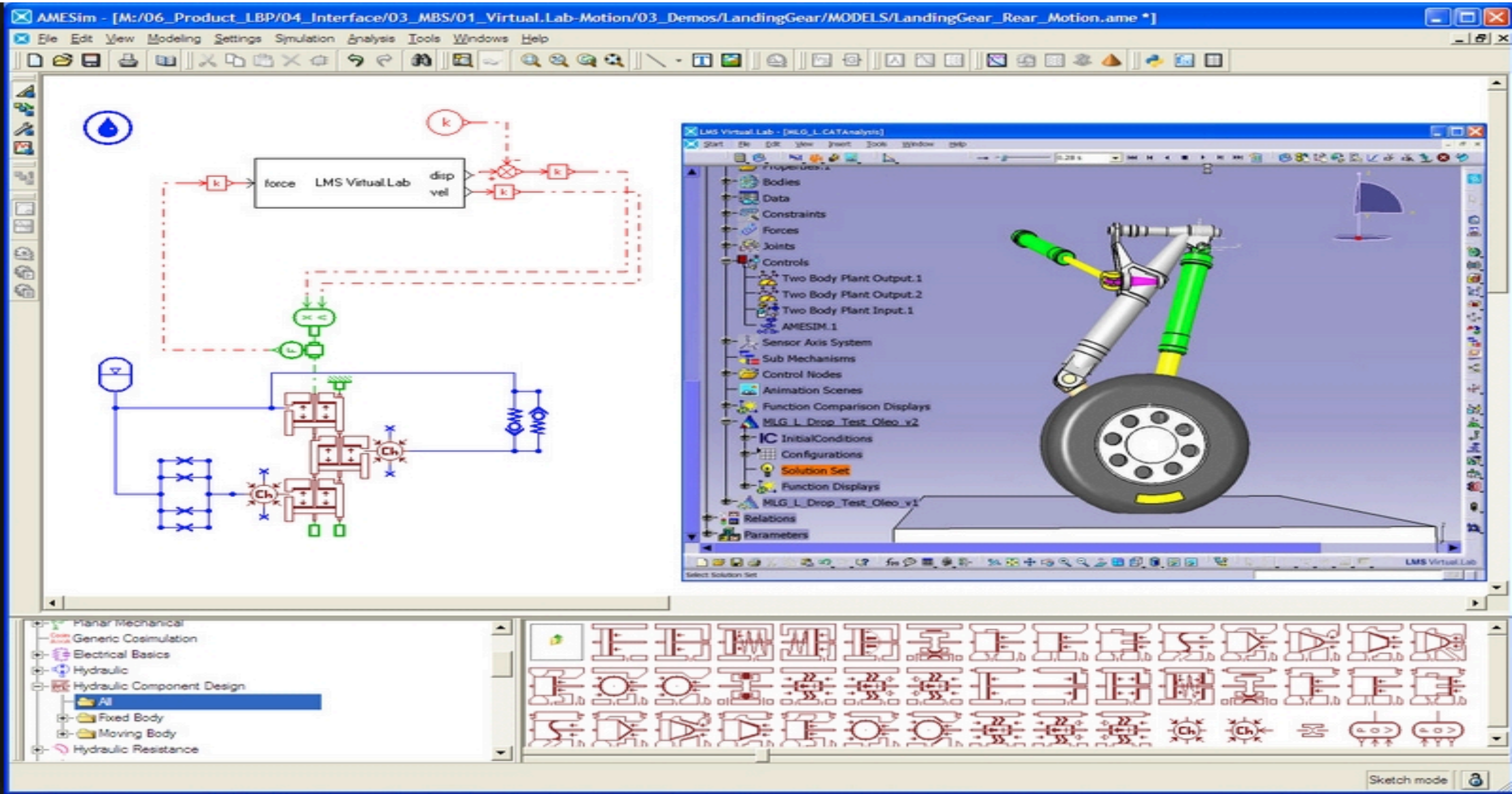
**Environment Models**
*Model terrain, atmosphere & space*



