U.S. Air Force

Integrity - Service - Excellence

Workshop With Industry

Applying Digital Engineering to Reduce Acquisition Cycle Time

Sponsored by NDIA and

SAF/AQ Office of Transformational Innovations

December 13, 2016

Washington, DC

Why We Are Here

A Digital Engineering revolution is sweeping the Aerospace and Defense Industry. How can we leverage integrated Model Based Engineering/Model Based Systems Engineering to increase the value of Developmental Testing to acquisition and sustainment? To succeed will require very close collaboration between industry and government. The intent of the workshop is to *gain insight from industry's point of view on how to use digital engineering to change acquisition cycle time through innovative changes in policies and practices.*

This is the First of Three Planned Workshops

- Phase 1 – The Technical Assessment
  - What barriers exist to establishment of digital engineering and T&E environments across Air Force systems?
  - What tools and technologies are already in use that could establish digital environments?
  - What policies and practices are affected by establishing an integrated digital ecosystem?
- Phase 2- The Business Model Assessment
  - How can this approach be effective on contract?
    - Policy, clauses, regulations, contract language
  - What are the barriers?
    - Tech data, IPR, etc.
  - What are the incentives?
  - Language to insert digital engineering processes into the Milestone A TEMP and RFP release?
- Phase 3 – Institutionalize Digital Environments
  - What policies /processes need to be established?
  - What specific steps need to be taken?
    - Near term
    - Long term

Agenda for Today

0900	Welcome and Introductions
	Opening Comments - Dr. Camron Gorguinpour, SAF AQ OTI
	Digital Engineering Applications to Developmental Test & Evaluation -- Dr. Ed Kraft, AFTC
1000	Exercise to identify Barriers (use post it notes to identify and pass forward) Capabilities/Technologies; Policies; Practices
1020	Post issues and identify breakout groups
1030	Break
1045	Breakout Sessions Identify barriers, propose solutions, address concerns for Capabilities/Technologies; Policies; Practices
1200	Lunch (on your own)
1300	Brief outs by each group Group discussion / Feedback
1430	Define priority list of issues What would have the biggest impact? How could we change? What would it take to do so?
1500	Summary Define out brief issues and Prioritization Setup for Phase 2 meeting Next Steps
1530	Conclusion

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Digital Engineering Applications to Developmental Test & Evaluation

Dr. Ed Kraft

December 13, 2016

NDIA / SAF/AQ-OTI

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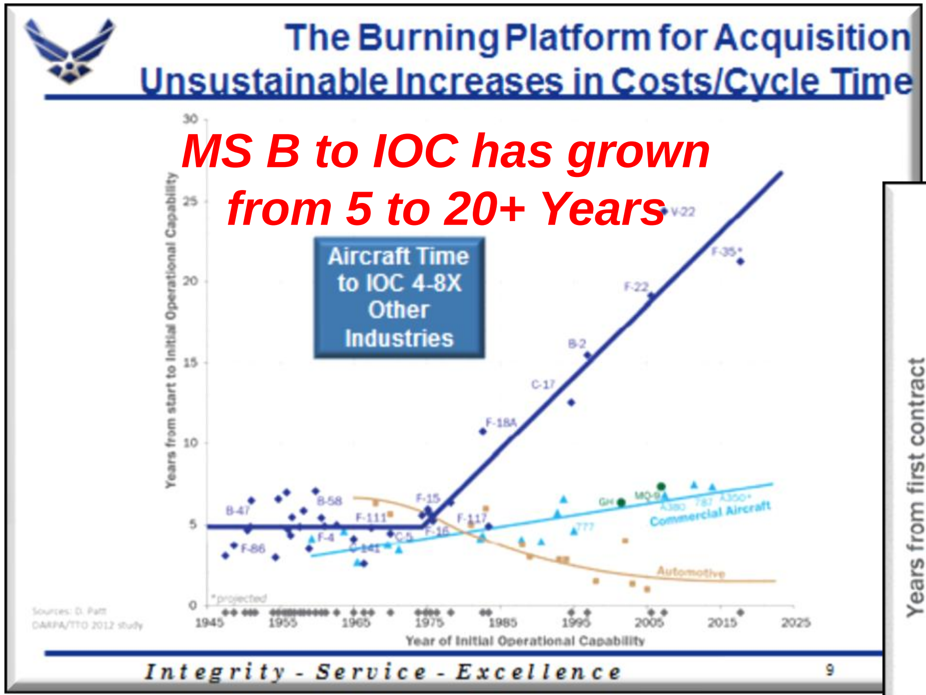
Introduction

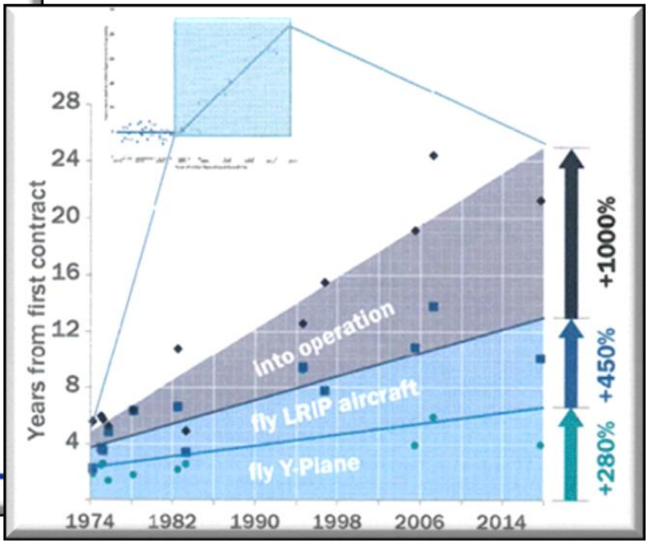
- There is a Digital Engineering revolution sweeping the Aerospace and Defense Industry
- The DoD is focusing on Digital Engineering applications to Systems Engineering in support of Acquisition and Sustainment
- Most OEMs have ongoing internal digital thread model-based engineering activities
- Industry related groups like the AIAA, NDIA, ITEA, etc., are focusing symposia on topics related to Digital Engineering

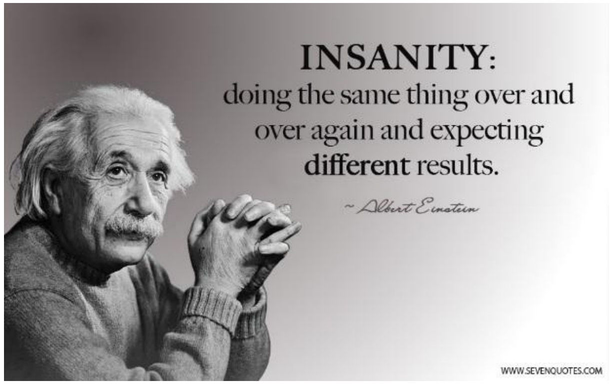
How does the T&E community fit in and how can we leverage the Digital Engineering environment to increase the value of T&E to acquisition and sustainment ?

