Air Force Materiel Command

Developing, Fielding, and Sustaining America's Aerospace Force

How to Use Engineering Resilient Systems Technologies to Improve Defense Acquisition Processes

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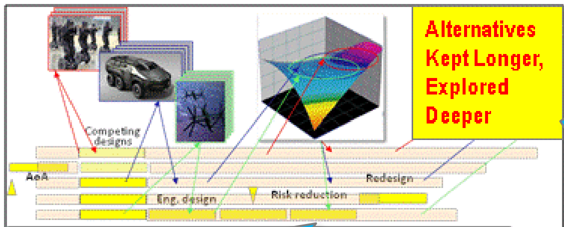
Defense Acquisition Challenges

- **Defense acquisition is already broken**
  1. **Systems Engineering – event driven vs effects based**
  2. **Requirements – not necessarily connected to physical and fiscal reality**
  3. **Complexity – aerospace/defense community self inflicted wound**
  4. **Capacity – "procurement holidays" increase cycle time**
- **Reduced budgets are a fact of life**
  - **Fewer acquisition new starts**
  - **Reduced infrastructure, reduced capacity**
- **Can Engineering Resilient Systems technologies be an enabler to overcome pending reductions and increase the quality and output of the US aerospace industry?**

ERS Key Technical Thrust Areas

Systems Representation and Modeling

– Physical, logical structure, behavior, interactions, interoperability…



Characterizing Changing Operational Contexts

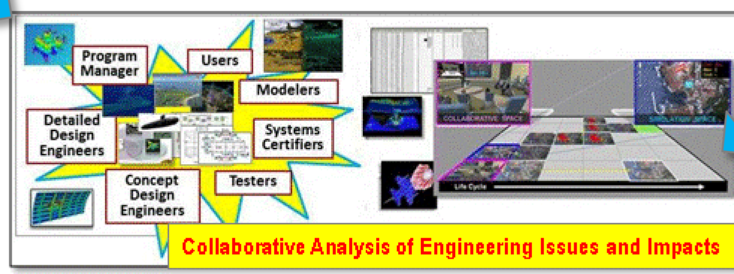
– Deep understanding of warfighter needs, impacts of alternative designs

Cross-Domain Coupling

– Model interchange & composition across scales, disciplines

Data-driven Tradespace Exploration and Analysis

– Multi-dimensional generation/evaluation of alternative designs



Collaborative Design and Decision Support

– Enabling well-informed, low-overhead discussion, analysis, and assessment among engineers and decision-makers

Correlating Key Technical Thrust Areas and Challenges to Defense Acquisition

	Effects Based Systems Engineering	Requirements	Complexity	Capacity
Systems Representation and Modeling	•Early assessment of TRL, MRL, IRL, RAM through integrated modeling and testing	•Probabilistic based analysis/design tools •Family of resilient designs •Resilient, robust AoA	•Probability based assessment of system uncertainty/risk for added complexity	•Increased throughput through integrated M&S/RDT&E processes •Reduction of late defects
Characterizing Changing Operational Contexts	•Assess resilient design space at critical systems engineering decision points	•Translation of operational scenarios to system requirements through coupled models	•Sensitivity of design space to changing operational complexity •Insensitive architectures	•Rapid engineering response to changing operational scenarios
Cross-Domain Coupling	•Subsystem optimization/integration for total system performance	•Integrated wargame, LVC simulators and physics based models •Interoperability assessment	•Assessment of subsystem design on integrated system of systems interoperability	•Reduced cycle time for subsystem integration •Early, continual assessment of reliability and suitability
Data-driven Tradespace Exploration and Analysis	•Quantified uncertainties at critical decision points •Programmatic "loss functions" tied to uncertainties	•AoA feasibility and affordability •Tradespace between achieving all KPPs and warfighter utility	•Impact of added complexity on RDT&E , manufacturing, and life cycle costs	•Minimum analog/digital data set to quantify margins and uncertainties over tradespace
Collaborative Design and Decision Support	•Interface between govt / industry analysis capabilities •Critical decision metrics	•Independent govt assessment of requirements and milestones achieved	•Decision space for increased complexity and impact on LCC, throughput, and O&S costs	•Management of models and data over life cycle – reuse in different programs

1. Systems Engineering Key Leverage Points
Marked by Events – Mired by Lack of Effectiveness

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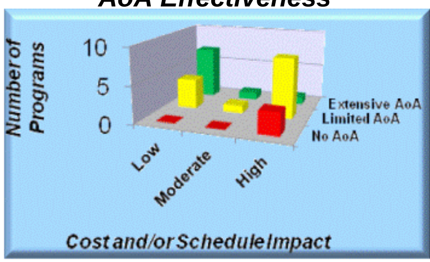
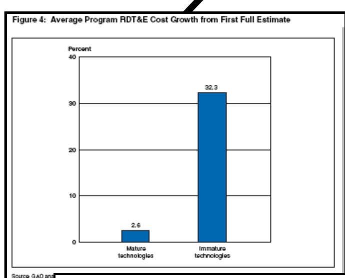
GAP	MDD	A	B	C	
Capability Based Planning (CBP)	Materiel Solution Analysis (MSA)	Technology Development (TD)	Engineering and Manufacturing Development (EMD)	Production and Deployment (P&D)	O&S

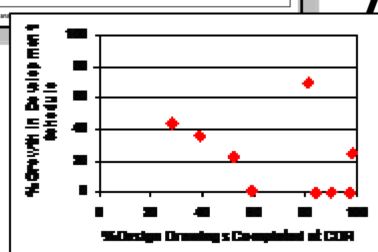
AoA Effectiveness



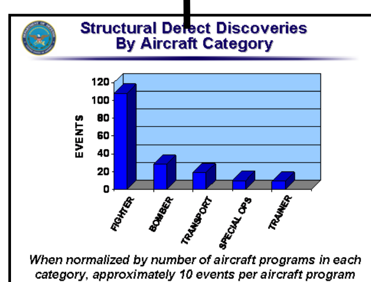
1. 75% LCC fixed @ MS A



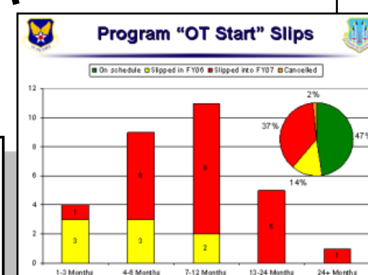
2. Technology Maturity @ MS B



3. Design Closure @ CDR

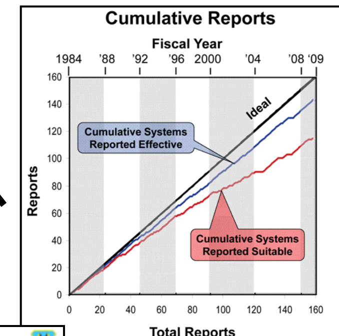


4. Late Defects



5. IOT&E Pause Test Rate

6. Suitability



CREATE-AV

(Computational Research Engineering Acquisition Tools Environment for Air Vehicles)