**Comms & Radar Models**
*Model RF propagation & interference*

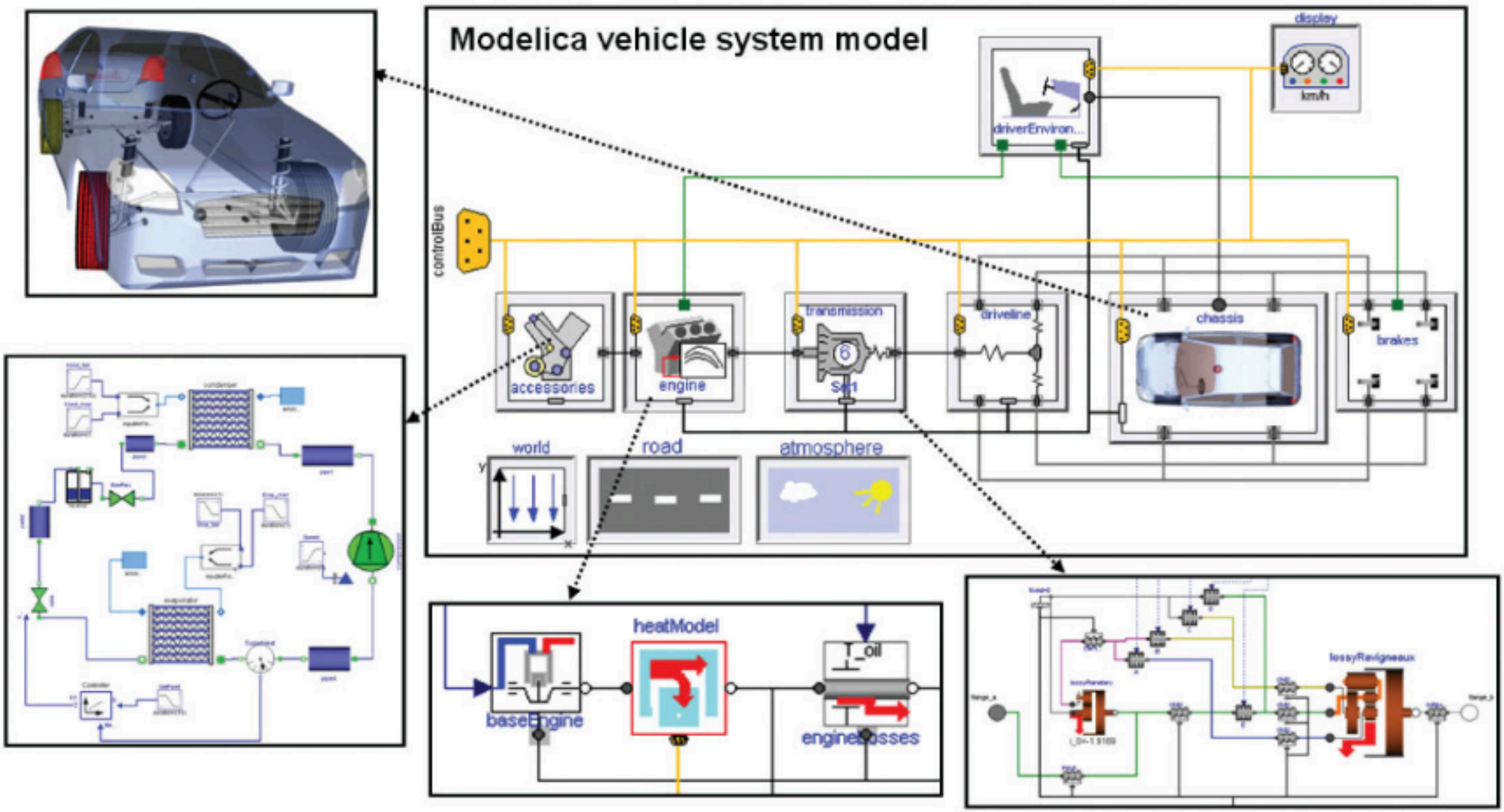
# 1D, 2D & 3D Models have Simulation and Analysis Capabilities