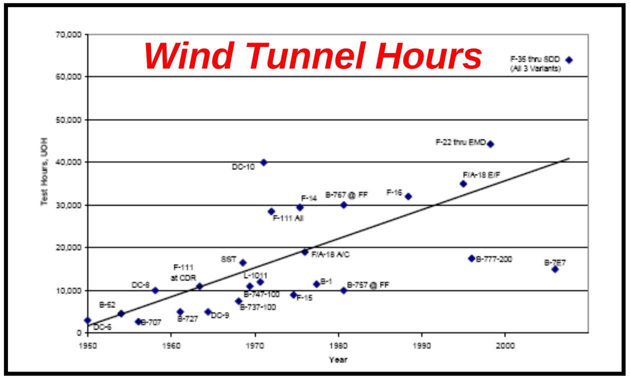
Why T&E Needs to Change

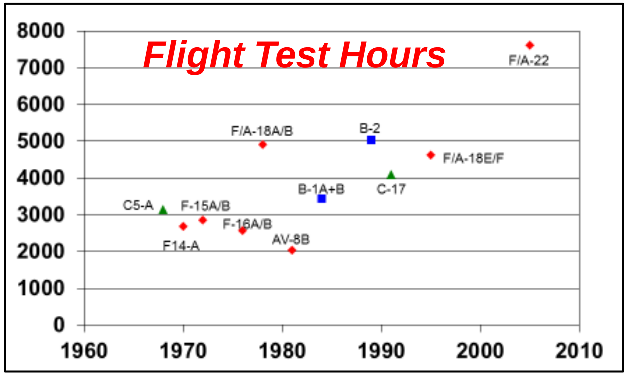


T&E isn't the only cause,
But overlays 85% of the cycle time . . .



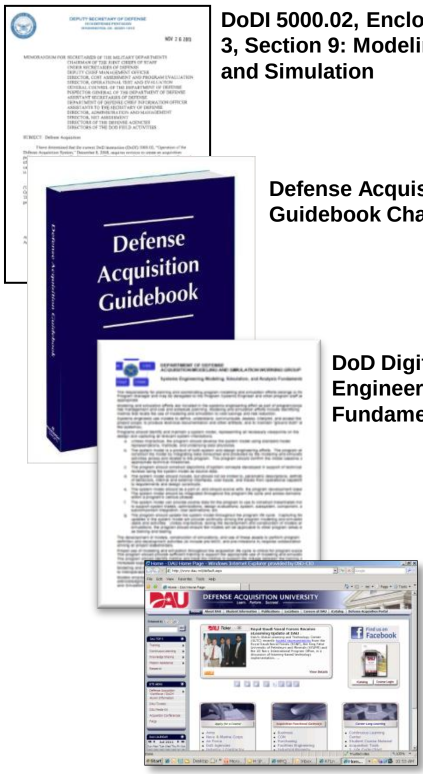






Leveraging Multiple Activities to Advance Digital Engineering within DoD

Infusion in Policy and Guidance



DoDI 5000.02, Enclosure 3, Section 9: Modeling and Simulation

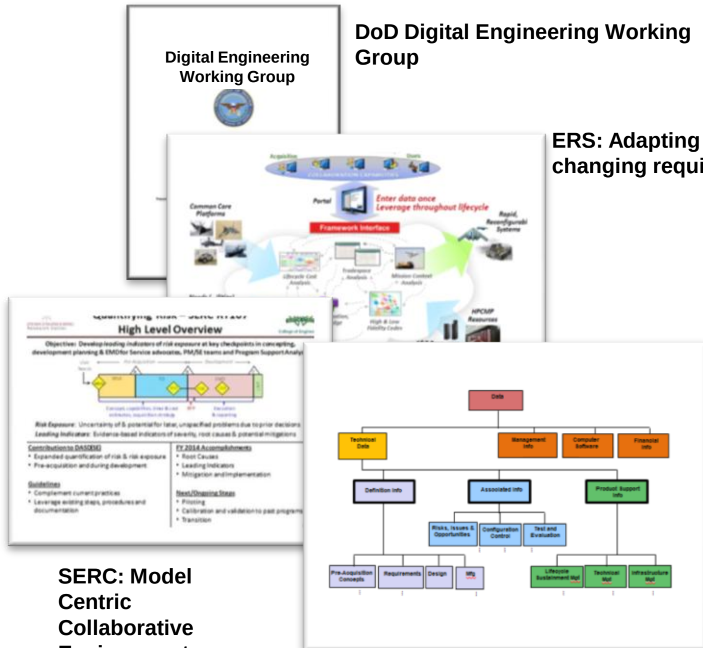
Defense Acquisition Guidebook Chapter 4

DoD Digital Engineering Fundamental

Defense Acquisition Guidebook Chapter 4

http://www.acq.osd.mil/se/pg/guidance.html

DoD Initiatives

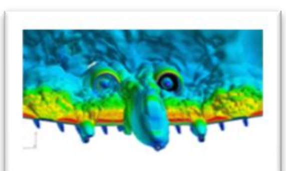


DoD Digital Engineering Working Group

ERS: Adapting to changing requirements

SERC: Model Centric Collaborative Environment

DSM Taxonomy: Foundation for defining categories of data across acquisition



HPCMP CREATE: Physics Based Modeling

Other Partnerships

DMDII
DIGITAL MANUFACTURING AND DESIGN INNOVATION INSTITUTE

Additive Manufacturing

IAWG

Inter-Agency Working Group on the Engineering of Complex Systems

NASA: Sounding Rocket Program

NDIA: Essential Elements of the System Model

USAF Own the Technical Baseline

Digital Thread/Digital Twin

Advancing the state of practice for Digital Engineering within DoD

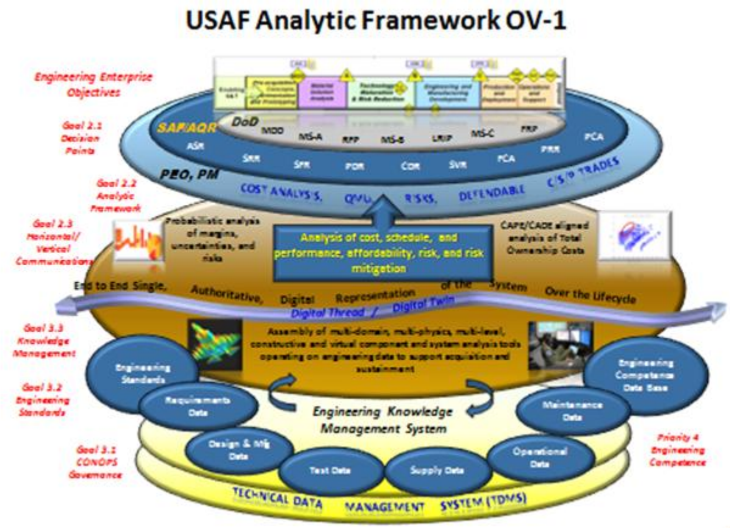
OSD Digital Engineering Definitions
(Defense Acquisition Guide Glossary)