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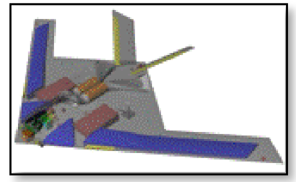
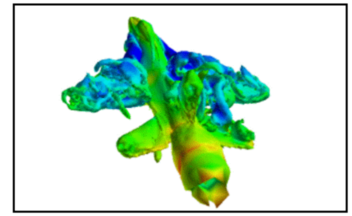
- **A rapidly maturing physics-based flight system modeling architecture enabled by large scale computing**
  - Development focused on impact to acquisition by embedded subject matter experts
  - Successfully delivering a family of products supporting activities from early trade studies to detailed engineering design
  - Using pilot studies to demonstrate ability to efficiently provide better physics-based design and analysis capabilities

DaVinci



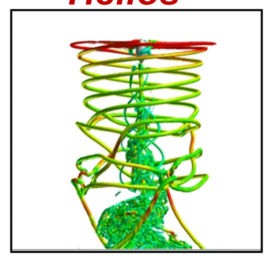
- Early engineering, design, and analysis

Kestrel



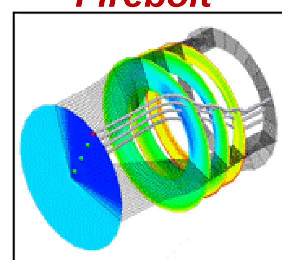
- High-fidelity, fixed wing flight system modeling

Helios



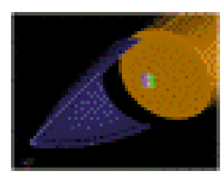
- High-fidelity, rotary wing flight system modeling

Firebolt



- Propulsion module integrated into Kestrel and Helios

Sentri



- CREATE-RF radio frequency modeling capability compatible with DaVinci

Characteristics of M&S Domains

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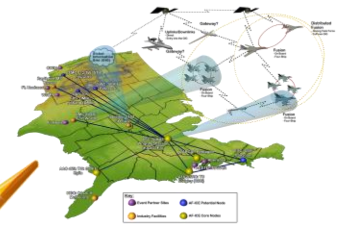
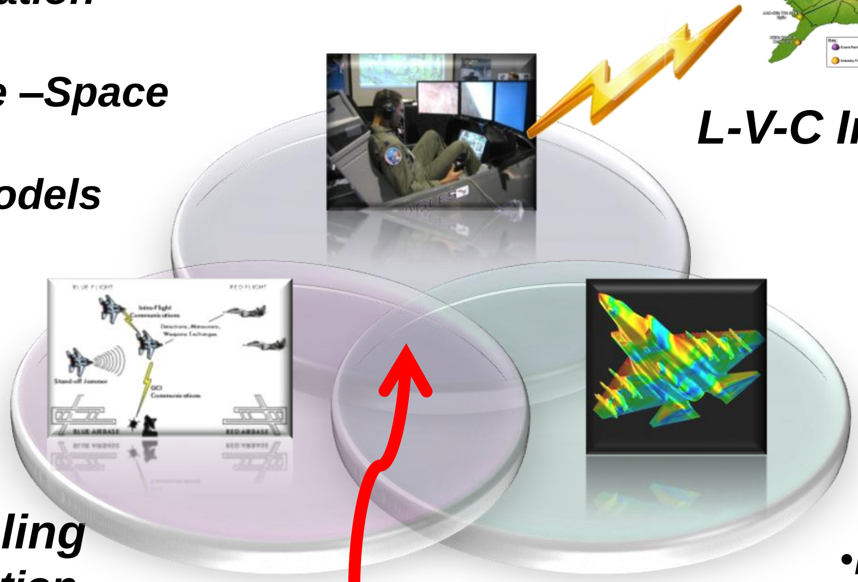
Comm Models



L-V-C Interface

Simulator

- *Discrete Event Simulation*
- *Real Time*
- *High Resolution Time –Space Visualization*
- *Event Engineering Models*
- *Table Look Ups*



Operational Modeling

- *Discrete Event Simulation, Agent Based Modeling*
- *< Real Time*
- *Scenario Visualization*
- *Event Engineering Models*
- *Table Look Ups*

Physics Modeling

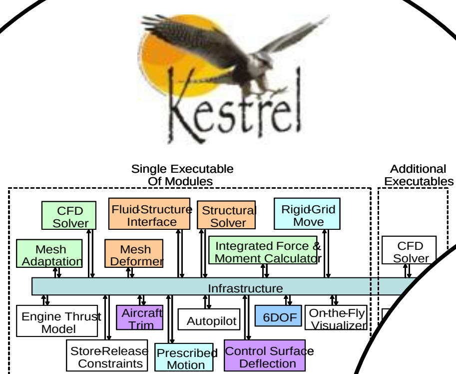
- *Discretized Physics*
- *> Real Time*
- *Phenomena Visualization*

Common Interface Built on Reducing Physics Models to Light Weight Algebraic Relations Using High Performance Computing

Recent Breakthrough
CREATE-AV

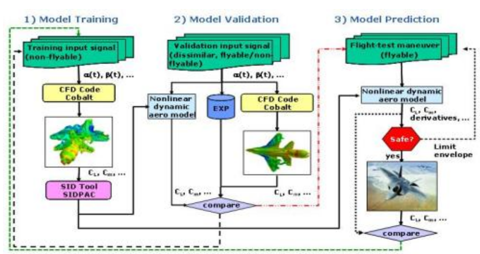
Game Changing Engineering Process Improvement that creates lightweight algebraic models from hi-fi simulations

Scalable to 1000's of processors



High Performance Computing

System Identification



Modular architecture for multi-discipline, multi-fidelity physics modeling – not a one size fits all CSE model

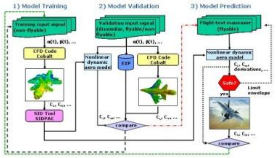
Interchangeable analog and digital inputs

Conceptual Design
- Early discovery of nonlinear aerodynamic issues
- Nonlinear aero surface loads for conceptual structural design
- Nonlinear aero loads for flight control law development

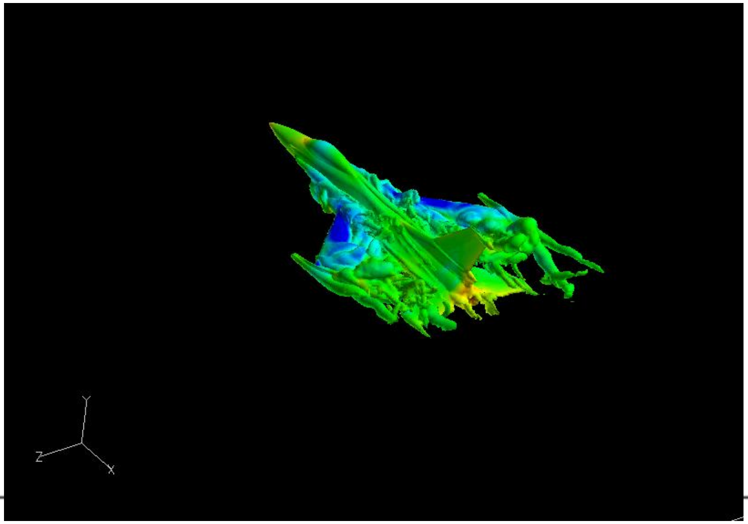
Detailed Design
- Evaluation of aerodynamics from outer mold line (OML) changes
- Updated nonlinear aerodynamic surface loads for changed OML to evaluate structural design
- Nonlinear loads for flight control law refinement with detailed control surfaces

Flight Test
- Pre-flight maneuvers planned for test with any store loadout
- Eliminate benign flight tests

System Identification Model Building



Example Game Changing Process

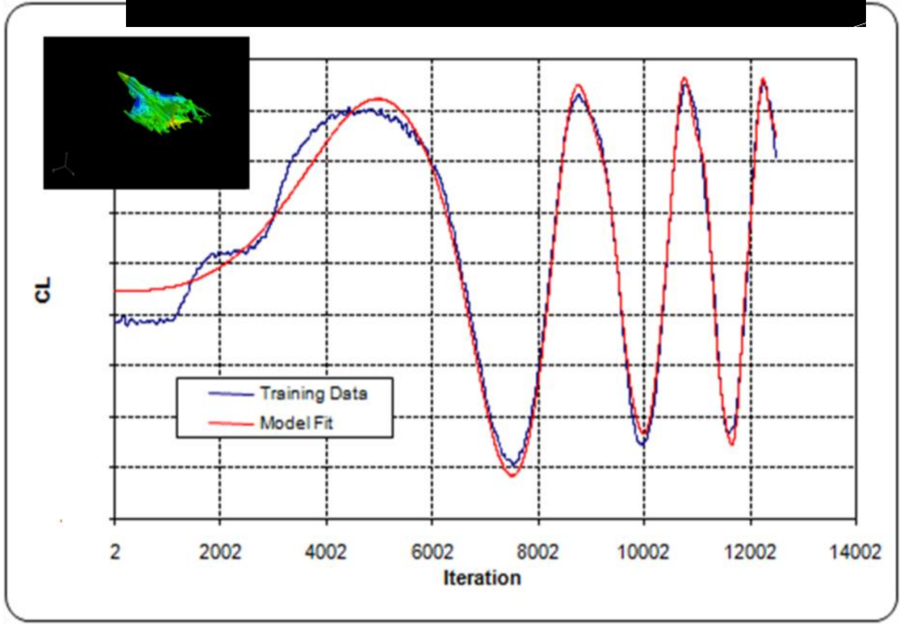


- Compute a maneuver at a particular flight condition (only need OML)
- Knowing input angles, rates and output loads, allows an algebraic model to fit to the data

$$C_L(\alpha, q, \dot{q}) = C_0 + C_1\alpha + C_2 q + C_3 q^2\alpha + C_4\dot{q}\alpha + C_5 q^4 + C_6\dot{q}q^2 + C_7 q\alpha^2$$

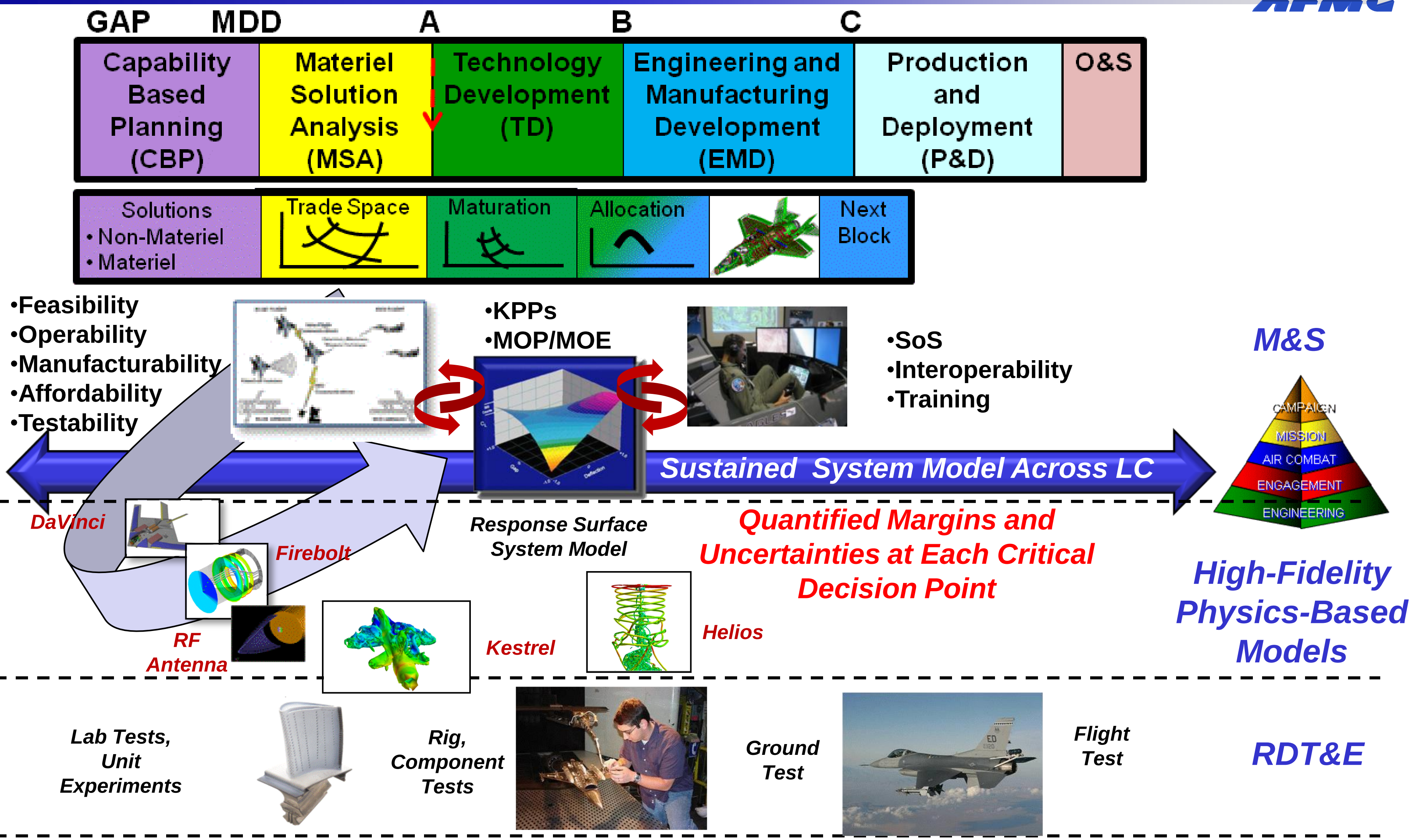
$$+ C_8\dot{q}q + C_9\alpha^3 + C_{10}\dot{q} + C_{11}\dot{q}^3 + C_{12}\dot{q}^2 + C_{13}q^2 + C_{14}q\alpha$$