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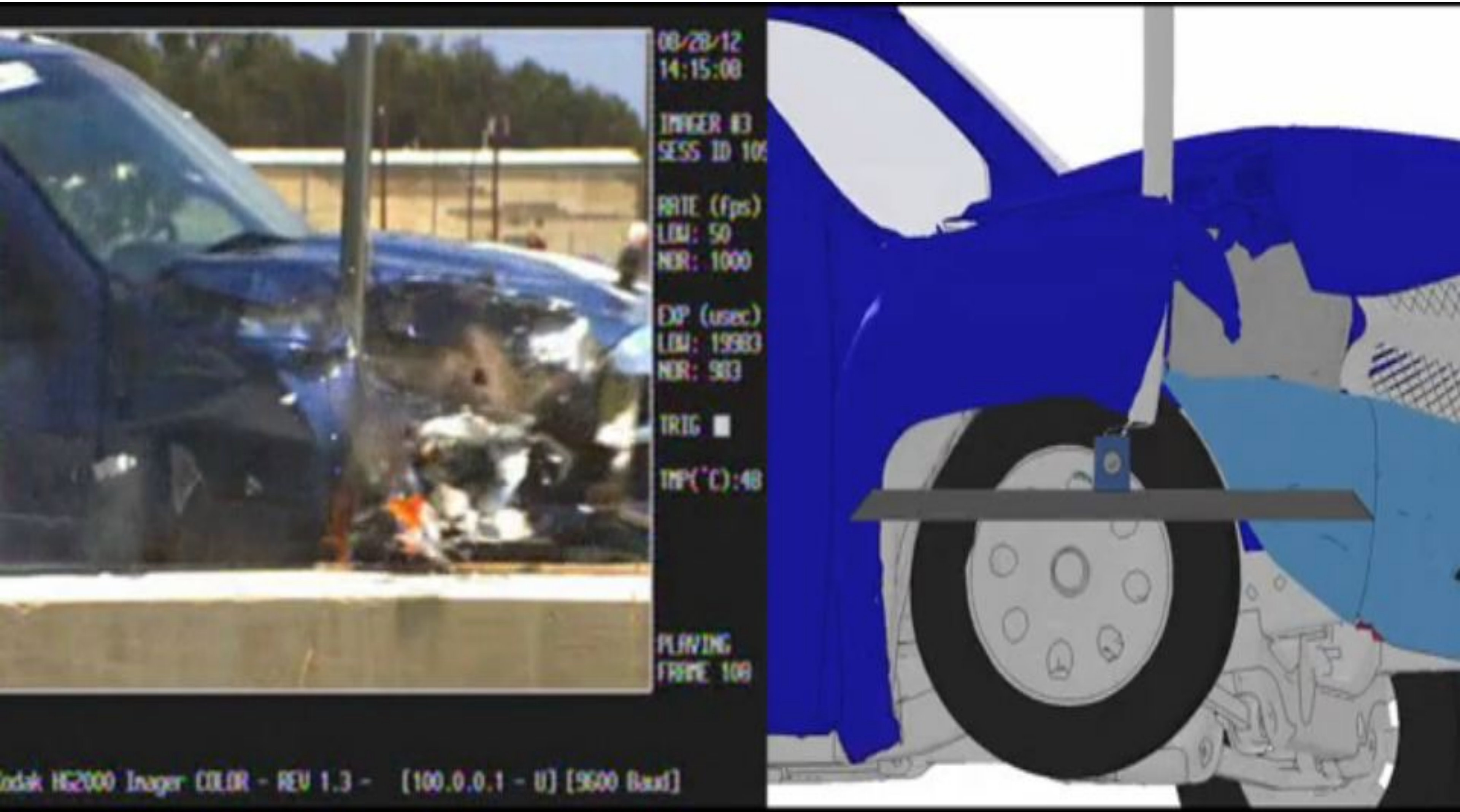
# Modeling and Simulation in the Automotive Domain is Reducing the Physical Crash Testing

- 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

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# 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
- Set-based design
- Modeling and simulation of manufacturing
- Model validation

Not exhaustive. . .

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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
  - NAVAIR has stated that they have made some progress in this area