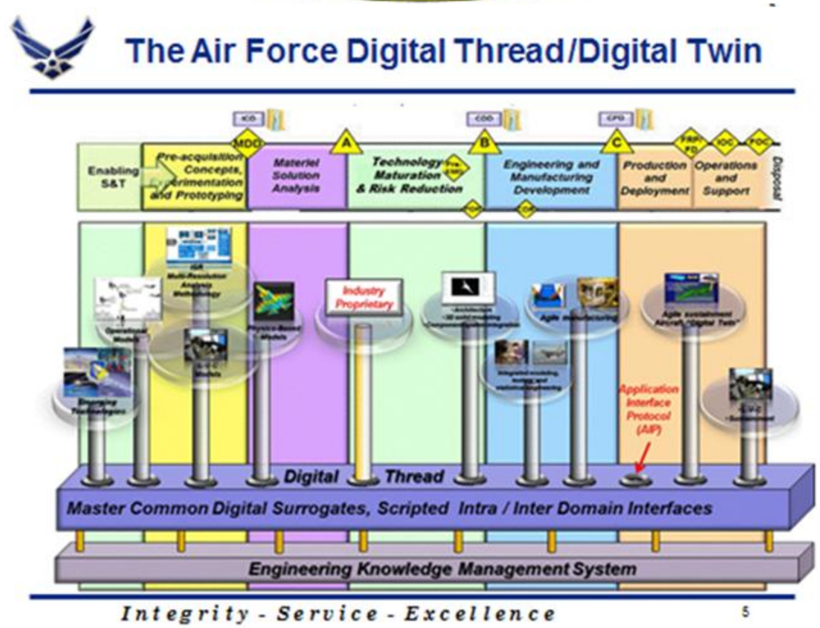
- **<u>Digital Engineering</u>: An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support lifecycle activities from concept through disposal.**
- **<u>Digital Engineering Ecosystem:</u> The interconnected infrastructure, environment, 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.**
- **<u>Digital Artifact:</u> The artifacts produced within, or generated from, the digital engineering ecosystem. These artifacts provide data for alternative views to visualize, communicate, and deliver data, information, and knowledge to stakeholders.**
- **<u>Technical Coherency:</u> The logical traceability of the evolution of a system's data and models, decisions, and solutions throughout the lifecycle.**

Digital Engineering Tenet - The Models are the Master
Moving from Paper to Digits

Paradigm Shift – Keys to Success

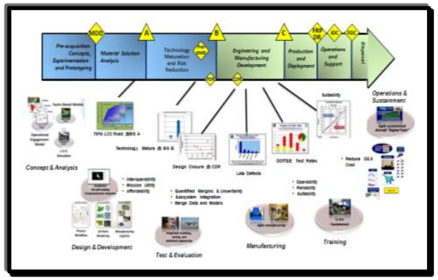
1. Policy changes – government as virtual monopsony
   - OSD BBP 3.0 Organic Engineering Capability
   - SAF/AQ Own the Tech Baseline/Bend the Cost Curve
   - AF Engineering Enterprise Strategic Plan – policies, tools, structure, skills
2. Analytic Framework
   - Digital Thread/Digital Twin –life cycle digital engineering
   - Knowledge Management
3. High fidelity, multi-level, multi-physics modeling tools
   - CREATE, ICME, Others





Key #2 – Analytic Framework
Engineering Tools and Environments

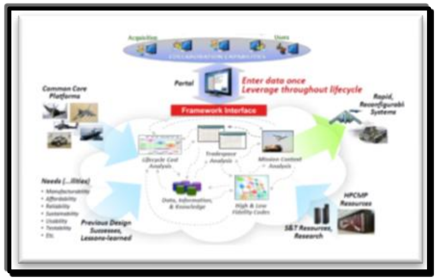
Digital Engineering



Transforming DoD towards model-centric practices by shifting from a linear, document-centric acquisition process towards a dynamic digital model-centric ecosystem

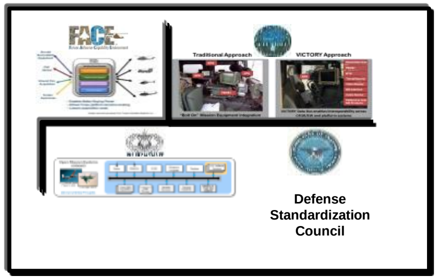
– **Digital System Model: Develop a structure for organizing programs' technical data**

Engineered Resilient Systems



Developing integrated suite of modern engineering tools: models and related capabilities, tradespace assessment and visualization tools; all within an architecture aligned with acquisition and operational business processes

Modular Open Systems Architecture



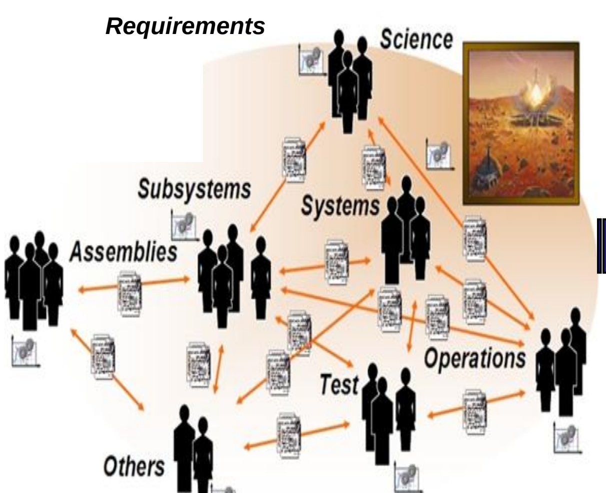
Identifying data, standards, and tools for modular and open systems design; identifying acquisition approaches and support for more capable, modular, and rapidly upgradeable systems

Engineering methods, processes, tools and techniques incorporating the latest digital practices for making informed decisions throughout the acquisition life cycle

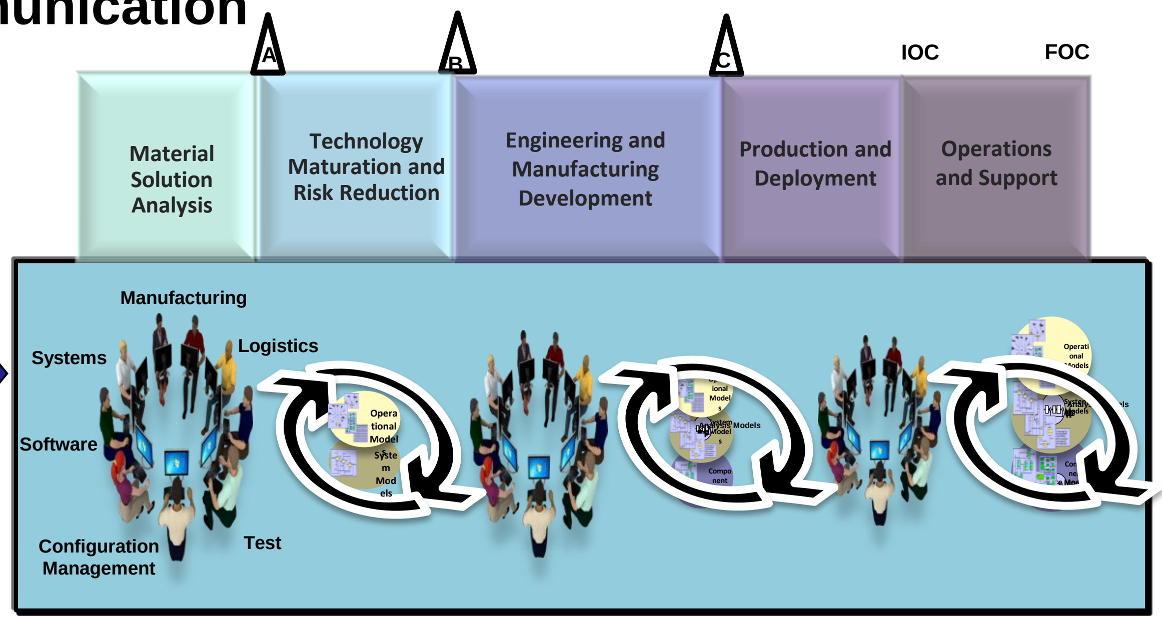
Overview of Digital Model-Centric Engineering

Shifting away from a linear, document-centric acquisition process towards a dynamic digital model-centric <u>ecosystem</u>

- **Digital Models: Data – or – algorithm – or – process – or – hybrid**
- **Low fidelity, implicit representations shift to high fidelity, explicit models serving as the "single source of truth" for all uses (e.g. ecosystem overlap with CADE, TRMC data efforts, etc.)**
- **Documents shift from the primary role of specification to the secondary role of communication**



Today: **Stove-piped data sources**



Future: **Dynamic lifecycle intelligence**

The AF Digital Thread / Digital Twin
The Analytical Framework

Digital System Model - A digital representation of a weapon system, generated by all stakeholders, that integrates the authoritative data, information, algorithms, and systems engineering processes which define all aspects of the system for the specific activities throughout the system lifecycle.

