U.S. Air Force

Integrity - Service - Excellence

Expanding the Digital Thread to Impact Total Ownership Cost

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AEDC/CZ

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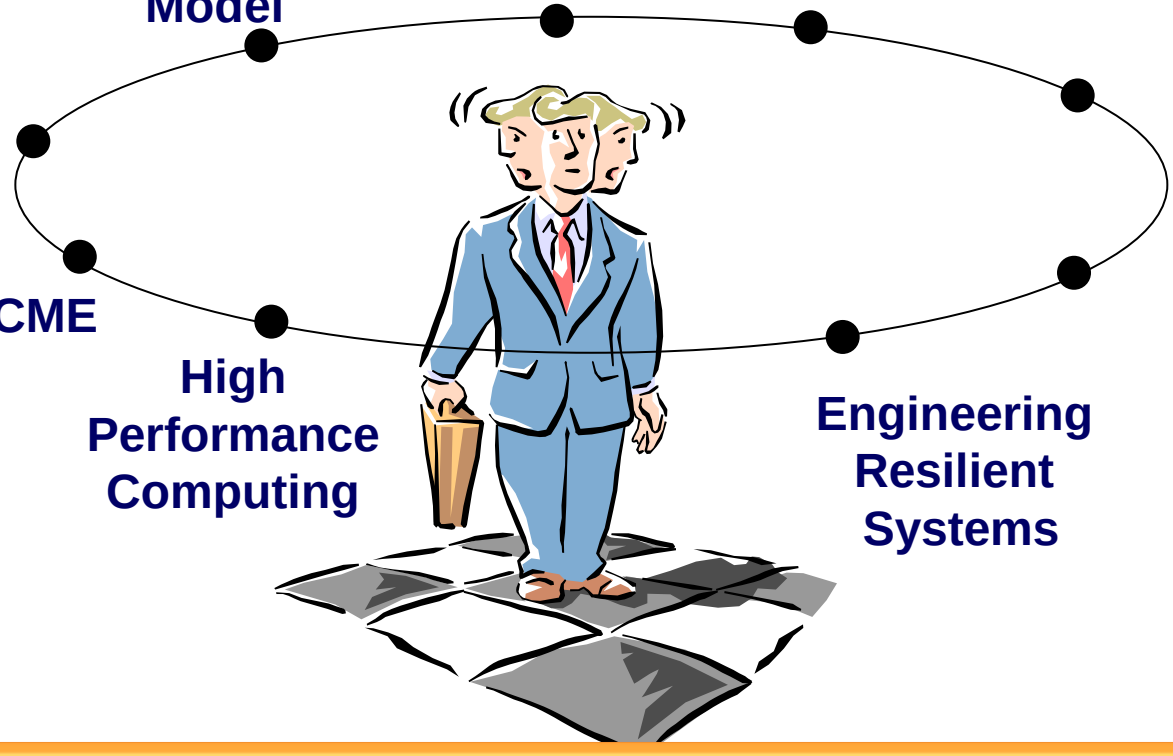
Objectives

- Put the Digital Thread (DT) Concept into context with multiple ongoing activities
- Introduce the vision for the DT to impact the total life cycle of systems
- Highlight initial DT pilot efforts

What Are We Talking About?



These are interdependent activities focused on the same outcome - improved acquisition and sustainment

Putting the Activities in Perspective

Acquisition community can better support Agile Acquisition by leveraging advances in physics-based modeling to reduce development cycle time/costs

More "Tails on the Ramp"

Agile Acquisition
Outcome Focused Development, Deployment, and Sustainment of Warfighting Capability

Better Discipline

AF Engineering Revitalization
Governance, Roles/Responsibilities
Engineering Decisions
Technical Rigor
Engineering Workforce

Engineering Knowledge Management
Collaborative Environment and Repository for Engineering Knowledge in Support of Life Cycle

Streamlined Processes

Digital Thread / OSD System Model
Instantiation of Model Based Engineering Over the Entire Life Cycle of a System

Better Tools

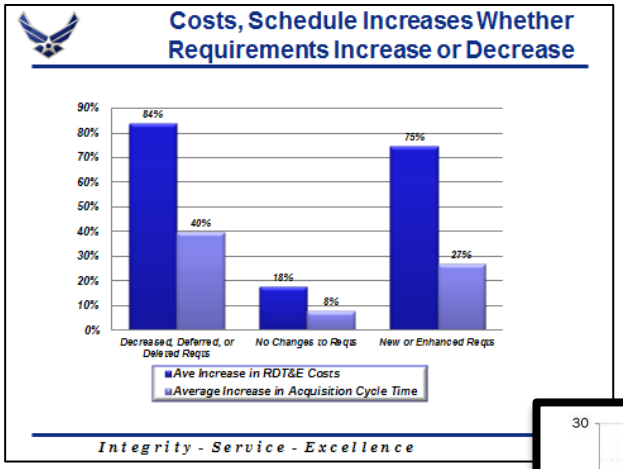
Engineering Resilient Systems
Collaborative, Cross-Domain, Model-Based Technologies

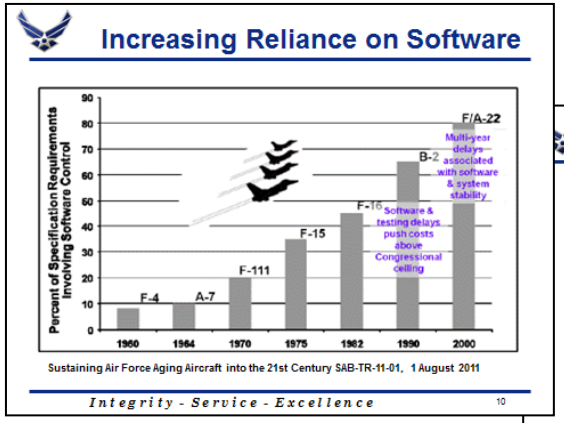
HPC, MBE, CREATE, ICME, Statistical Engineering
Enabling Technologies

Initiatives Underway

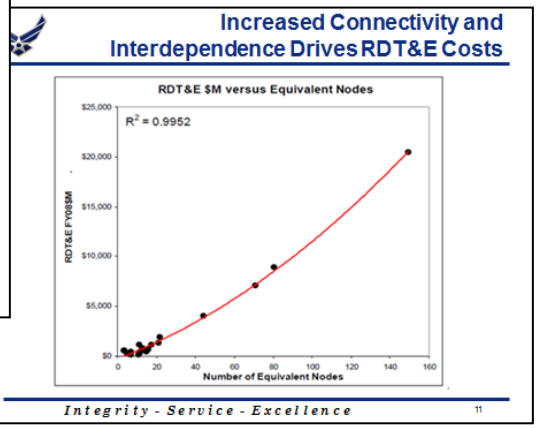
Burning Platform
Unsustainable Increases in Cycle Time/Costs