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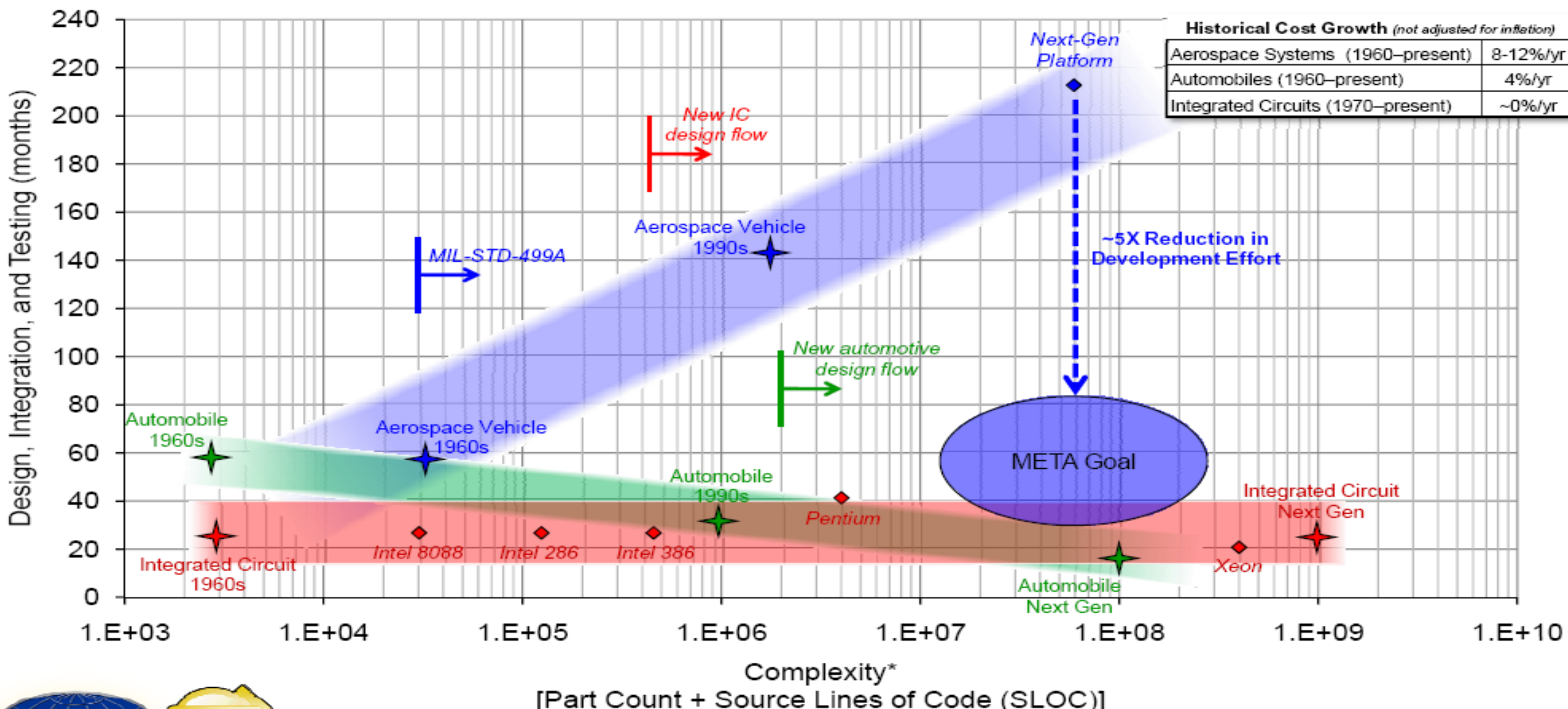
# Producing Software-intensive Systems of the Same Complexity as Hardware is Taking ~5x Longer

- 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

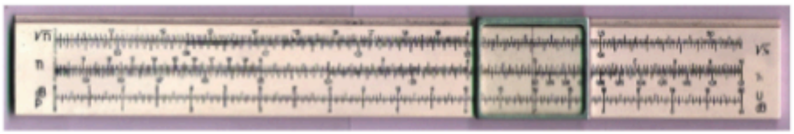



DARPA TTO

*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

*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~~ >9M
*LOC*


**6th Generation**
>90M
*LOC*

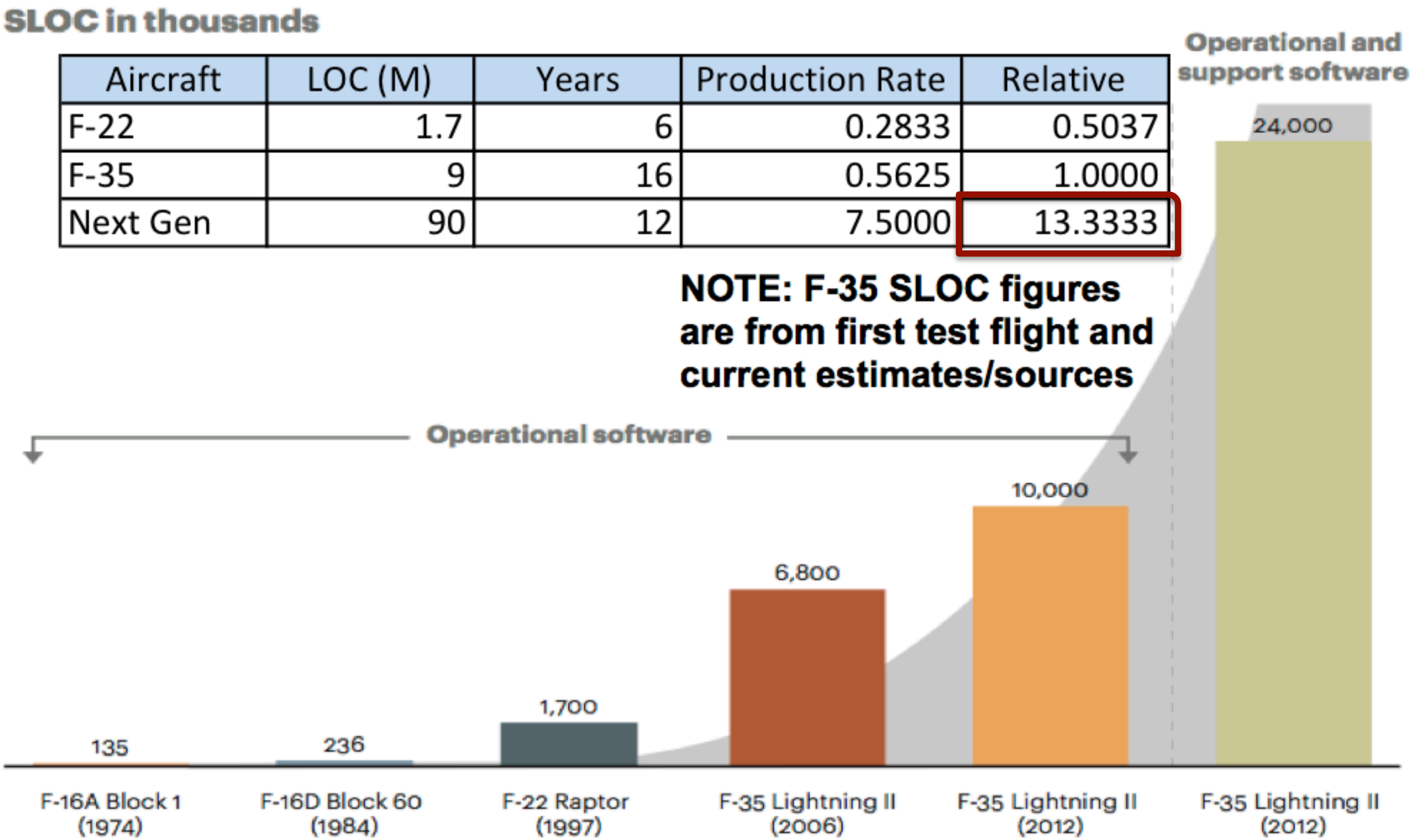
Image credit: Ken Nidiffer

# 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**

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# 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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# Conclusions

- 29 Discussions, 21 on site with Industry, Government and Academia – our summary is not exhaustive
- NAVAIR has adopted Model-centric over Model-based
- There are some gaps and challenges
  - Starting follow-ups to investigate some of the challenge areas more deeply

**How do we have a radical transformation in “how we work”**
**?**

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# 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.


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# 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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# Breakout Session Themes

- MODEL-CENTRIC PERSPECTIVE:
  - This group will view IMCSE from the model-centric perspective. Topics include how models are developed and maintained, how models are re-used, formalisms and platforms used, what forms models take, how models generate information, how models accept user inputs, how sensitivity analysis is performed, how information is displayed, how models are integrated with other models, potential role of theory versus data, how model-related information fosters trust and reuse, how models development is iterated, how models are bundled with validation information, how models are interoperable, and more.
- INTERACTIVE PERSPECTIVE:
  - This group will view IMCSE from the interactive perspective of the stakeholders (decision makers, analysts, system architects/engineers, involved design practitioners, end-users, etc.) who use models. Topics under human-model interaction include: explore a tradespace, input data into a model, query a model, use a model to make design choices or investment decisions, perceive of the interaction, perceive accuracy of a model, perceive whether a model works correctly, validate their decisions with models, avoid cognitive biases, develop trust in models, how stakeholders decide what models to use, and more.

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