Digital Thread - An extensible, configurable and Agency enterprise-level analytical framework that seamlessly expedites the controlled interplay of authoritative data, information, and knowledge in the enterprise data-information-knowledge systems, based on the Digital System Model template, to inform decision makers throughout a system's life cycle by providing the capability to access, integrate and transform disparate data into actionable information.

Digital Twin - An integrated multiphysics, multiscale, probabilistic simulation of an as-built system, enabled by Digital Thread , that uses the best available models, sensor information, and input data to mirror and predict activities/performance over the life of its corresponding physical twin.

Common interest in a physics-based, multi-discipline, multi-physics, cross-domain, model of a system’s capabilities and performance

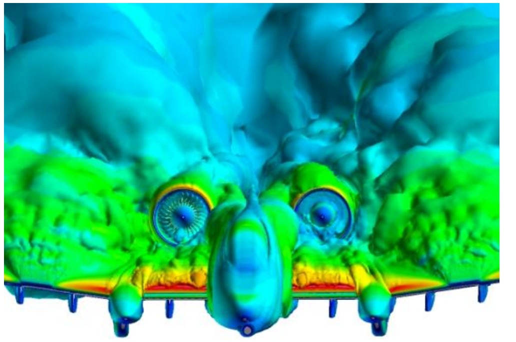
Tenets of the Digital Thread/Digital Twin

- **Access to and ability to exercise data to enable the government to understand performance and technical risk, i.e., "Own the Technical Baseline"**
- **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**
- **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**

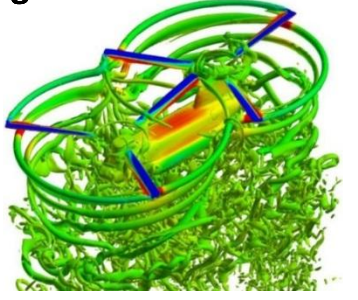
Key #3 -Computational Research Engineering Acquisition Tools Environment (CREATE-AV)

- **Multi-discipline, multi-physics, multi-fidelity capability –**
  - ***Davinci* design trade analysis tool**
  - ***Kestrel* fixed wing modeling capability**
  - ***Helios* rotary wing modeling capability**
  - ***CREATE-RF Sentri* signature modeling**
- **Modular architecture enables**
  - **Insertion of additional capabilities and attributes as they mature**
  - **Industry use of internal proprietary algorithms with digital output to a common framework for analyses**
- **Scalable to take advantage of high performance computing assets**
- **Configuration management and Quality Control critical to confidence in applications across multiple regimes**

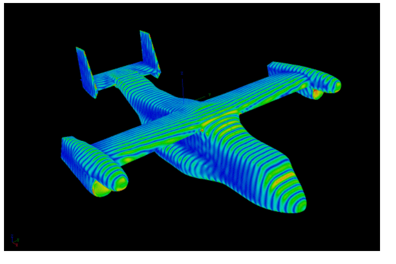
CREATE-AV – Designed for a 30-40 Year Life!



Kestrel – Fixed Wing Capability
A-10 Integrated Aero/Loads/Propulsion



Helios – Rotary Wing Capability
CH-47F Rotor – Fuselage Interactions

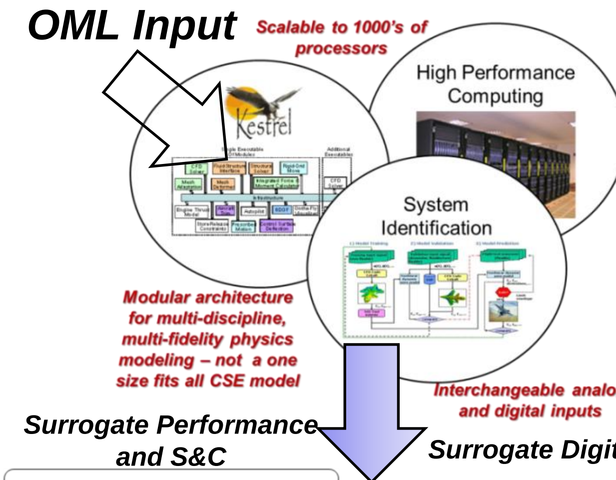


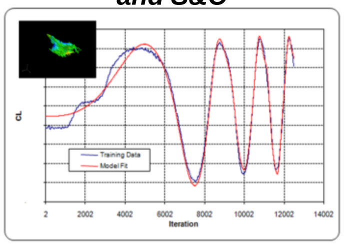
Sentri – RF Capability V-22 RF Signature

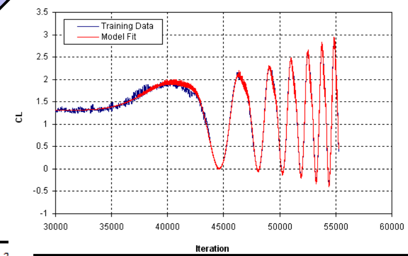
CREATE-AV Kestrel Fixed-Wing Capability

- **Multi-discipline, multi-physics, multi-fidelity capability**
- **Ability to rapidly and efficiently generate reduced order models for digital surrogate representations**
- **Ability to address system integration issues during detailed design (fluid/structures, airframe/propulsion, airframe/weapons)**
- **Key enabler for AF Digital Thread**
- **Being adopted across the A&D Industry**
  - **391 Active Licenses**
  - **21 Defense Organizations**
  - **All OEMs evaluating capabilities**
  - **In use at Service Academies and select university**

Kestrel developers are embedded in the AF Test Center

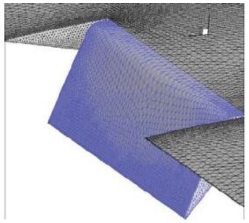


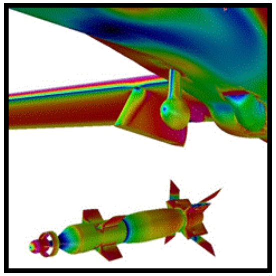




$$C_L(\alpha,q,\dot{q}) = C_0 + C_1\alpha + C_2 q + C_3 q^2\alpha + C_4\dot{q}\alpha + C_5 q^4 + C_6\dot{q}q^2 + C_7 q\alpha^2 + C_8\dot{q}q + C_9\alpha^3 + C_{10}\dot{q} + C_{11}\dot{q}^3 + C_{12}\dot{q}^2 + C_{13}q^2 + C_{14}q\alpha$$

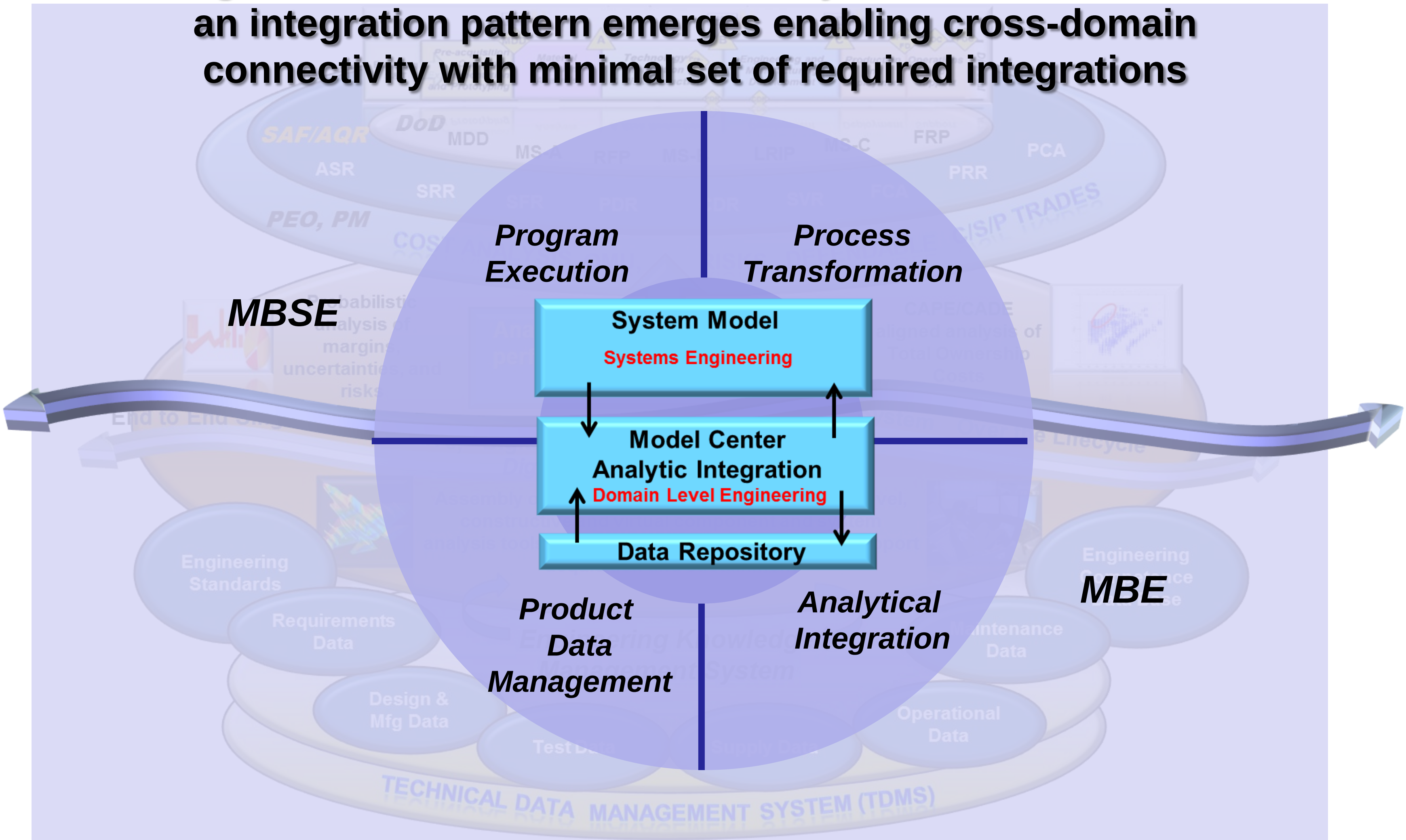
$$Loads = f(\bar{q}, M, \alpha, \alpha^2, q, \alpha q, \dot{q}^2, \ldots)$$





Digital Thread / Digital Twin
The System Architecture Model

Viewing the DT/DTw as the Hub of the System Architecture Model, an integration pattern emerges enabling cross-domain connectivity with minimal set of required integrations



Decision Analytics

INPUT

- Quantified assessment of the state of the SUD* relative to KPP/KSAs
- Probabilistic assessment of risk and costs
- COA scenarios

Prescriptive Analytics:
Used to understand what should be done or to recommend the best course of action for any pre-specified outcome

OUTPUT

- Prognosis of future states
- Comparative analysis of COAs
- Recommended COA

- SUD requirements
- Updated authoritative digital surrogate for system in reduced order model format

Predictive Analytics:
Probabilistic analysis of system state, used to forecast what might happen or could be accomplished.

- Quantified margins and uncertainties
- Risk assessment
- Probable cost assessment

- Engineering standards
- Program requirements
- Digital drawings
- Technical data
- Test data

Descriptive Analytics:
Application of Model Based Engineering analysis tools to transform technical data into useful technical information. Used for data interpretation, evaluation of system/subsystem capabilities wrt requirements

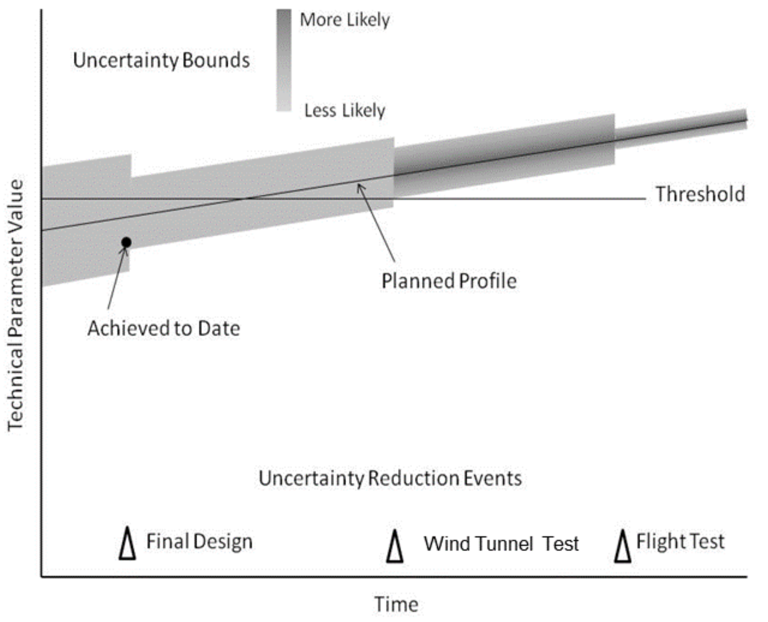
- Analysis of alternatives
- Evaluation of SUD
- Technical reports/briefings
- Updated authoritative digital surrogate for the system/subsystems

** SUD – System Under Development*

MBSE and T&E

MBSE instantiation of the Digital Thread can improve test processes in several ways.

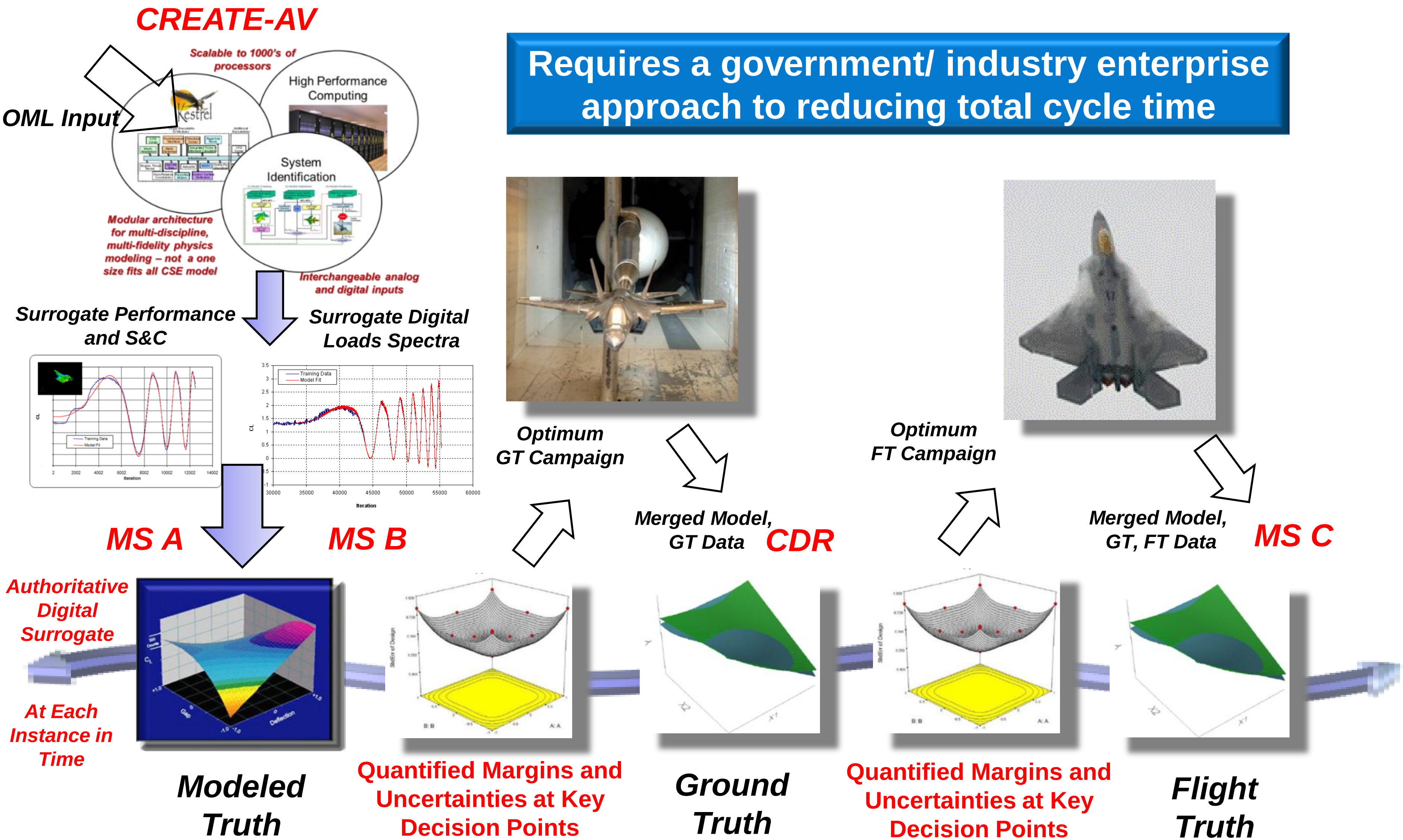
- **Enhanced communication can help test planners to better understand the system they are testing and influence the SEMP/TEMP processes**
- **Improved requirements definition and an emphasis on requirements traceability and testability can help test planners by providing clear test objectives with measurable outcomes**
- **MBSE can help to define an optimum test program by determining the information that is needed and the acceptable uncertainty of the information derived from testing**
- **MBSE approaches can use the system model, along with operational analysis, to establish uncertainty budgets for technical performance measures leading to uncertainty goals for specific test events.**



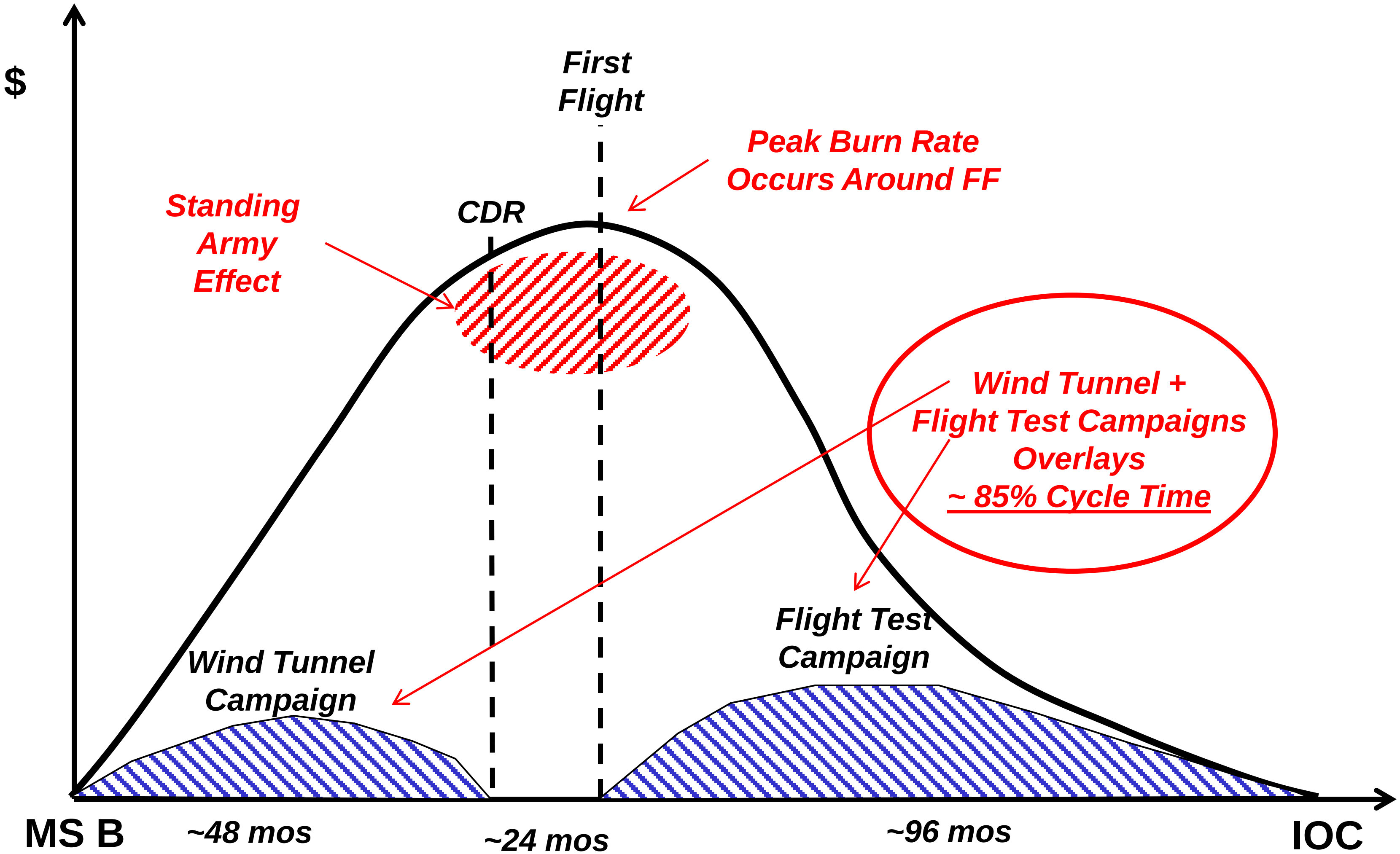
Eileen A. Bjorkman, Shahram Sarkani, Thomas A. Mazzuchi "Using Model-Based Systems Engineering as a Framework for Improving Test and Evaluation Activities"

The Digital Thread is the communication architecture for an MBE/MBSE approach to lifecycle management

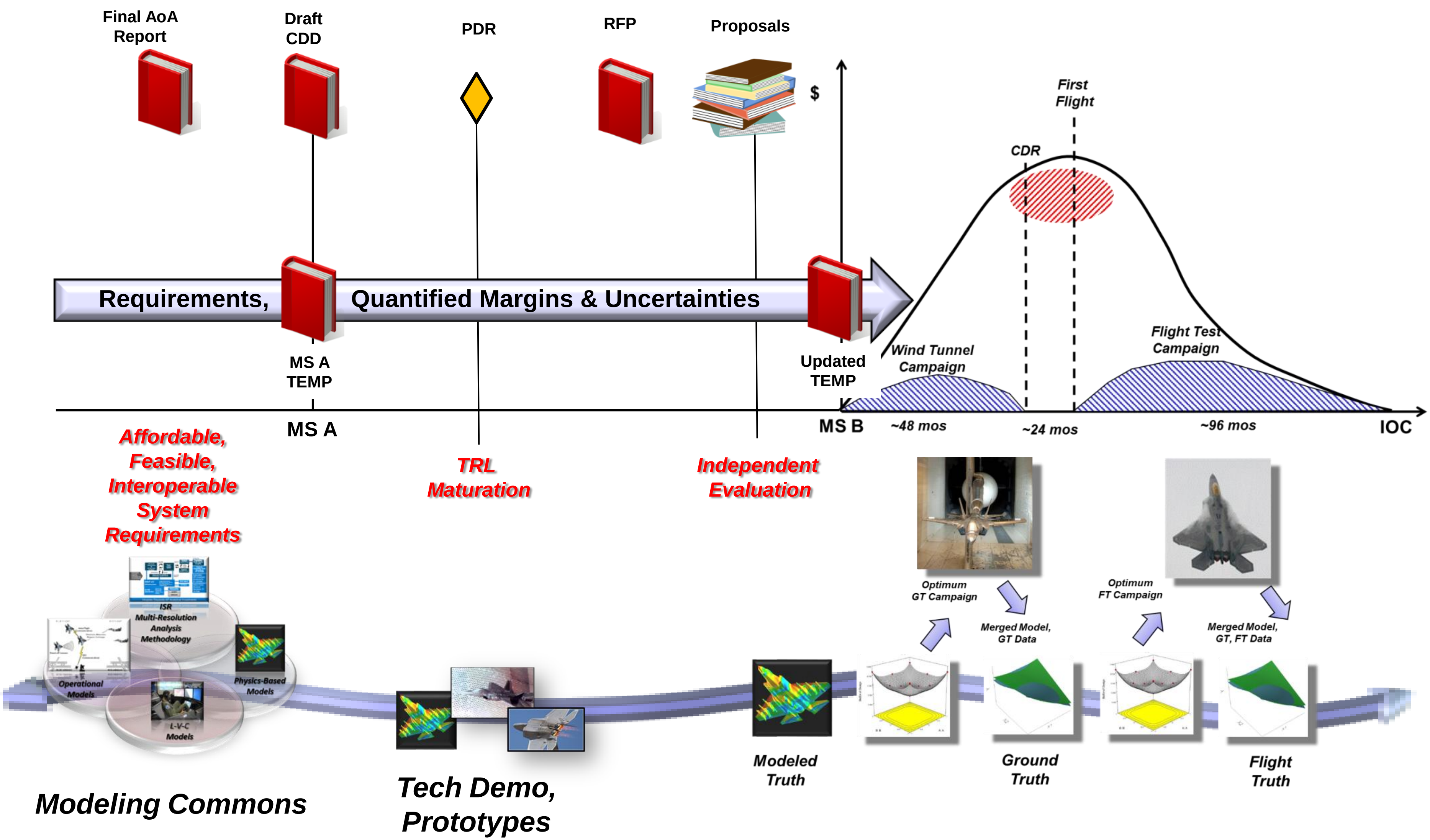
Digital Thread Approach to Aerodynamic Testing – Providing the Performance Baseline Truth



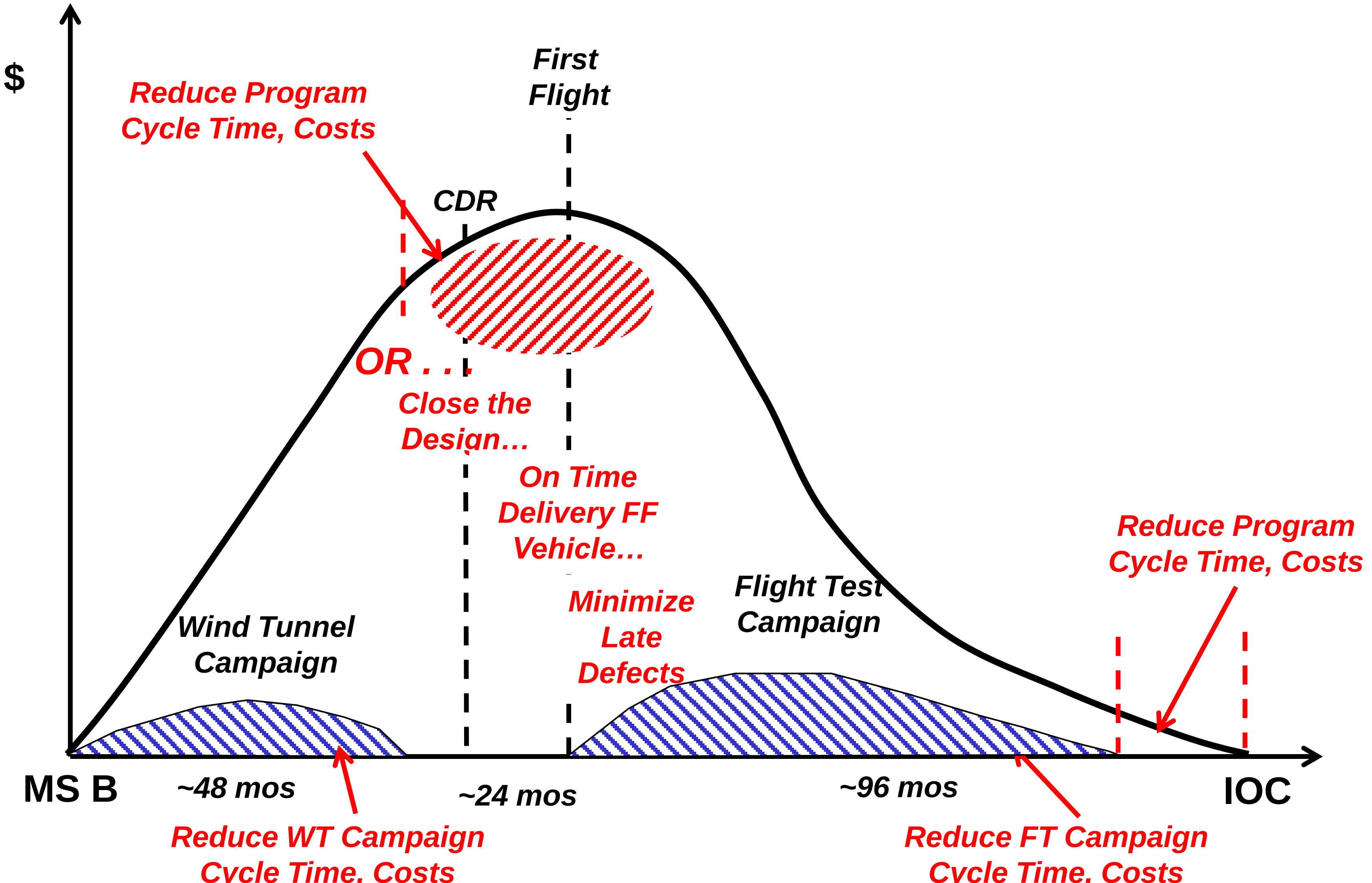
Anatomy of a Fixed-Wing Air Vehicle SDD Program



Starting at Milestone B is Late to Need

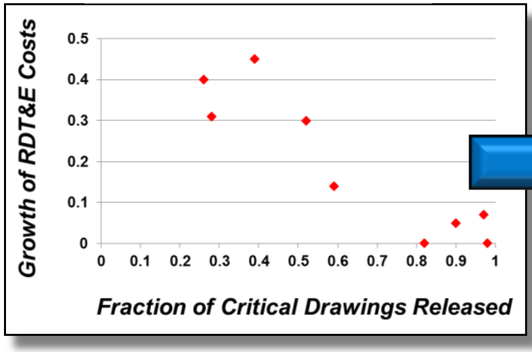


Potential Impacts in the SDD Phase

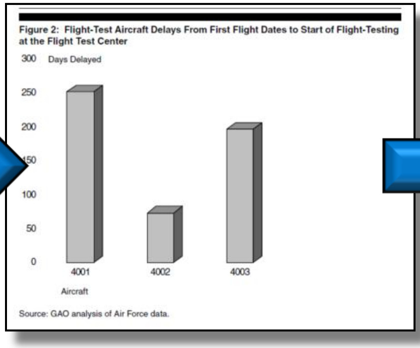


Value of a Quantified Digital Performance Evaluation Baseline

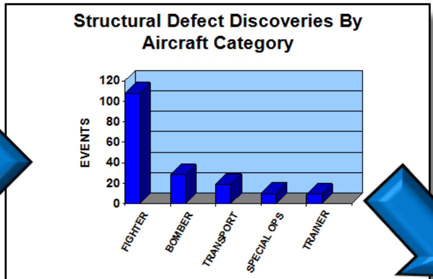
Close the Design at CDR…



Deliver FF Vehicle On Time…

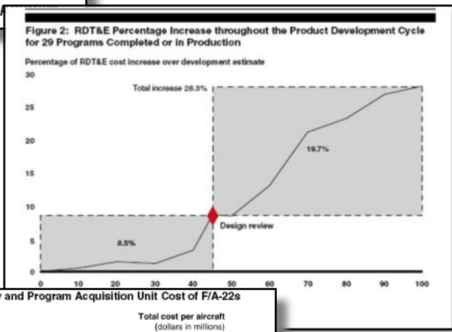


Minimize Late Defects



When normalized by number of aircraft programs in each category, approximately 10 events per aircraft

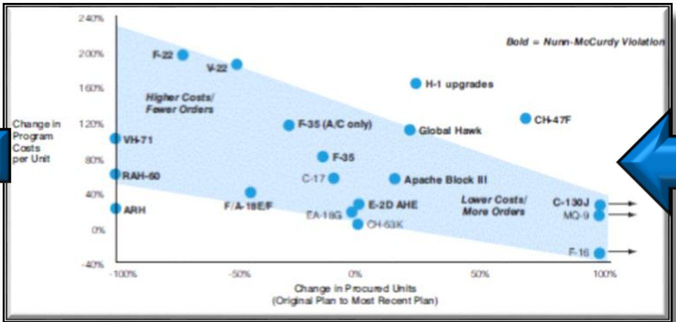
Minimize RDT&E Overruns

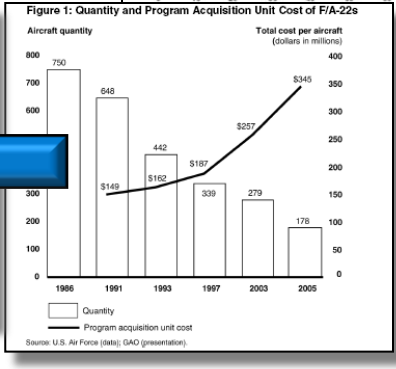


Value is Enhanced with Quantified Performance Margins and Uncertainty Assessments at CDR

$$VALUE \equiv \frac{AIRCRAFT\ AVAILABLE}{PV(TOTAL\ OWNERSHIP\ COST)}$$

Maximize RDT&E Impact on Lifecycle Value

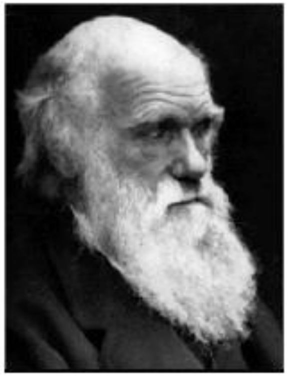




Deliver Contracted Number of Systems on Time/Cost

Summary

- The Digital Engineering revolution is underway across the Aerospace and Defense industry
- The T&E community needs to integrate Digital Engineering as a natural companion to testing
- The T&E community is best positioned to provide a quantified assessment of baseline performance in support of key decision points in the acquisition process, most notably the Critical Design Review
- Successful instantiation of Digital Engineering into the T&E environment will require
  - Policies to ensure T&E expertise is leveraged to provide the quantified baseline performance assessment
  - Very close collaboration between government and industry to improve processes leading to increase value from RDT&E



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"

How Might We…?

- **Develop the policies for a collaborative govt / industry digital thread as the single authoritative surrogate for the system performance?**
- **Develop and sustain a Digital Engineering Ecosystem that enables a collaborative authoritative digital surrogate while protecting equities of the stakeholders?**
- **Collaboratively deploy a Digital Thread/Digital Twin approach to reducing DT&E ground test and flight test cycle time?**

Early Thoughts

	Pre MS A	Pre MS B	Pre MS C
Policies	• Requirements for instantiation of a Digital Engineering approach • Guidance to map TEMP to SRD/ICD • Guidance on use of AoA concepts and MBE tools to quantify TEMP reqts	• Dynamic TEMP – open govt/industry dialogue, streamlined bureaucracy to adjust • Coordinated TEMP and OEM Master Test Plan tied to requirements • Clear definition of Digital Engineering data requirements in RFP • RFP guidance on govt expectations for streamlined T&E • Preserve equities at RFP – clear definitions of rules/tools for evaluation	• Guidance on implementation of the updated MS B TEMP to deliver a streamlined DT&E campaign deploying authoritative digital surrogates and published uncertainty budgets for key KPPs/KSAs • