The Role of CREATE™-AV in Realization of the Digital Thread

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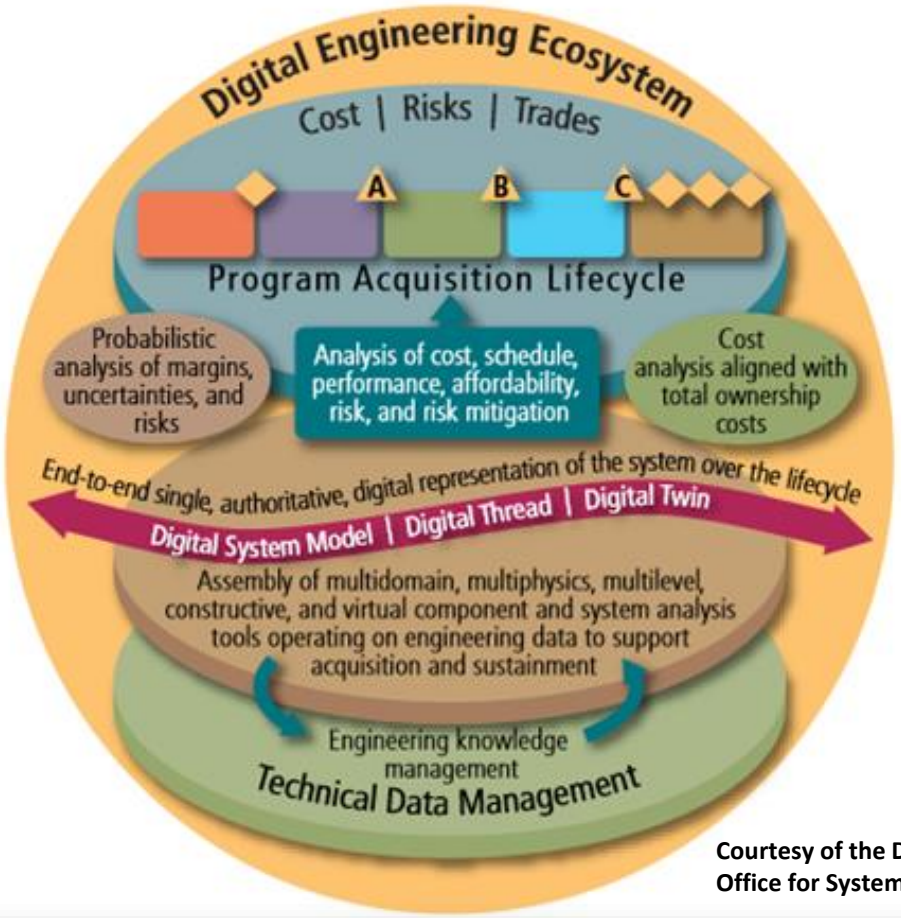
Introduction

- The Aerospace & Defense Industry is investing heavily in Industry 4.0
- The AF in particular, and the DoD in general, are at the threshold of developing Digital Engineering Ecosystems in collaboration with Industry to take advantage of the Digital Revolution
- The HPC CREATE™ Program has evolved into an important source of high-fidelity, physics-based performance modeling tools with inherent capabilities enabling development of authoritative digital surrogate truth sources key to realization of a Digital Thread / Digital Twin

It is Time to Move From Abstraction to Realization in the Integration of Physics-Based Modeling into Digital Engineering Ecosystems

Digital Engineering Ecosystem

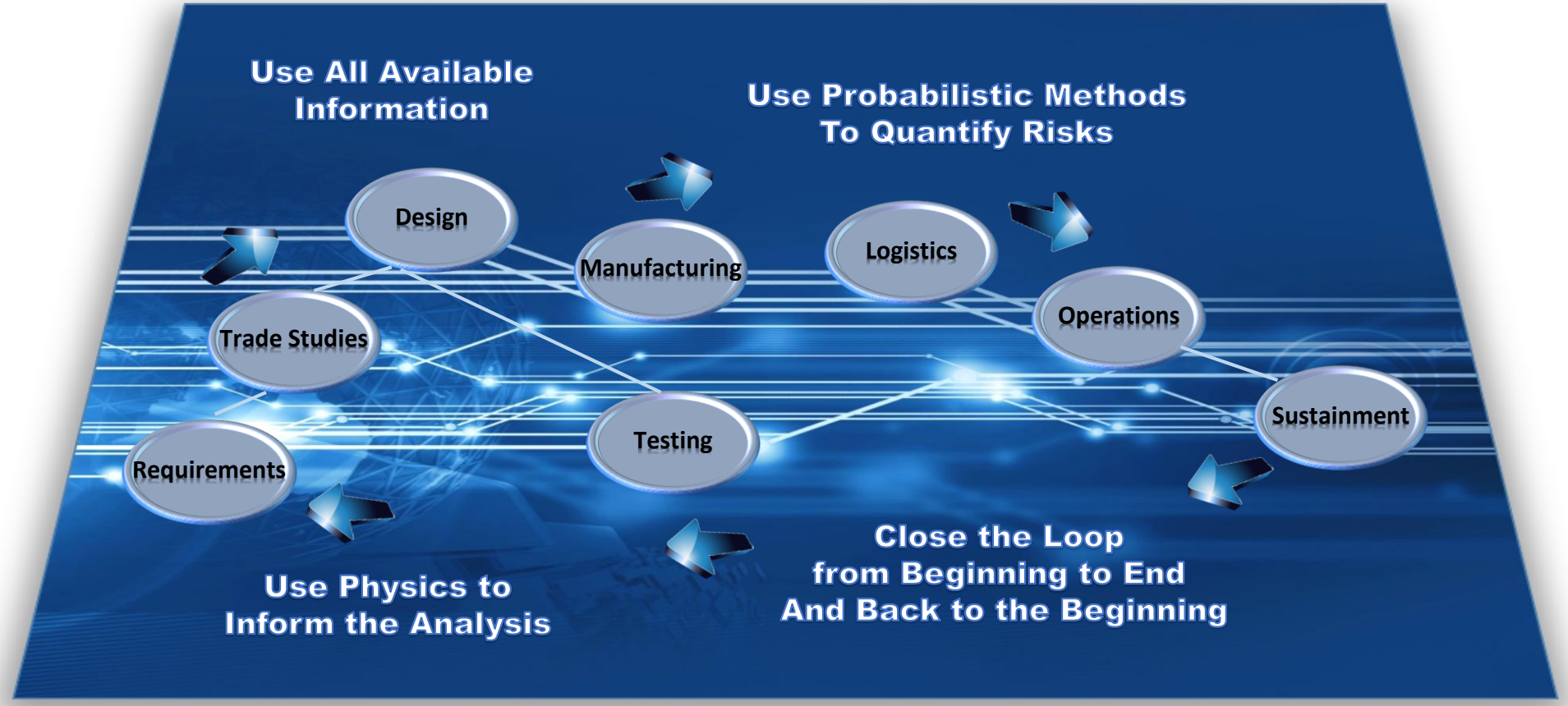


Courtesy of the Deputy Assistant Secretary of Defense Office for Systems Engineering

The interconnected infrastructure, environment, and methodology (process, methods, and tools) used to store, access, analyze, and visualize evolving systems' data and models to address the needs of the stakeholders.