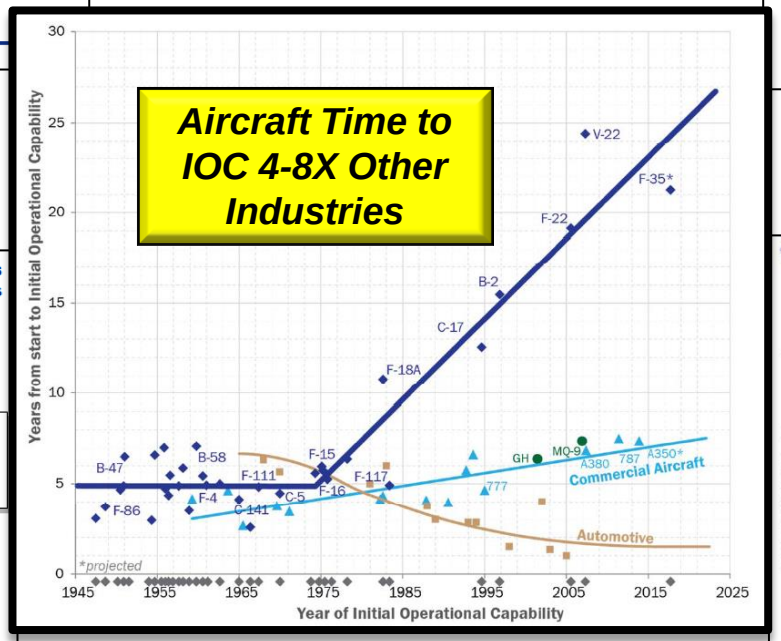
Requirements



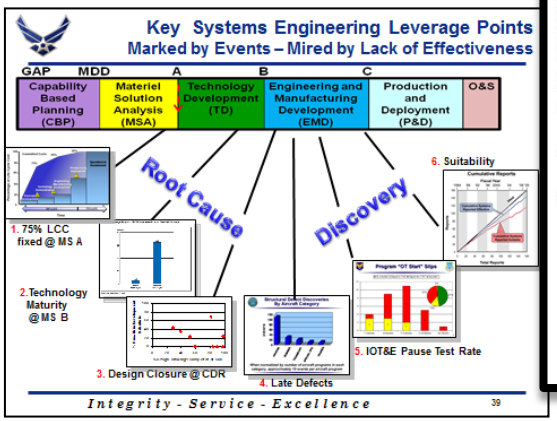


Complexity

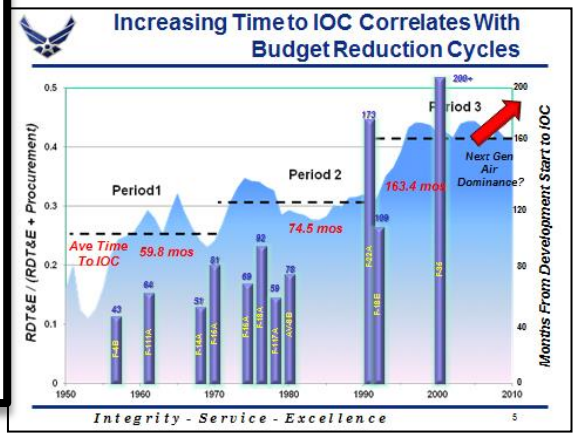




Event Driven SE



Capacity

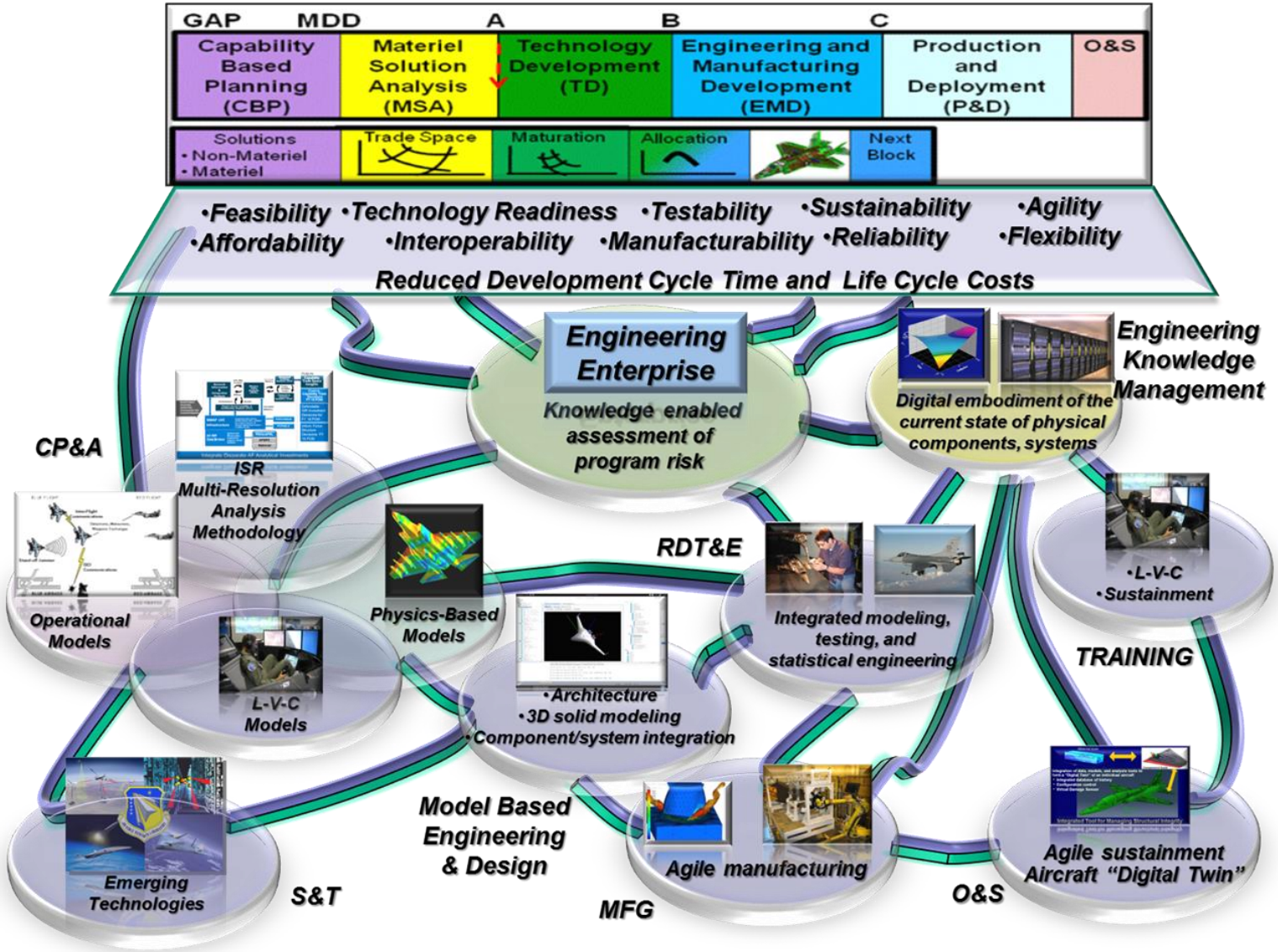


What is a Digital Thread? (Current Working Definition)