- Sys ID model gives dynamic behavior for ANY maneuver inside the regressor space AND static lift curve slope
  before a wind tunnel or flight test article exists



Effects Based Systems Engineering

Integrating M&S, RDT&E, and Statistical Engineering



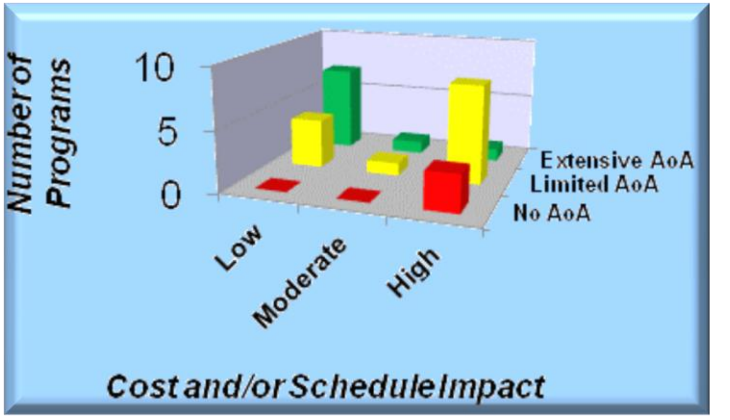
Underpinned with Statistical Engineering to Quantify Margins and Risks at Key Decision Points

2. Requirements Setting
Cost of Inadequate Analysis of Alternatives

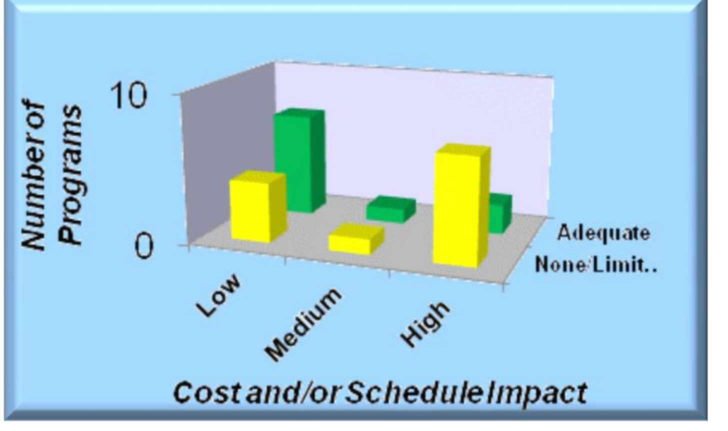
- GAO* concluded that the majority of AoA's evaluated did not sufficiently inform the business case for starting new programs.
- AoA should provide the basis for a solid, executable business case before committing resources to a new system development;
  - Warfighter needs are valid and can be best met with chosen concept
  - The chosen concept can be developed and produced within existing resources (proven technologies, design knowledge, adequate funding, and adequate schedule)
- Narrow scope and limited risk analysis in AoA's attributed in part to:
  1. Choosing a solution too early in the process
  2. Compressed timeframes for conducting an AoA
  3. Lack of guidance for conducting an AoA including to what extent to perform a risk analysis

Can ERS positively impact acquisition by providing resilient and robust trade study capabilities, tools to expedite the AoA processes, and a framework for consistent and comprehensive risk assessment?

Scope of AoA Analyses Impact On Cost and Schedule



Quality of AoA Risk Assessment Impact On Cost and Schedule



**Source:GAO-09-665 "Many Analysis of Alternatives Have Not Provided a Robust Assessment of Weapon System Options", September, 2009*

Objectives for an ERS Demonstration

Through application to a flight system of interest, demonstrate the use of ERS concepts and enabling tools can improve the Pre-Milestone A Analysis of Alternatives process by:

1. ***Identifying and maintaining a broader range of feasible solutions* using high-performance computing and scalable, multi-discipline, physics-based models to efficiently and rapidly provide a data-driven resilient trade space for exploration and analysis of alternative materiel solutions**
2. ***Accelerating the analysis time* by connecting physics-based models through surrogate response surfaces with operational and functional models to dynamically evaluate alternative materiel concepts against requirements**
3. ***Performing a structured assessment of cost, schedule, and performance risk* using probability based design methods to statistically connect concept feasibility with performance and affordability**

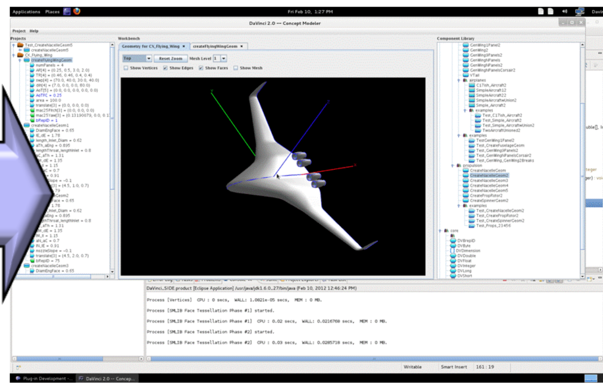
ERS C-X Pilot Demonstration

Use the CREATE-AV DaVinci modeling capability as the scalable multi-physics based design tool to efficiently explore a resilient design space using the associated design variables,

DESIGN VARIABLES

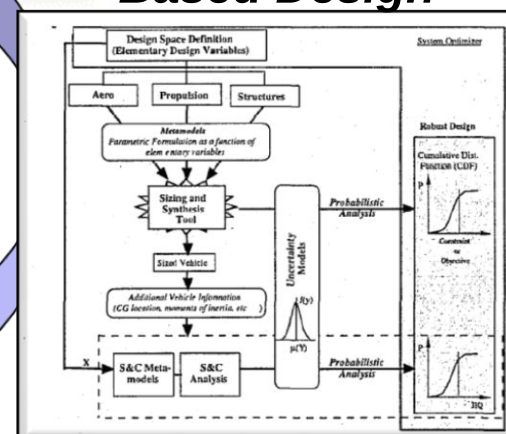
- *Size*
- *Planform*
- *Component layout*
- *Aspect ratio*
- *Propulsion system*
- *Materials*
- *et*

DaVinci



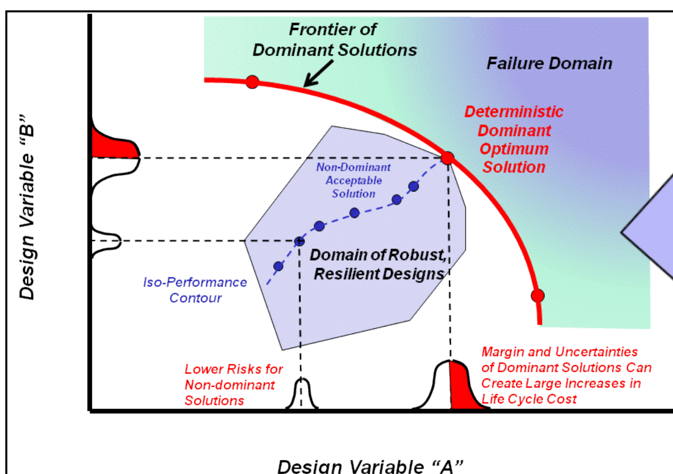
High Performance Computing

Probability Based Design



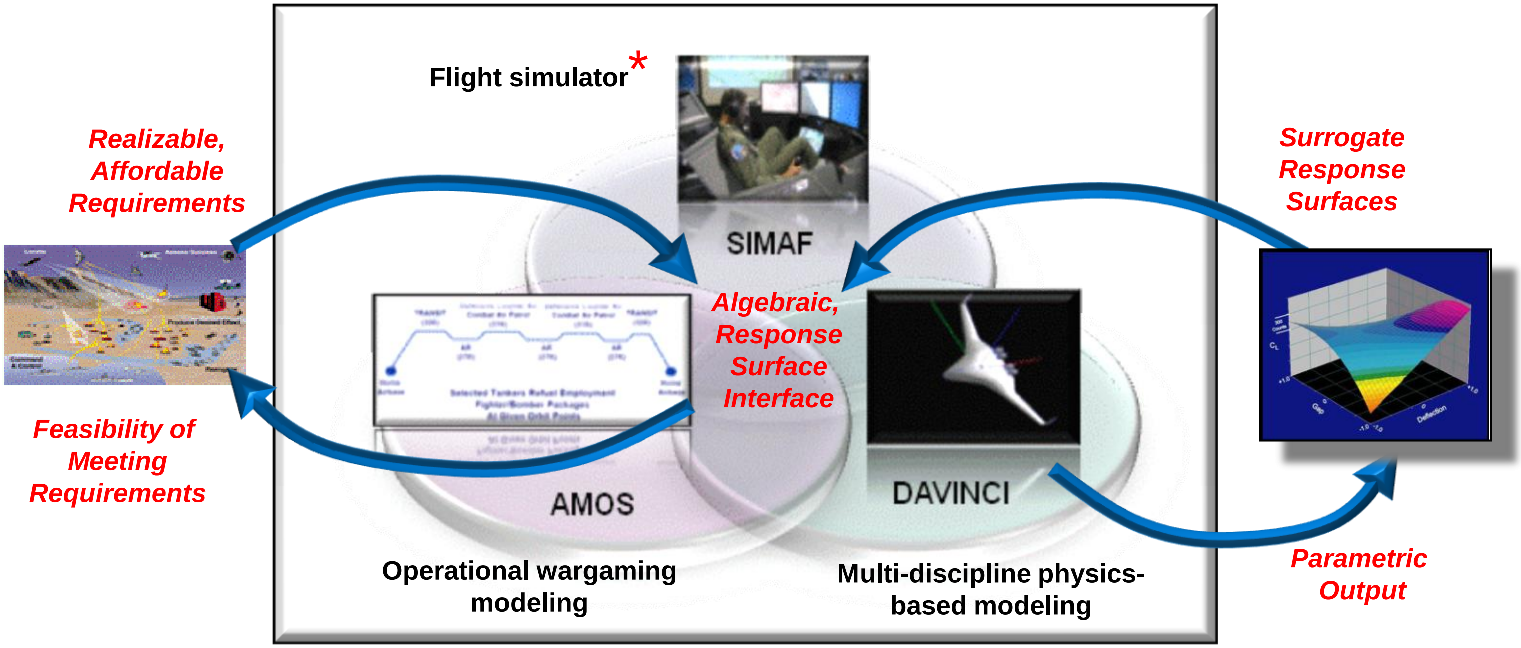
Includes probability of achieving performance goals

Resilient Design Space



ERS C-X Pilot Demonstration (continued)

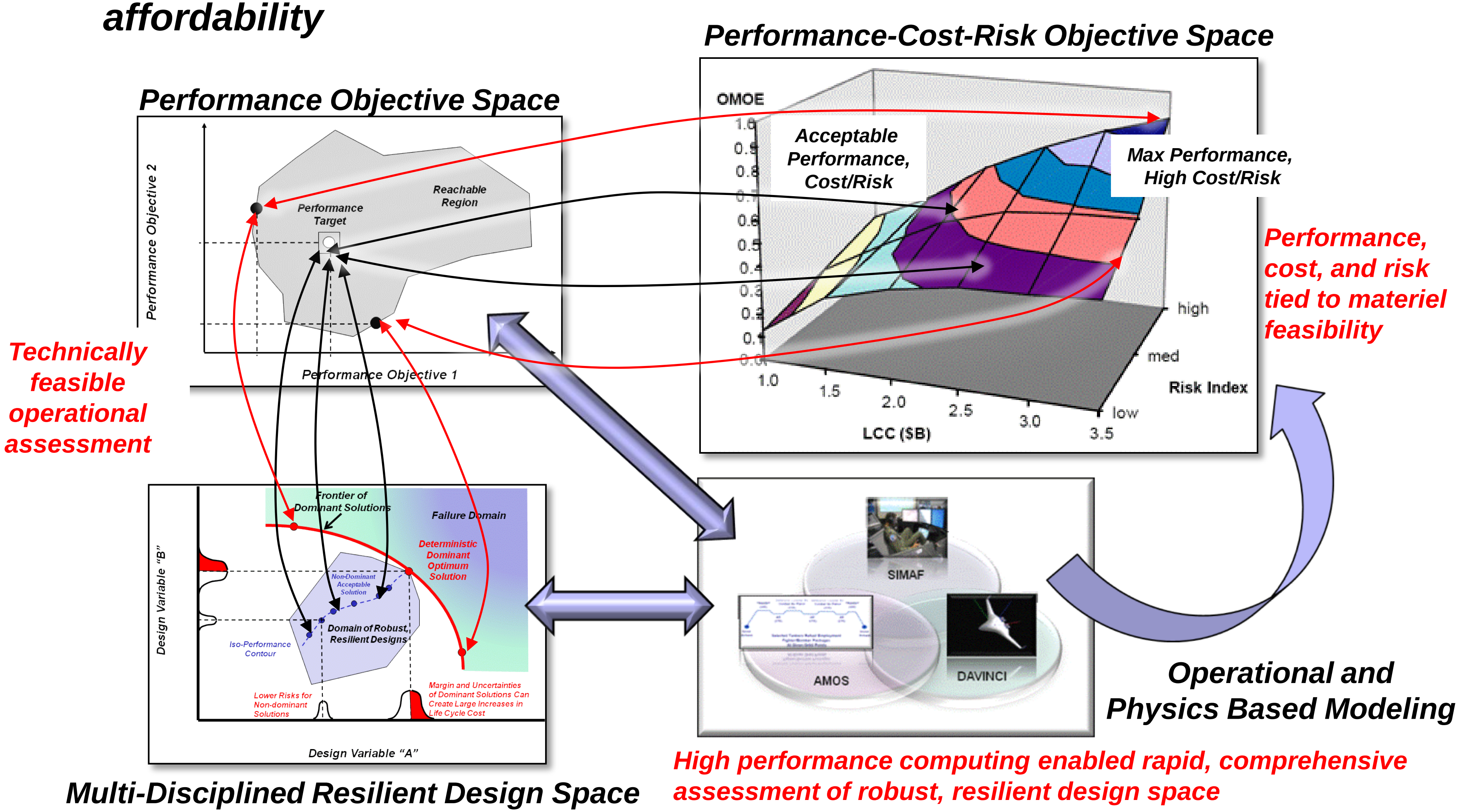
Demonstrate that the DaVinci model output can be accurately represented by a surrogate response surface and injected into engagement models to show an iterative ability to adjust scenarios and requirements to physical feasibility



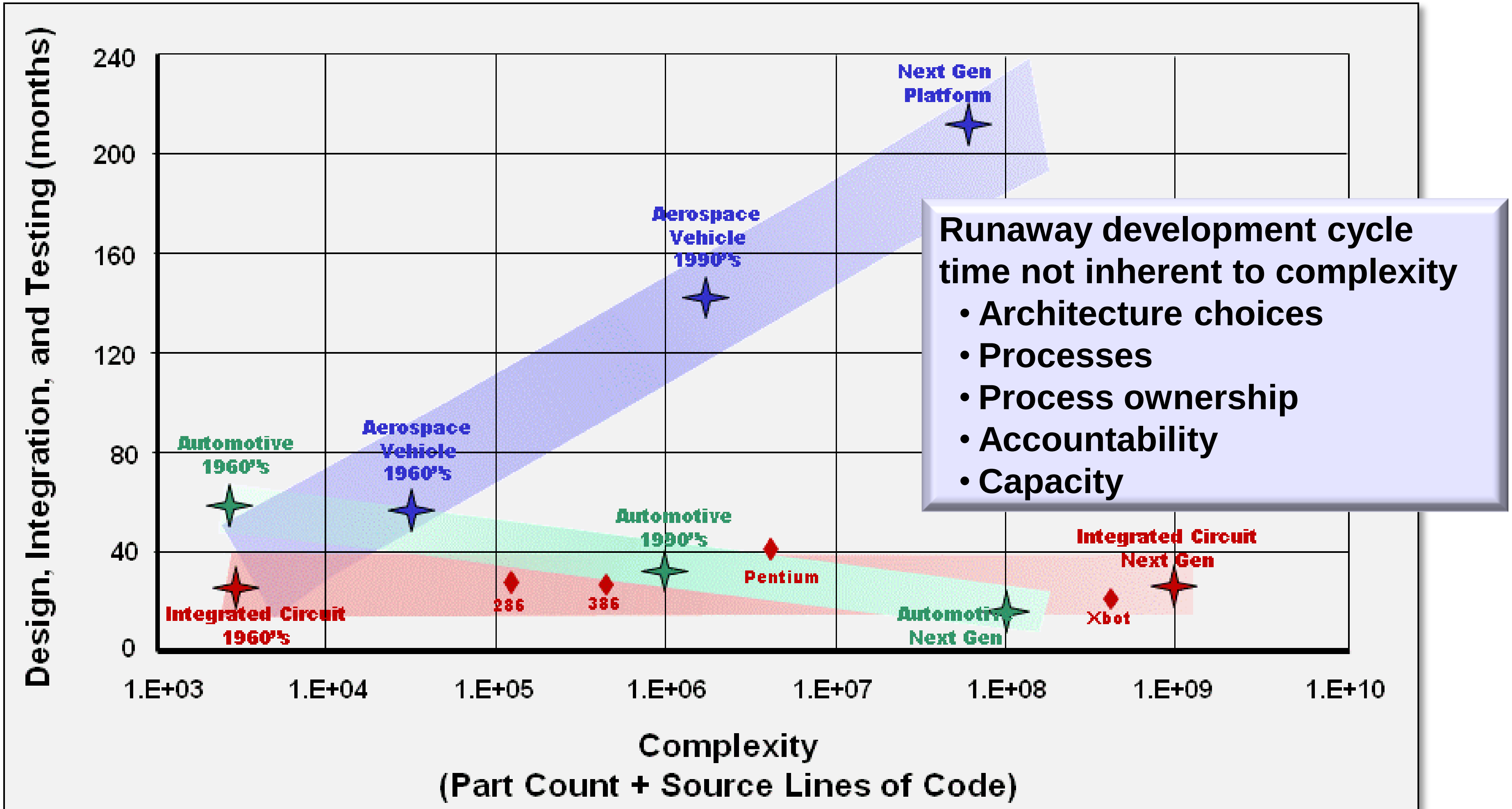
* Future potential demonstration using the same surrogate response surface model to interface with flight simulators in a distributed mission operation to assess interoperability of alternative concepts.

ERS C-X Pilot Demonstration (continued)

Perform a structured assessment of cost, schedule, and performance risk using probability based design methods to statistically connect operational requirements and concept feasibility with performance and affordability



3. Complexity



Source: Dr. Kirstie L. Bellman **Making DARPA META Goals Come True: How do we Revolutionize Verification and Validation for Complex Systems?** S5 2010, WPAFB, June 17, 2010

Complicated or Complex?

Different Domains Require Different Design, Integration and Testing Approaches

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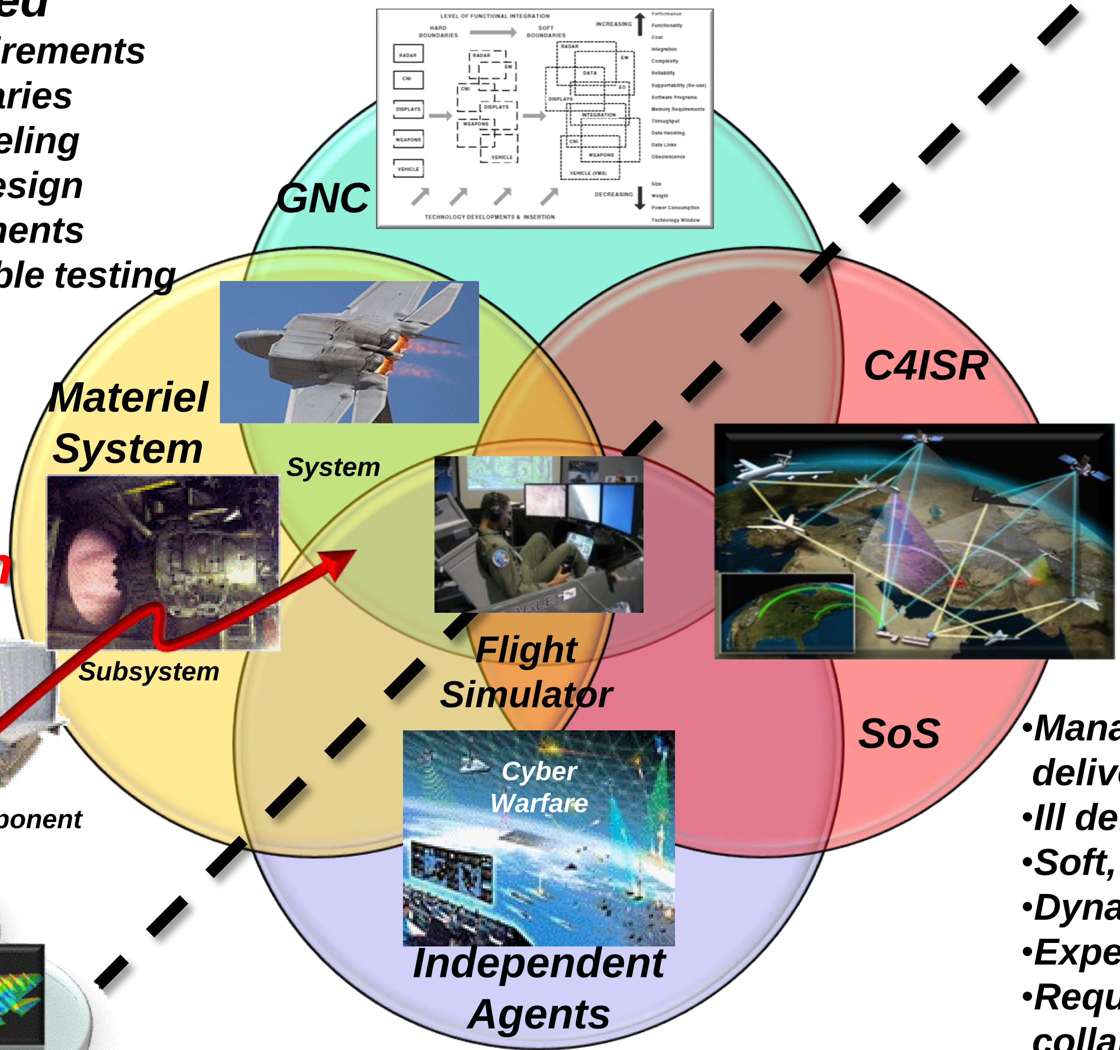
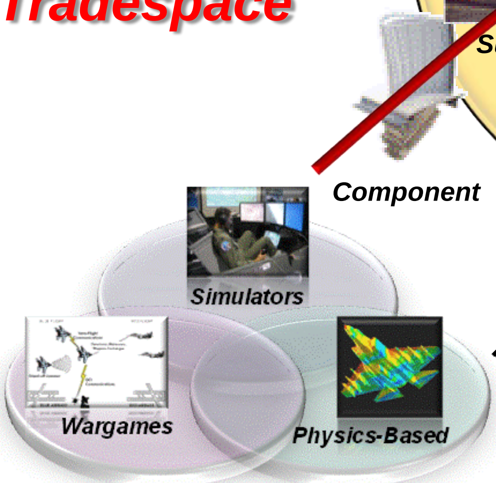
Complicated

- Design, test to requirements
- Well defined boundaries
- Physics-based modeling
- Probability based design
- Precision measurements
- Statistically defensible testing
- Regression testing

Bring Complex Scenarios into Resilient Design Tradespace





Complex

- Manage outcomes vs delivering requirements
- Ill defined boundaries
- Soft, stochastic modeling
- Dynamic environment
- Experiential learning
- Requires holistic, collaborative approach
- Future built on scenarios not predictions

4. Reduction in Capacity
Unless We Do Something Different

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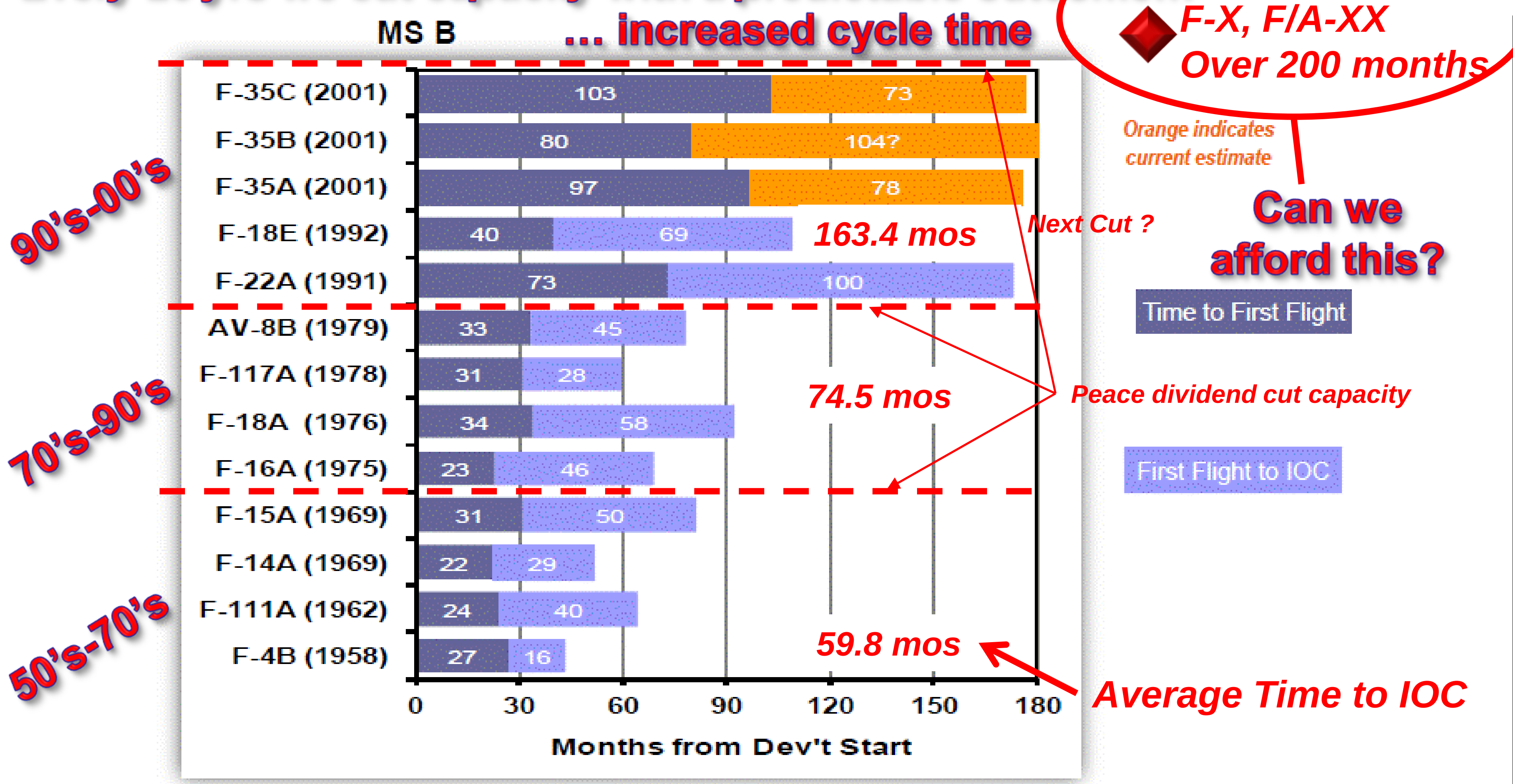
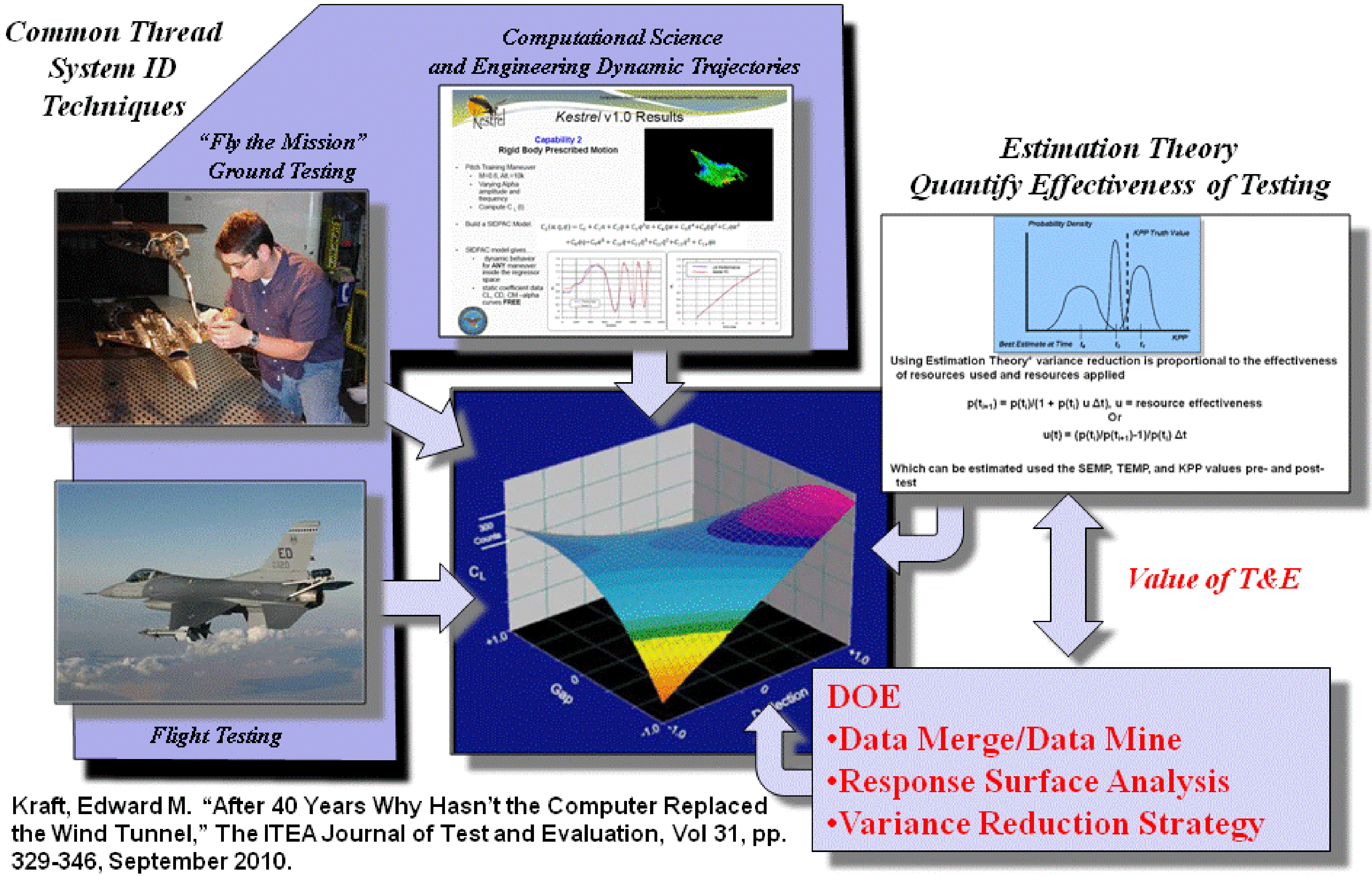
Every 20 yrs we cut capacity with a predictable outcome…



Complex Systems + Reduced Capacity/Capability → Long Development Cycle

Reducing Workload/Increasing Capacity
Streamlining Testing at the Campaign Level
New T&E Tools + DOE



Kraft, Edward M. "After 40 Years Why Hasn't the Computer Replaced the Wind Tunnel," The ITEA Journal of Test and Evaluation, Vol 31, pp. 329-346, September 2010.

Keys to ERS Success

- Development of ERS technologies and tools necessary but not sufficient
- Requires integration of tools/technologies into changing processes
  - Critical processes
  - Govt / industry roles
  - Inertia of legacy processes
- Need to develop Use Case for application of ERS technologies/tools to change processes
  - Identify stakeholders, process owners
  - Clarify as-is
  - Demonstrate to-be with ERS tools/technologies identifying who, what, how, why