Defense Acquisition Guide

Connected and Integrated Data
Digital Thread / Digital Twin



Make Informed Decisions Throughout the Lifecycle

Tenets of the Digital Thread/Digital Twin

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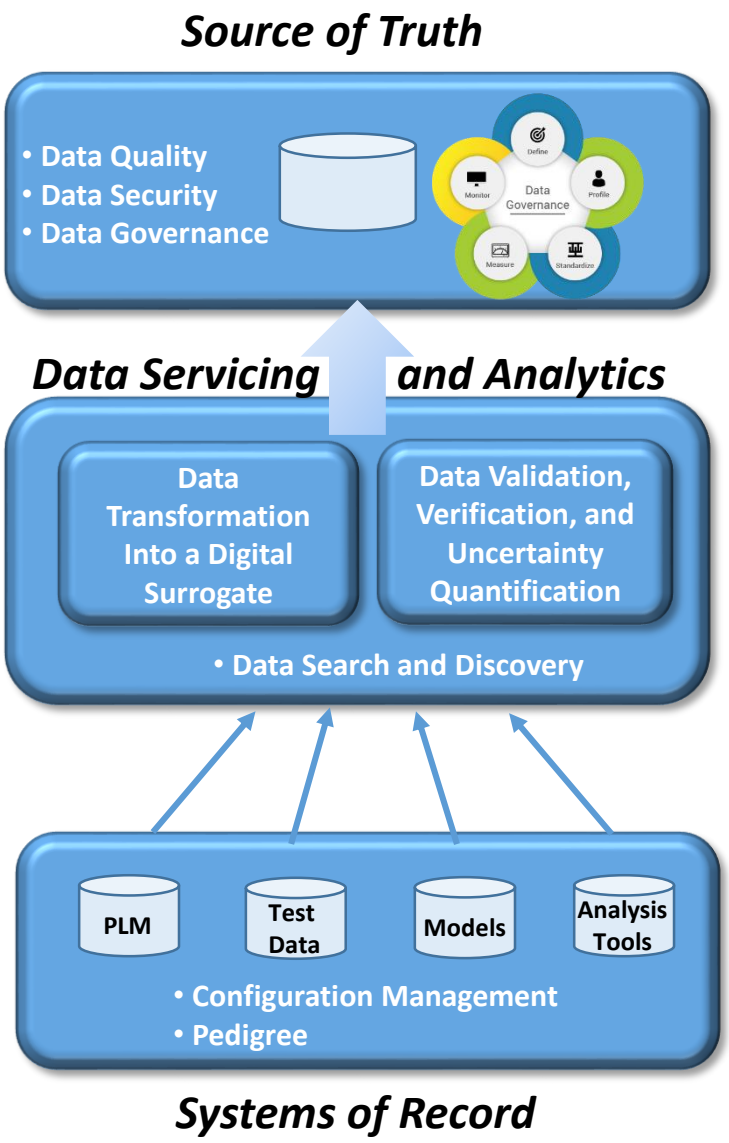
- **Access to and ability to exercise data to understand performance and technical risks**
- **End-to-end system model – ability to transfer knowledge upstream and downstream and from program to program**
- **Single, authoritative digital representation of the system over the life cycle – the authoritative digital surrogate "truth source"**
- **Application of reduced order response surfaces and probabilistic analyses to quantify margins and uncertainties in cost and performance**
- **Preserve meta-data on decision processes and outcomes**

It is Not Sufficient to Just Digitize Current Processes – We Need to Reinvent Processes Leveraging the Digital Connectivity of Trusted Data and Knowledge

A Single, Authoritative Digital Surrogate "Truth Source"

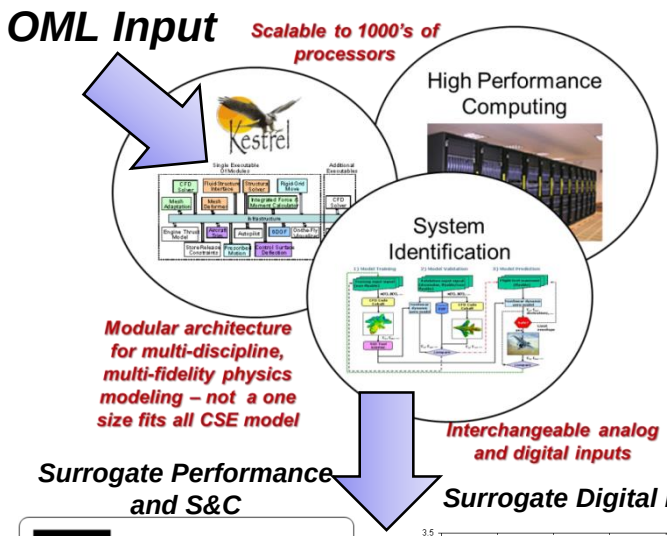
- A technical definition declares quality of a truth source to be "the state of completeness, validity, consistency, timeliness and accuracy that makes the data appropriate for a specific use"
- System of Record (SOR) – the authoritative data source for a given element or piece of information
- Source of Truth (SOT) – trusted data source that gives a complete picture of the data object as a whole
- Trusted data source connotes
  - An entity authorized by a governing authority to develop or manage data for a specific purpose
  - Shared by all stakeholders with all equities preserved