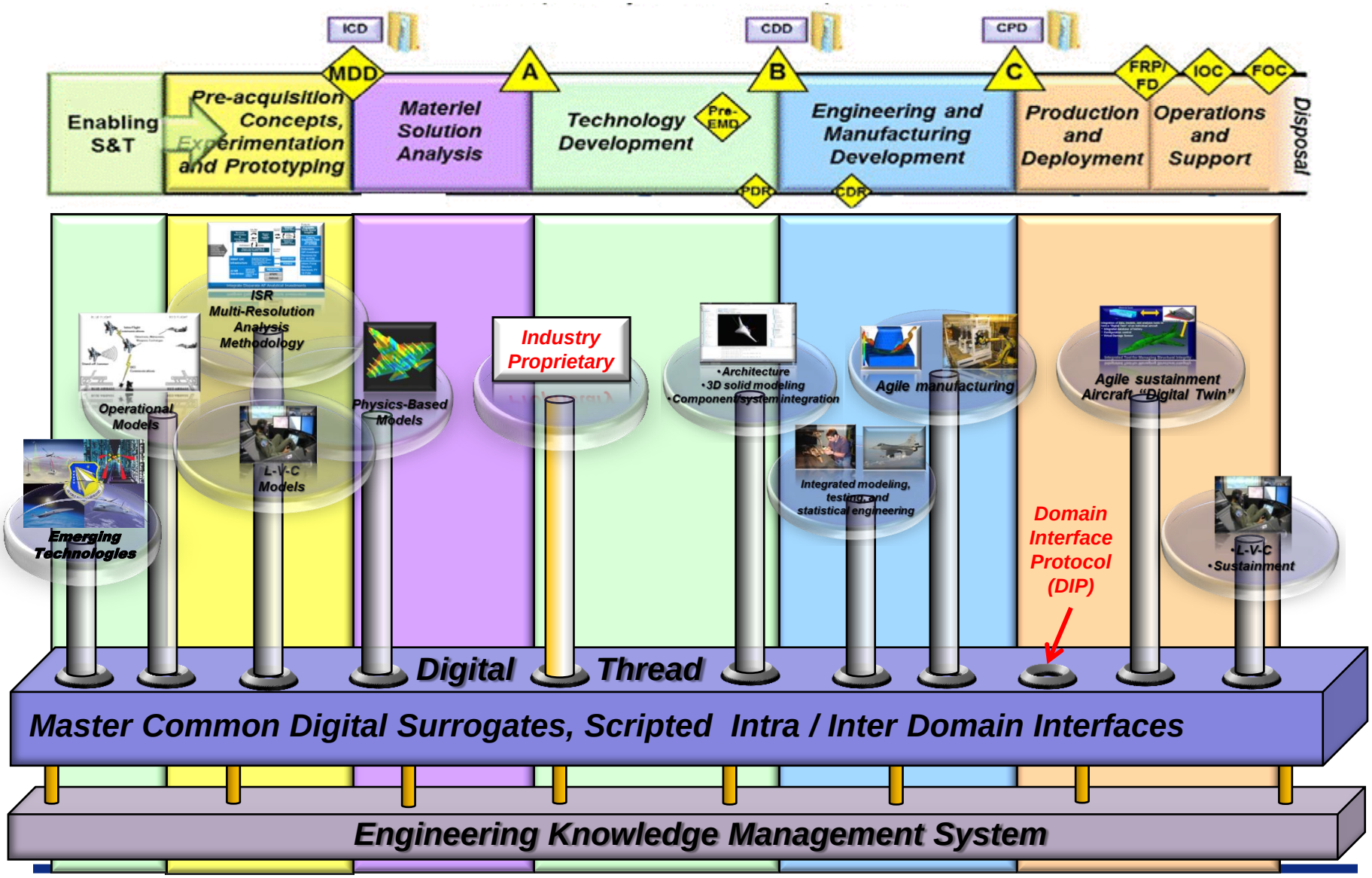
Digital Thread is the creation and use of cross-domain, common digital surrogates of a materiel system to allow dynamic, contemporaneous assessment of the system's current and future capabilities to inform decisions in the Capability Planning and Analysis, Preliminary Design, Detailed Design, Manufacturing, Testing, and Sustainment acquisition phases. The digital surrogate is a physics-based technical description of the weapon system resulting from the generation, management, and application of data, models, and information from authoritative sources across the system's life cycle.

The Digital Thread Puts Engineering Back Into Systems Engineering

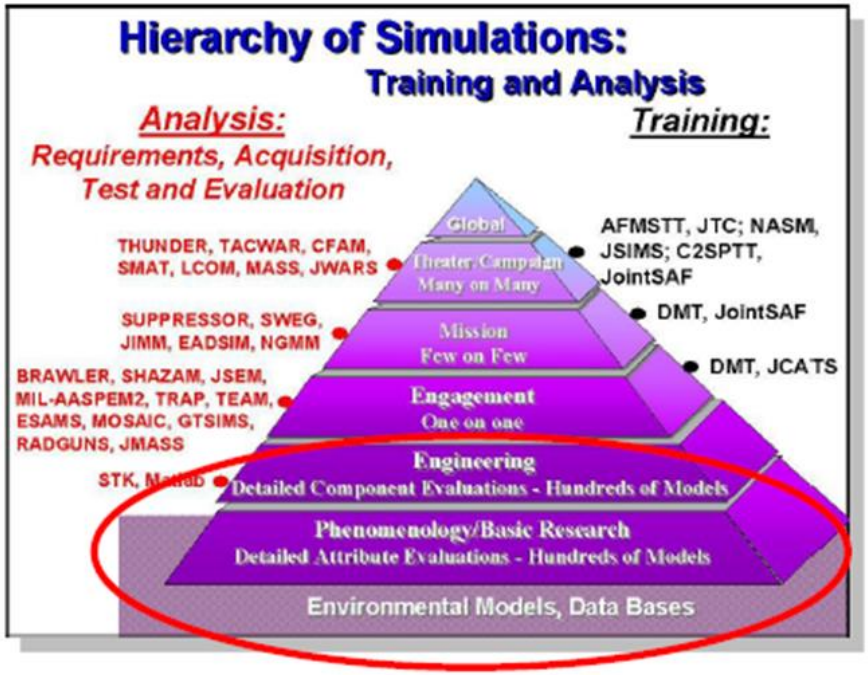
Digital Thread OV-1



Notional Digital Thread Architecture



Why Now? What's Different?



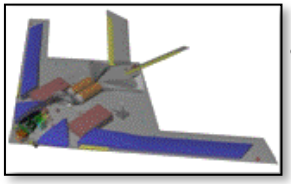
High-fidelity, physics-based models
The untapped M&S capability

- **The Digital Thread provides the analytical framework for organizing output from high-fidelity, physics-based models across the entire life cycle**
- **Representation of results from multiple disparate physics-based models transferrable through digital surrogate response surfaces**
- **Rapid advances in High Performance Computing enable high-resolution simulations of complex systems practical and efficient**

We don't have to organize 100's of physics-base engineering models, just establish format and protocols for digital surrogate representations of the output from specialized models for each application domain

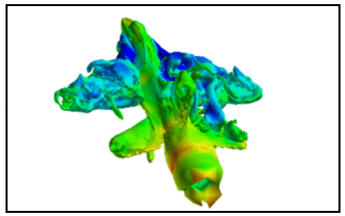
CREATE-AV
(Computational Research Engineering Acquisition Tools Environment for Air Vehicles)

DaVinci



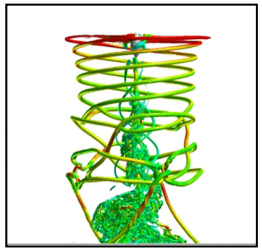
- Early engineering, design, and analysis

Kestrel



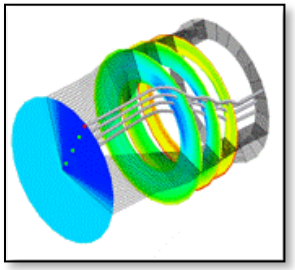
- High-fidelity, fixed wing flight system modeling

Helios



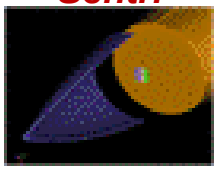
- High-fidelity, rotary wing flight system modeling

Firebolt



- Propulsion module integrated into Kestrel and Helios

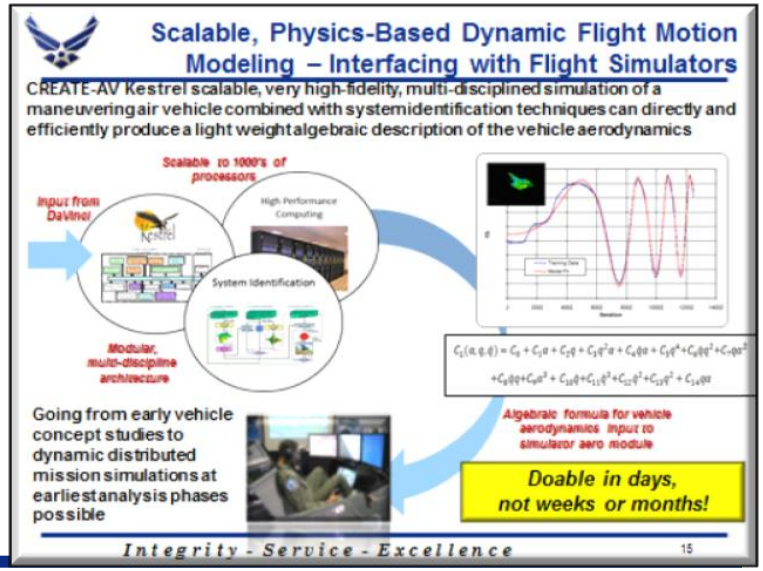
Sentri



- CREATE-RF radio frequency modeling capability compatible with DaVinci

- **A rapidly maturing physics-based flight system *modeling architecture* enabled by large scale computing**
- ***Scalable* to take advantage of HPC advances**
- ***Requirements* established by assessing 27 *acquisition and sustainment processes***
- **Embedded capability to *efficiently generate digital surrogate response surfaces***

Already over 250 Users Across the DoD; Industry Investigating



The Digital Thread and the OSD System Model

OSD System Model (Chapt 4 Defense Acquisition Guidebook)

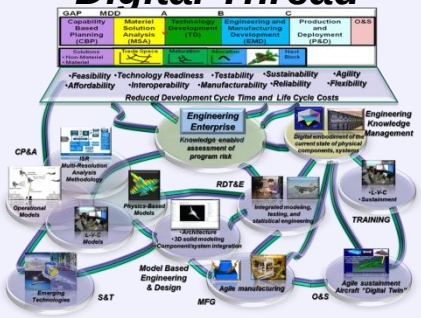
ISSUE: **Current DoD acquisition activities do not develop, or maintain a single, integrated authority/artifact (aka system model) for a TBD subset of program data. Further, relevant data between acquisition activities is not adequately shared.**

VISION: **Use of a single model (aka system model) as an evolving, cohesive representation and unifying instantiation of the program under conceptualization, development, manufacture, and/or support: will increase efficiency of DoD system acquisition lifecycle activities, and increase confidence in decisions made regarding an acquisition program when the single (system) model (data) for that program is used.**

METHOD**: A system model will be instantiated by using artifacts and processes which already exist, or are already required by DoD acquisition policies, guidance, and best practices.**

OUTCOME: **The system model will be used by anyone performing activities related to the program as it evolves across the acquisition lifecycle, including but not limited to defining requirements, trading design aspects, designing, engineering, cost budgeting, staffing, manufacturing, fielding, training, sustaining, and disposing. The resultant system model will integrate program data into a complete description of the system.**

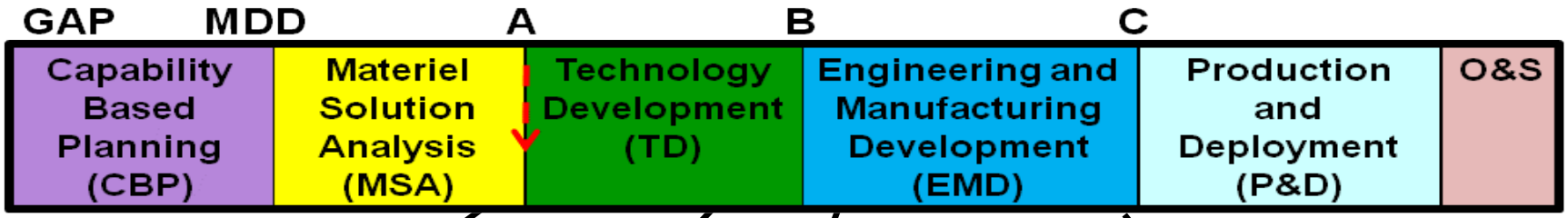
Digital Thread



Digital Thread is the creation and use of cross-domain, common digital surrogates of a materiel system to allow dynamic, contemporaneous assessment of the system's current and future capabilities to inform decisions in the Capability Planning and Analysis, Preliminary Design, Detailed Design, Manufacturing, Testing, Training, and Sustainment phases. The digital surrogate is a physics-based technical description of the weapon system resulting from the generation, management, and application of data, models, and information from authoritative sources across the system's life cycle.

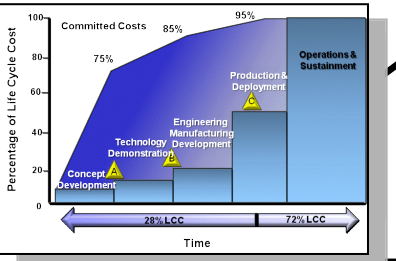
The Digital Thread is the physics-based modeling instantiation of the OSD System Model designed to meet acquisition decision maker information needs

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

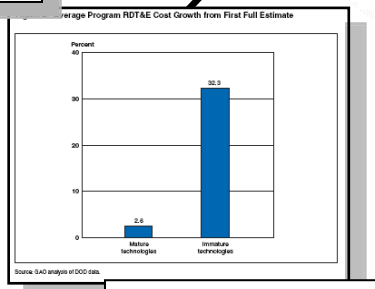


Root Cause

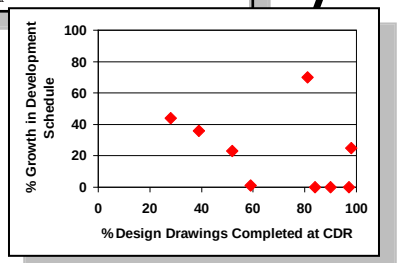
Discovery



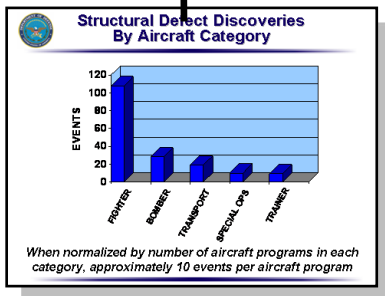
1. 75% LCC fixed @ MS A



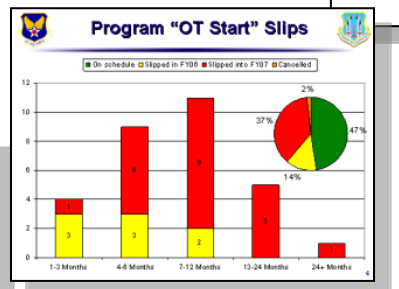
2. Technology Maturity @ MS B



3. Design Closure @ CDR

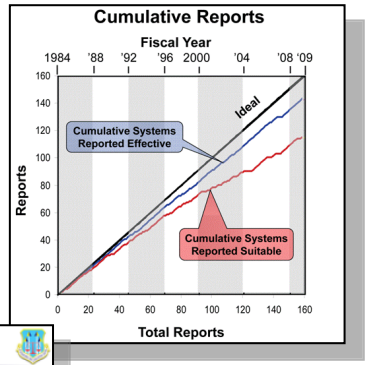


4. Late Defects



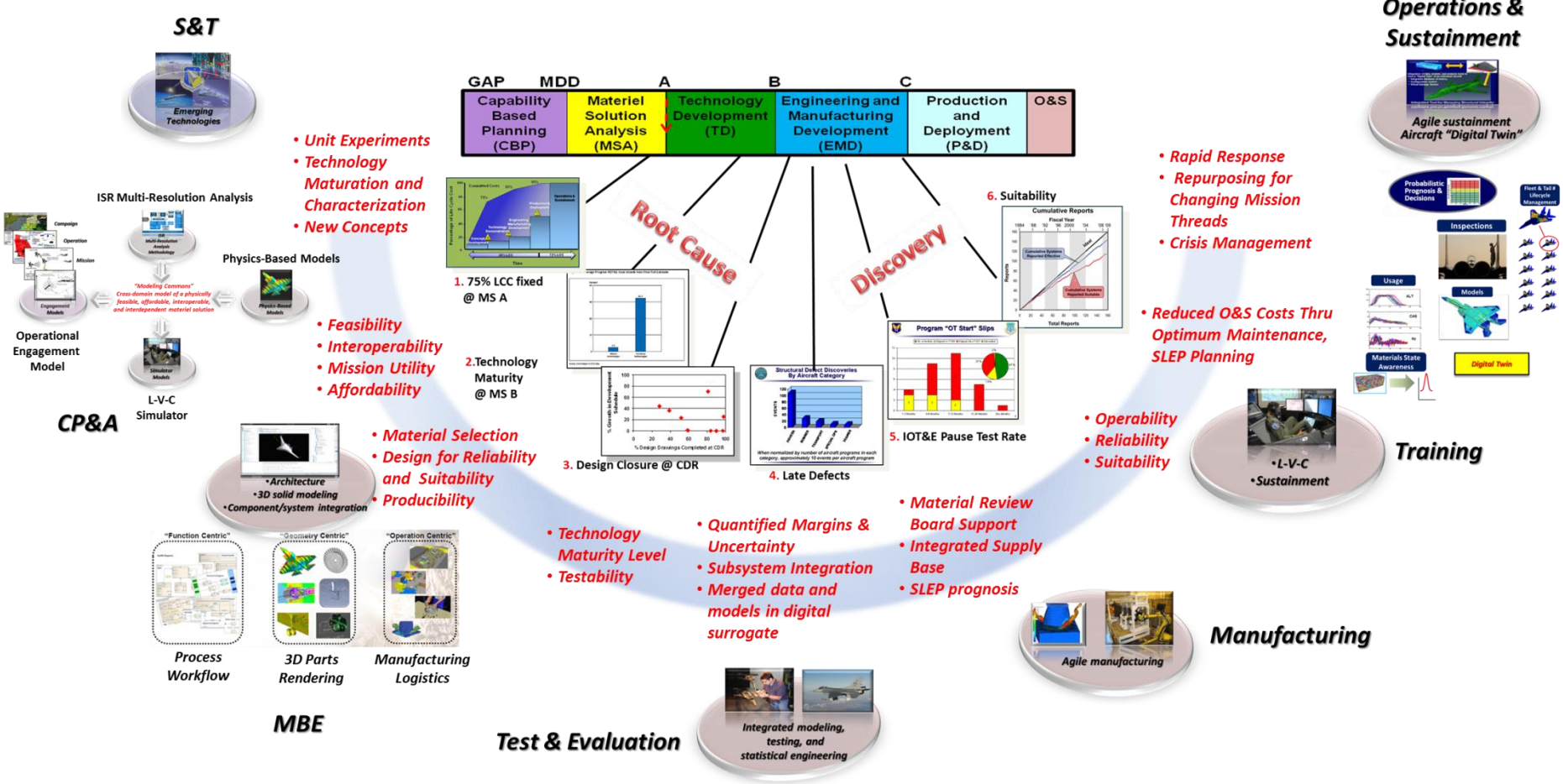
5. IOT&E Pause Test Rate

6. Suitability



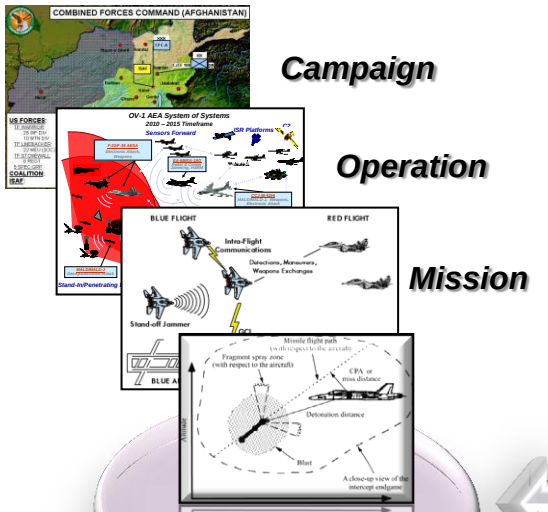
Digital Thread Instantiation of Decision Support

A Continuum of Authoritative Digital Surrogate Representations Leveraged Over the Entire Life Cycle



Creating a "Modeling Commons" for Capability Planning &Analysis – 1st Step to the Digital Thread

Disparate skills, models, and communities



Campaign

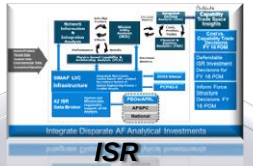
Operation

Mission

Engagement Models

Operational Modeling

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



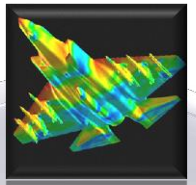
ISR Multi-Resolution Analysis Methodology

ISR MRA

- *ISR modeling*
- *System of Systems*
- *DOT_PLF*
- *Networks*
- *Cyber interface*

Physics Modeling

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



Physics-Based Models

"Modeling Commons" Cross-domain model of a physically feasible, affordable, interoperable, and interdependent materiel solution

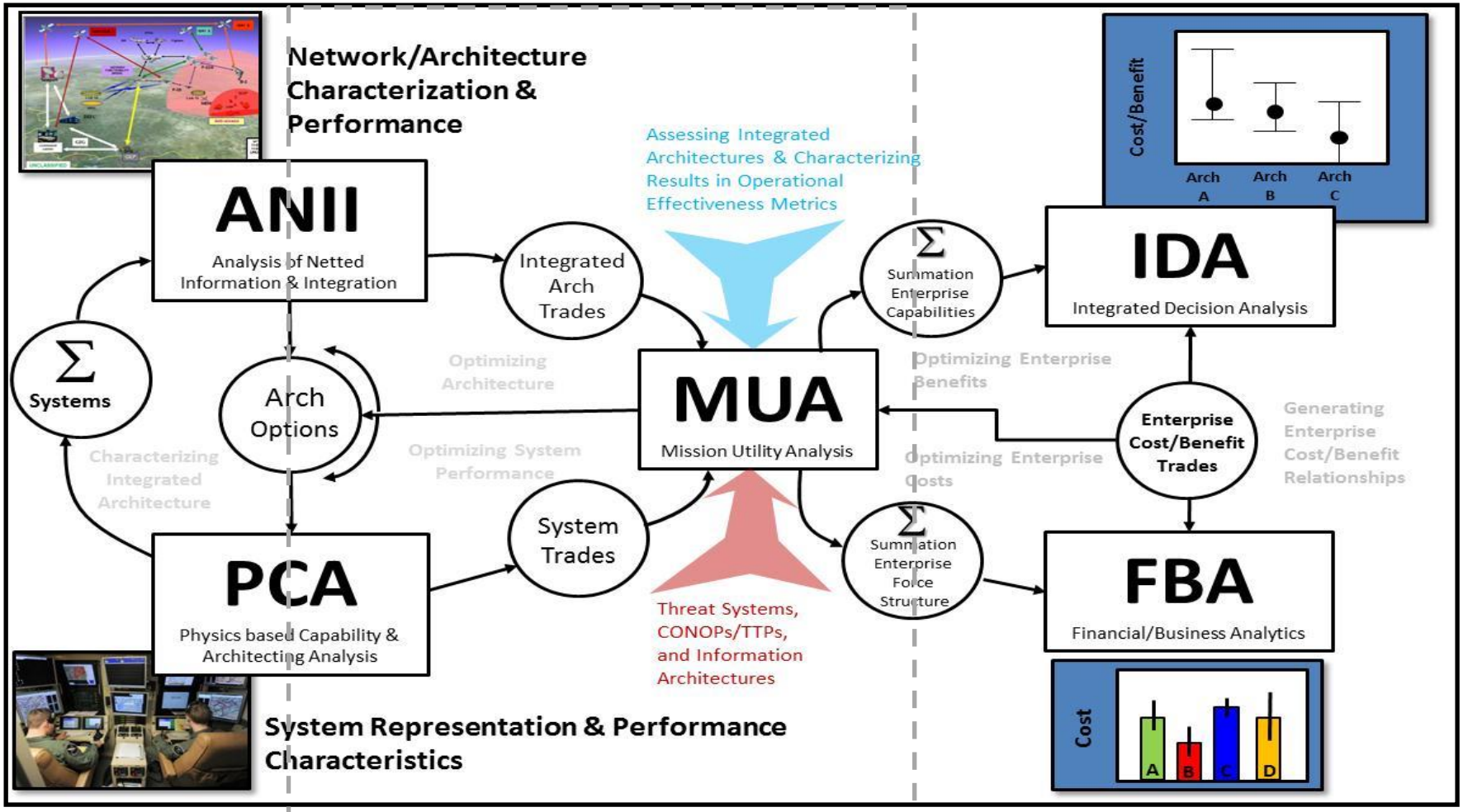
Simulator Models

LVC Simulator

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

ISR MRA Overview

Framework for Integrating the DT into CP&A



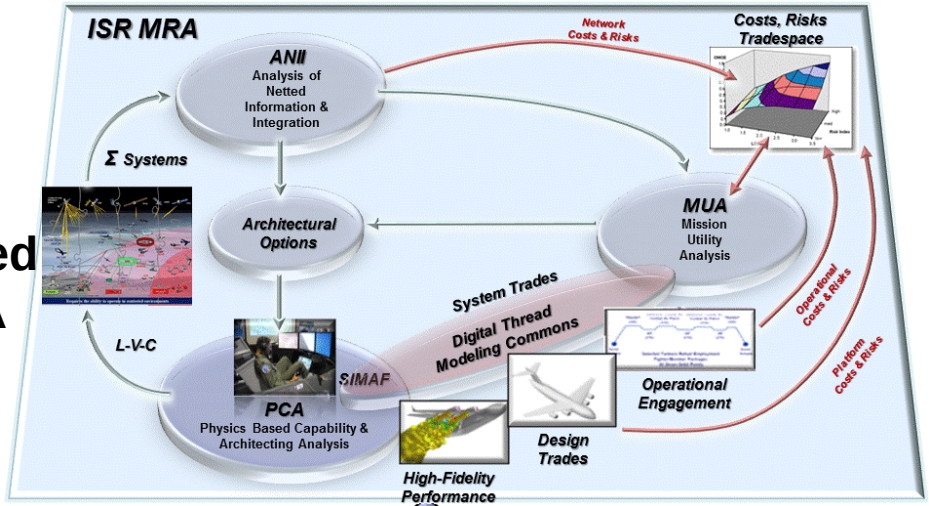
BLUE
System & Architectures

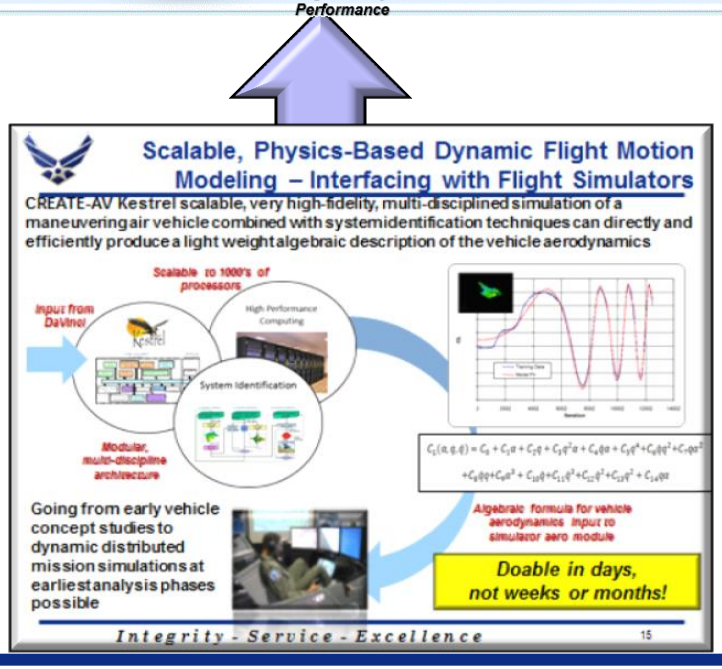
BLUE ON RED
Campaign/Mission

SUMMATION: BLUE ON RED
Rolled up across multiple missions, campaigns, theaters for the force structure

Capability Planning & Analysis –Pilot Demo Connecting DT with the ISR MRA Capability

- Objective is to address <u>feasibility</u>, <u>affordability</u>, <u>interoperability</u>, and <u>interdependency</u> during the earliest analysis phase
- Introducing a high-fidelity physics based "fly out" model into SIMAF in the CP&A phase enables connectivity between materiel solutions, avionics architectures, and SoS interoperability
- Enables comparison of operational effectiveness/military value with incremental cost of requirement
- Opportunity to leverage activities in the ISR MRA development, HPCMP CREATE-AV development and funded activities with industry, and the OSD Engineering Resilient Systems initiative
- Real fountainhead for the development and application of the digital thread

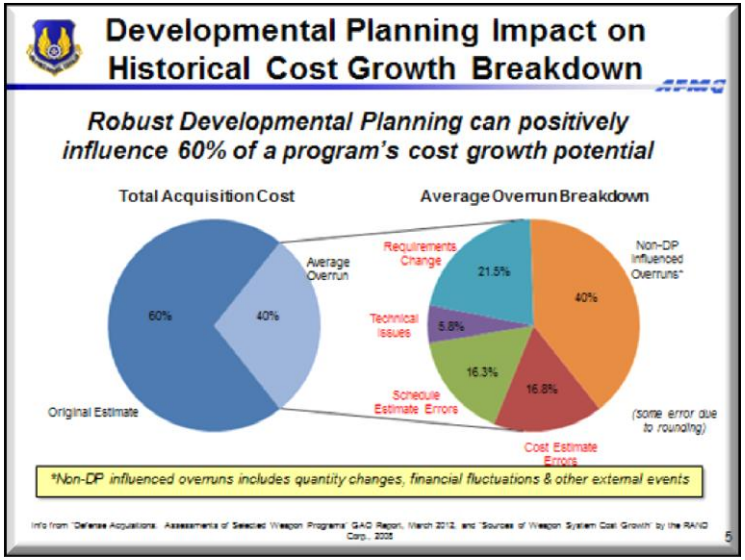


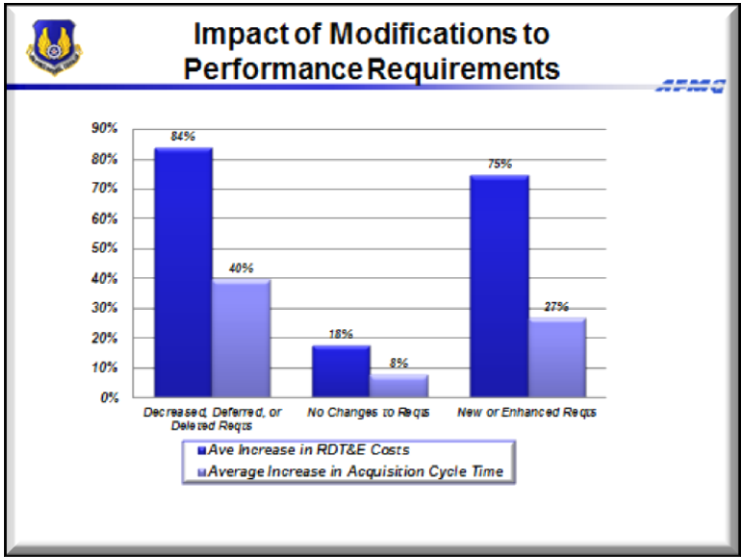


Benefits of the Digital Thread support to Capability Planning and Analysis

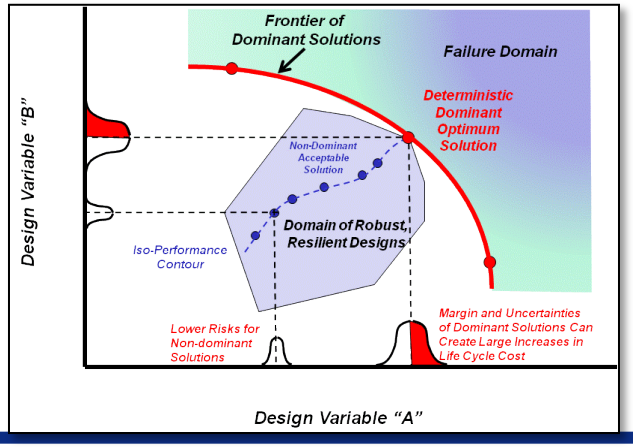
A. Reduced cycle time between JCIDS, MDD, and MS A through more efficient and comprehensive analysis of requirements

B. Reduced cycle time/costs between MS A and MS B as well as MS B to IOC through
- technology maturation assessment
- determination of resilient, realizable and affordable materiel solutions
- reduced requirements volatility

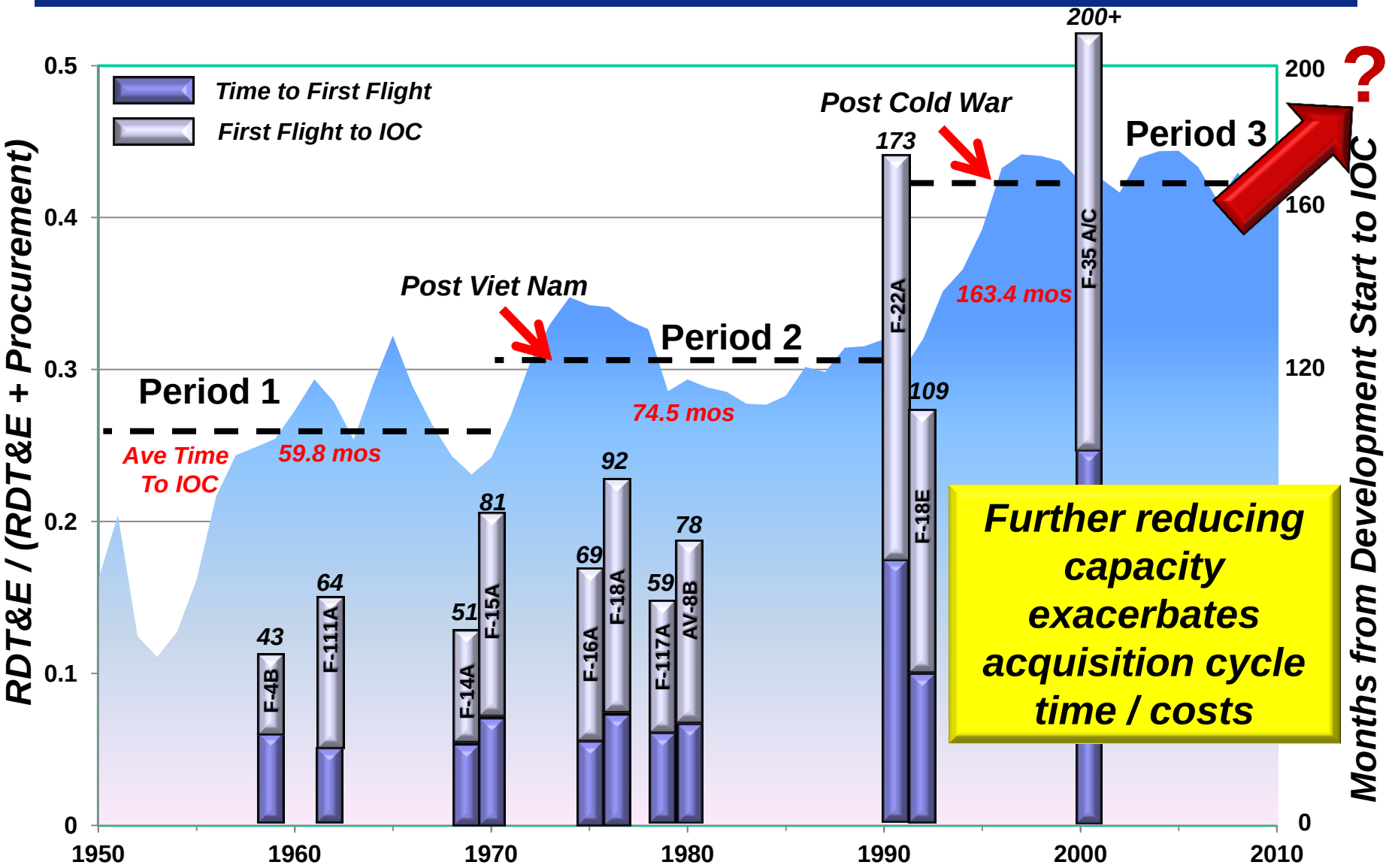




Resilient Design Space



Cost of RDT&E / Increasing Time to IOC Correlate with Budget Reduction Cycles



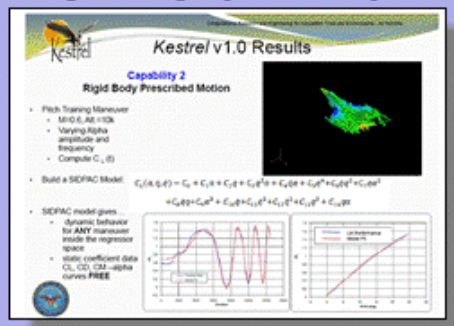
Streamlining Developmental Testing at the Campaign Level
(DT&E Overlays 80% of MS B to IOC Cycle Time)

Physics Based Modeling

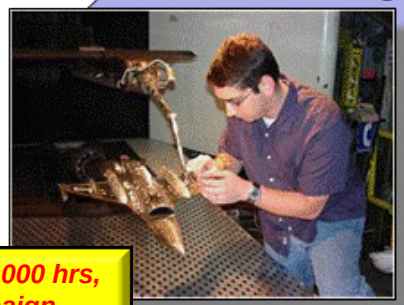
Digital Thread Enables Quantification of Uncertainty with Minimal Experimental Data

Common Thread System ID Techniques

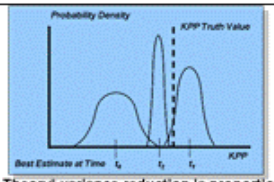
Computational Science and Engineering Dynamic Trajectories



"Fly the Mission" Ground Testing



Estimation Theory Quantify Effectiveness of Testing



Using Estimation Theory* variance reduction is proportional to the effectiveness of resources used and resources applied

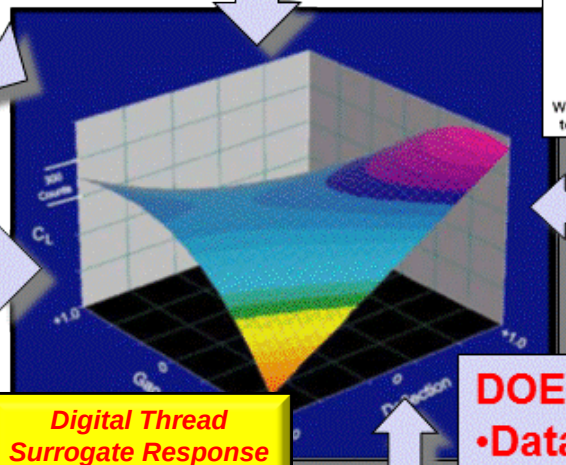
$p(t_{i+1}) = p(t_i)/(1 + p(t_i)\, u\, \Delta t)$, u = resource effectiveness

Or

$u(t) = (p(t_i)/p(t_{i+1})-1)/p(t_i)\, \Delta t$

Which can be estimated used the SEMP, TEMP, and KPP values pre- and post-test

Currently 22,000 hrs, 4-yr campaign, 2.5M data points for Stability &Control



Value of T&E

Currently 6-8000 Sorties requiring 6-8 years

Flight Testing

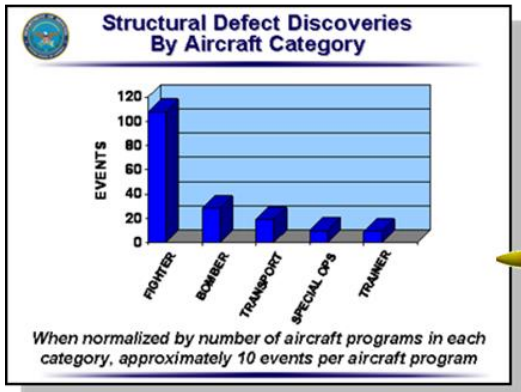
Digital Thread Surrogate Response Surface

DOE
- **Data Merge/Data Mine**
- **Response Surface Analysis**
- **Variance Reduction Strategy**

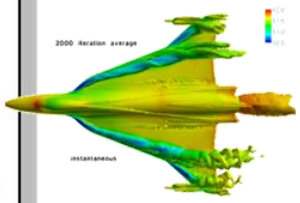
Kraft, Edward M. " Integrating Computational Science and Engineering with Testing to Re-engineer the Aeronautical Development Process," AIAA Paper 2010-0139 , January, 2010

Benefits of Digital Thread Support for RDT&E

- **Quantification of margins and uncertainties in system performance at critical decision points for more effective system engineering outcomes**
- **Integrates modeling and data into the digital surrogate response surface to mature the digital thread over the life cycle**
- **Requires addition of statistical engineering to quantify uncertainties**
- **Decreased cycle time through streamlined processes and minimum late defect discovery**

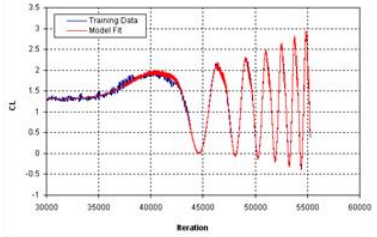


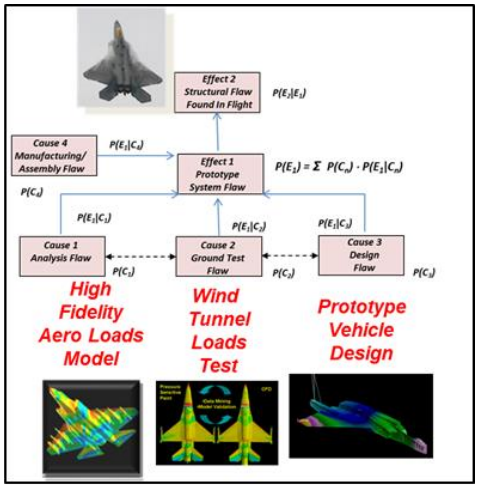
Kestrel + SID + Proper Orthogonal Decomposition



Surrogate Digital Loads

$$Loads = f(\bar{q}, M, \alpha, \alpha^2, q, \alpha q, \dot{q}^2, \square\ )$$



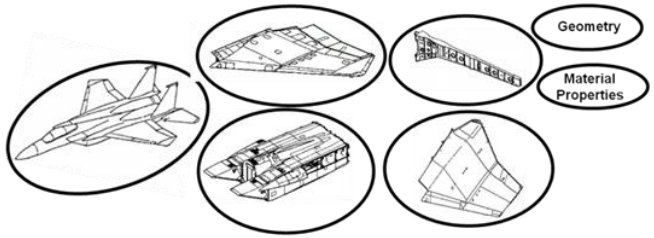


Using the Digital Thread to overcome deficiencies in systems engineering, reductions in capacity, and late defects provides best opportunity to reduce time to IOC

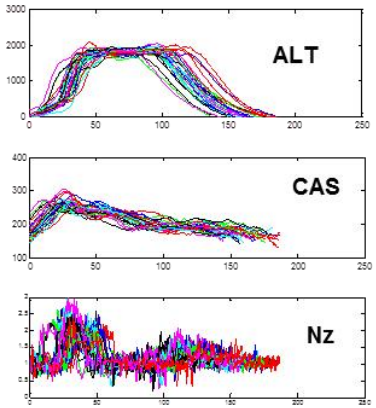
Airframe Digital Twin

Integrated Lifecycle Management Environment

Configuration Control



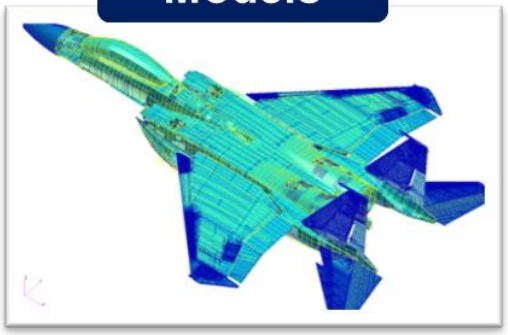
Usage



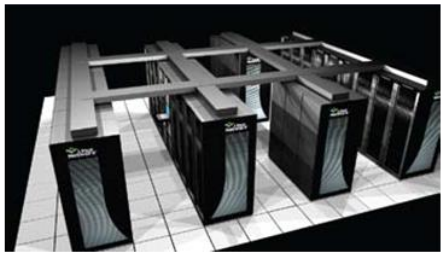
Materials State Awareness

Inspections

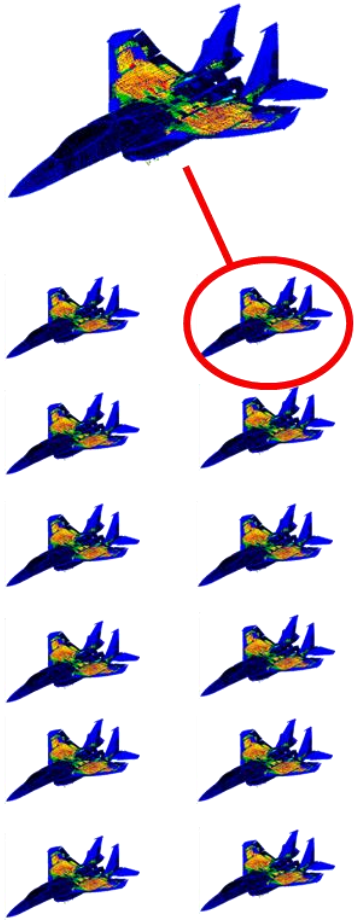
Models



Computation / Data



Fleet & Tail # Lifecycle Management



What We Need to Do

- **Establish an integrated Enterprise vision for a "Digital Thread" supporting the acquisition and sustainment process**
- **Validate the payoff of the digital thread through the selected Pilot Studies**
- **Coordinate with the AF Engineering Revitalization and OSD System Model efforts to identify domain SOA and develop a governance process for the digital thread**
- **Develop the architecture for the digital thread to identify the Domain Interface Protocols, connectivity to a Knowledge Management System**
- **Work with industry to implement and institutionalize enhancements to acquisition and sustainment**

Leverage cross-functional, cross- organizational activities to weave a digital thread into a whole cloth approach to acquisition and sustainment of warfighting capabilities

Parting Thought

“It must be remembered that there is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than a new system. For the initiator has the enmity of all who would profit by the preservation of the old institution and merely lukewarm defenders in those who gain by the new ones. ”

Prince Niccolo Machiavelli