Opportunities for CREATE™-AV to Enable the Digital Thread

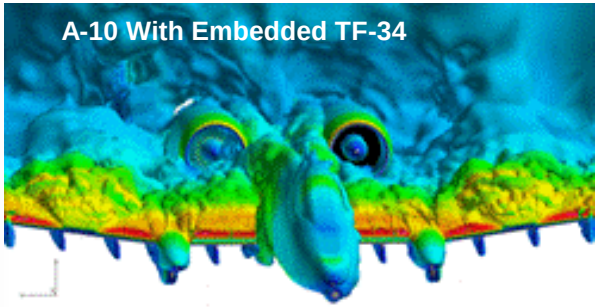
- Multi-discipline, multi-physics, multi-fidelity capability
- Ability to rapidly and efficiently generate reduced order models for surrogate representations
- Ability to address system integration issues during detailed design (fluid/structures, airframe/propulsion, airframe/weapons)
- Scalable to take advantage of high performance computing assets
- Configuration management and Quality Control critical to confidence in applications across multiple regimes.

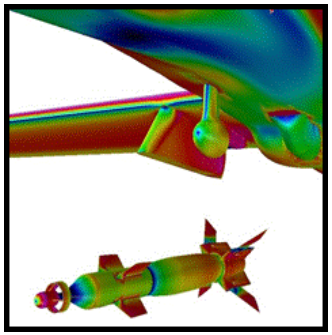
To Become an Integral Component of a "Truth Source" Requires a Pedigree, Transformation to a Digital Surrogate, Integration with Other Data Sources, and Uncertainty Quantification



$$C_L(\alpha,q,\dot{q}) = C_0 + C_1\alpha + C_2 q + C_3 q^2\alpha + C_4\dot{q}\alpha + C_5 q^4 + C_6\dot{q}q^2 + C_7 q\alpha^2 + C_8\dot{q}q + C_9\alpha^3 + C_{10}\dot{q} + C_{11}\dot{q}^3 + C_{12}\dot{q}^2 + C_{13}q^2 + C_{14}q\alpha$$

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

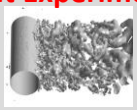


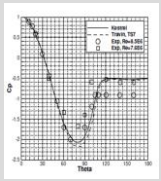


Developing the Pedigree

SOR Digital Library Of Unit Experiments, Validation Cases, Quantified Model Uncertainties

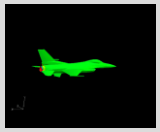
Unit Experiments

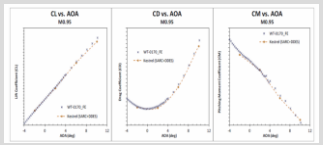




Unit Experiment Data

Validation Cases

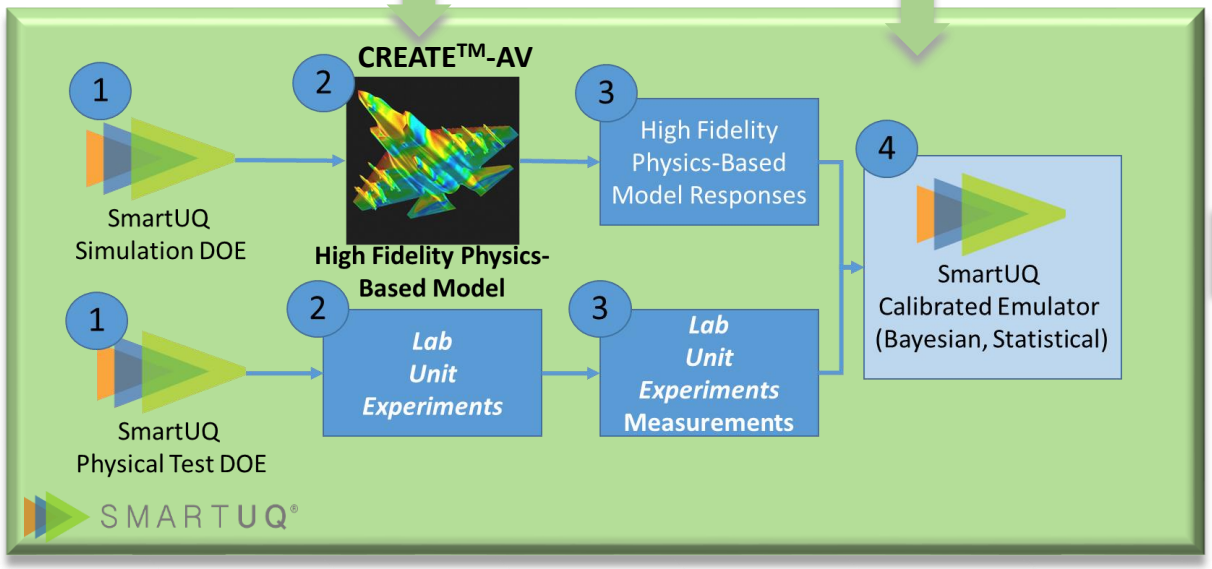




Vehicle Data

Additional V&V, Application Case Studies

Digital Thread



Quantified Model Uncertainties

Library of Experimental Validation Data and V&V of Models Digitally Preserved as a System of Record Will Expedite a Digital Truth Source

Developing the Model-Based Digital Surrogate

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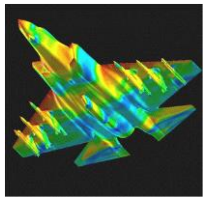
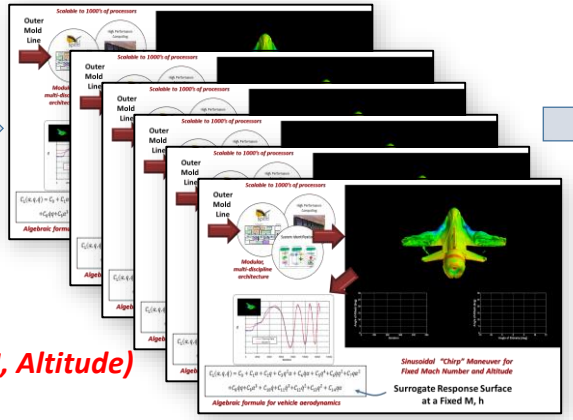
CREATE™-AV



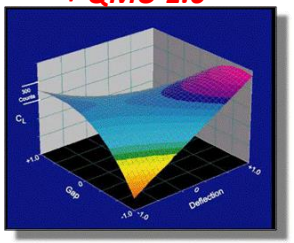
High Fidelity Physics-Based Models

Reduced Order Model Response Surface Generation Over Entire Operating Envelope



$C_X = f(M, Altitude)$

Model-Based Performance Response Surface 1.0 + QMU 1.0



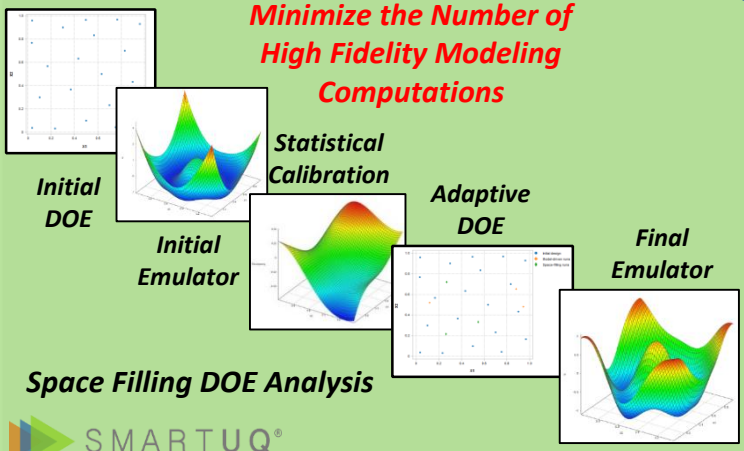
Digital Authoritative Truth Source

Digital Thread

Quantified Model Uncertainties

Additional V&V, Application Case Studies

Minimize the Number of High Fidelity Modeling Computations



Modeling Efficiency, Scalability, and Optimized UQ Methods Will Be Required to Generate Comprehensive Model-Based Surrogates

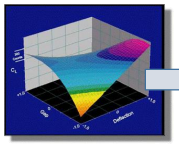
Merging Model and Test Data

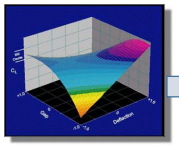
Digital Authoritative Truth Source

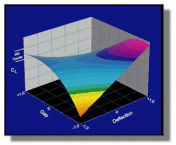
Response Surface 1.0 + QMU 1.0

Response Surface 1.1 + QMU 1.1

Response Surface 1.2 + QMU 1.2





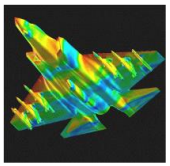


Digital Authoritative Truth Source

Digital Thread

CREATE™-AV *V&V'D Applied High-Fidelity Model*

Model Based



Ground Test Based

Flight Test Based

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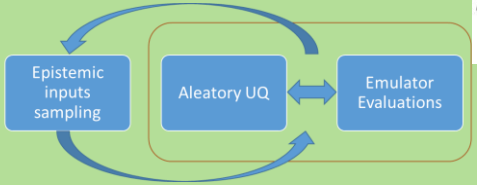
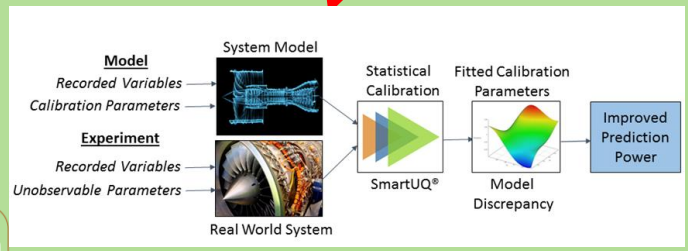
Baseline + *Epistemic Delta* = *Correction*

Identification of Source and Range of Epistemic Uncertainties

1. Modeled Assessment / Correction of Epistemic Uncertainty



2. Combined Epistemic and Aleatory Analysis of Experimental Data



3. Merge of Experimental and Modeled Data into New Authoritative Truth Source with Quantified Uncertainties

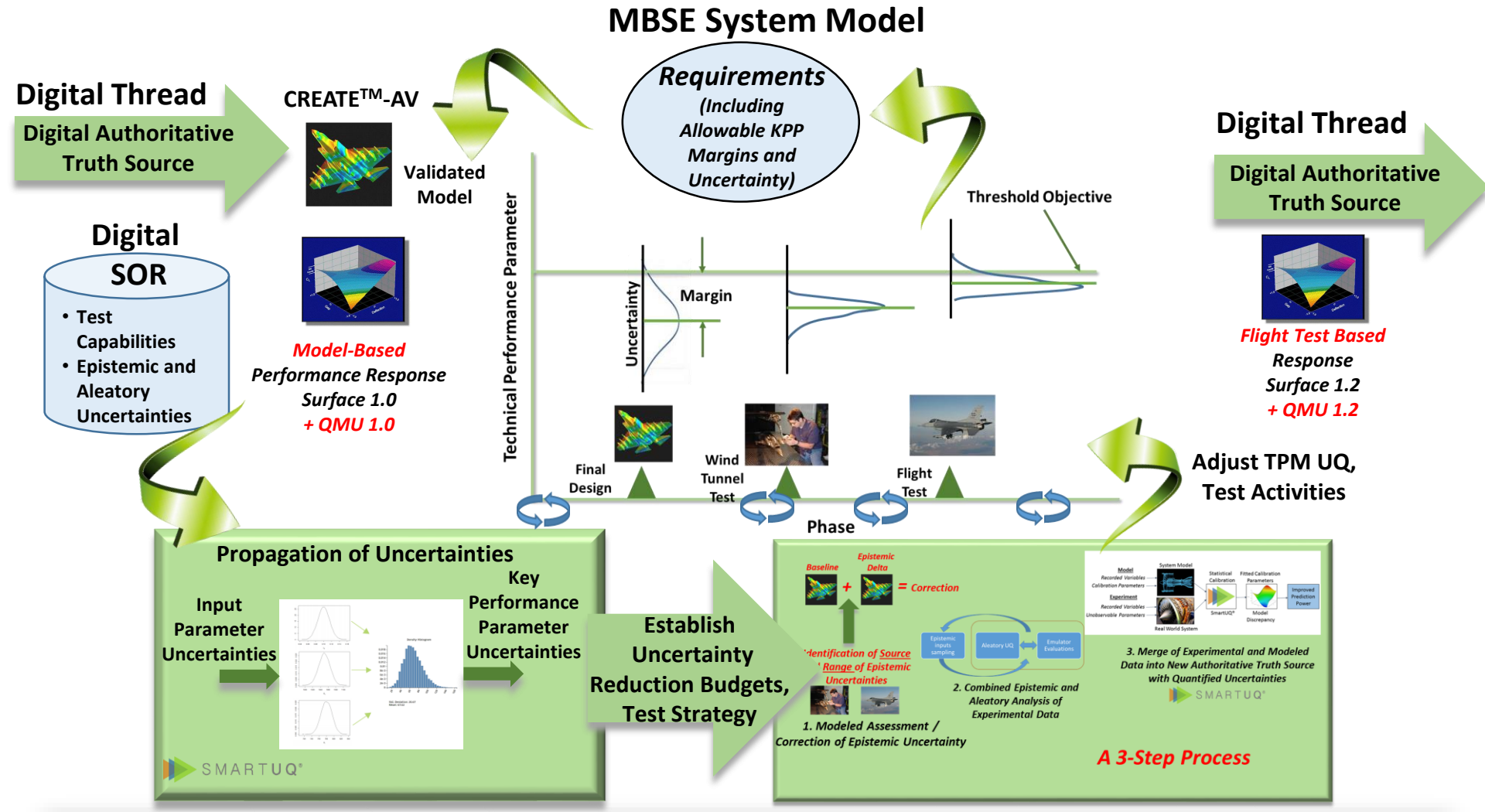
SMARTUQ®

Digital Thread

Additional V&V, Application Case Studies

A 3-Step Process

MBSE, MBE, UQ, and T&E – Transforming to a Digital Process



Moving Toward a "Digital TEMP" to Improve Quality of Performance Against Requirements and Reduce Cost and Schedule for T&E

CREATE™-AV Lifecycle Impact as a Truth Source
A Vision Realized

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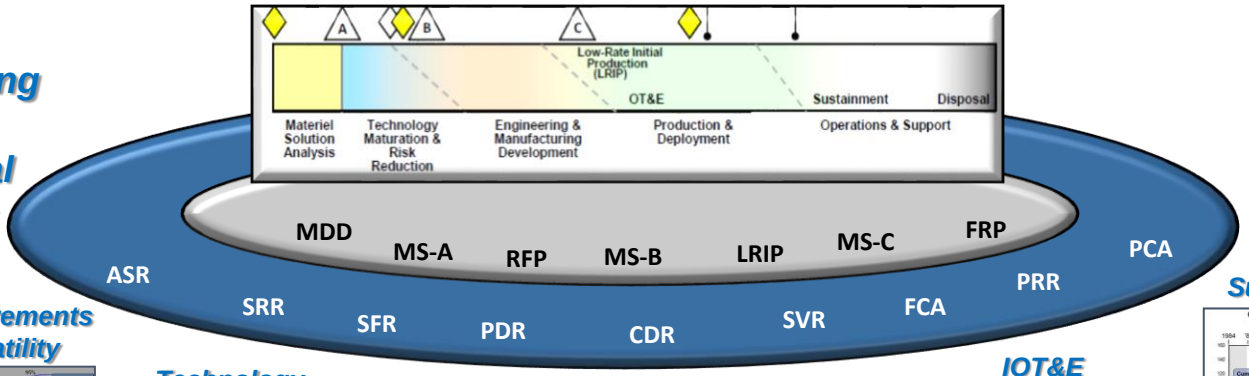
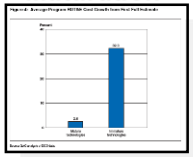
Systems Engineering Leverage Points for Reducing Total Ownership Costs

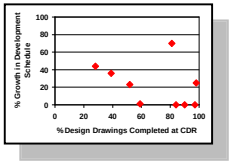


Requirements Volatility

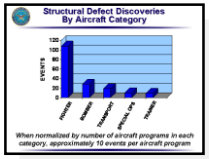
Technology Maturation



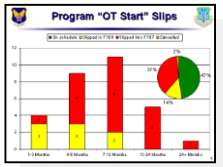
Design Closure @ CDR



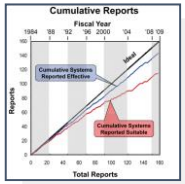
Late Defect Discoveries



IOT&E Pause Test



Suitability



Affordable, Feasible, Interoperable System Requirements

Single, Authoritative, Digital Representation of the System Over the Life cycle

Digital Thread / Digital Twin

Mishap Investigations

System Modifications

SLAP/SLEP

TRL Maturation

Independent Evaluation @ MS B

Design Closure @ CDR

Minimum Test Campaign

Minimize Defect Discovery

Air Worthiness

Weapons Integration

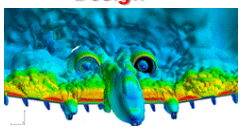
Suitability

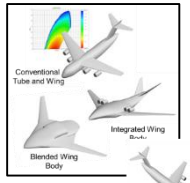
Optimum Maintenance

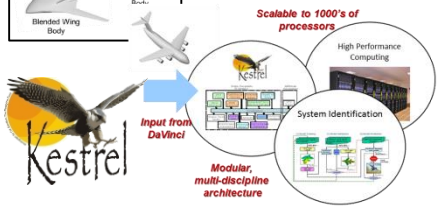
MRB Processing

Manufacturing

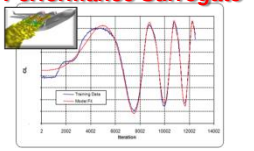
Integrated Design





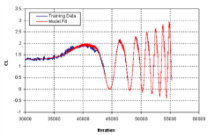


Performance Surrogate

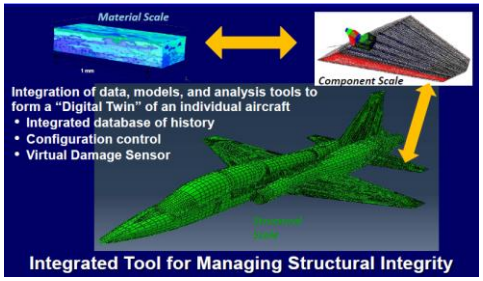


$$C_L(\alpha,q,\dot{q}) = C_0 + C_1\alpha + C_2\dot{q} + C_3\dot{q}^2\alpha + C_4\dot{q}\alpha + C_5\dot{q}^4 + C_6\dot{q}\dot{q}^2 + C_7\dot{q}\alpha^2 + C_8\dot{q}\dot{q}^2 + C_9\alpha^3 + C_{10}\dot{q} + C_{11}\dot{q}^3 + C_{12}\dot{q}^2 + C_{13}\dot{q}^2 + C_{14}\dot{q}\alpha$$

Loads Spectra Surrogate



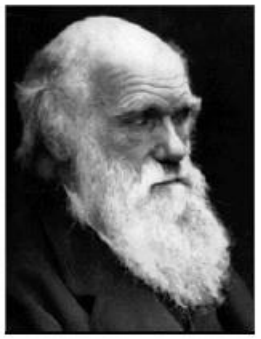
$$Loads = f(\bar{q}, M, \alpha, \alpha^2, q, \alpha q, \dot{q}^2, \square)$$



Integrated Computational Materials Engineering (ICME)

Summary

- The Digital Revolution is reshaping the development and sustainment of aerospace and defense systems
- The DoD is moving forward with Industry to develop the architecture for a Digital Engineering Ecosystem
- The crucial elements for a Digital Ecosystem are
  - Identification and preservation of Sources of Record
  - Transformation of SOR data into digital surrogates
  - Quantification of the quality of the digital surrogates
  - Governance of the Authoritative Digital Surrogate Truth Source



Charles Darwin 1809-1882

"It is not the strongest of the species that survive, nor the most intelligent, but the ones most adaptable to change"

CREATE ™ -AV has inherent capabilities conducive to providing an authoritative digital surrogate truth source for air vehicle performance, but will require focused attention on establishing its pedigree and persistently quantifying uncertainties at each application phase over a system lifecycle

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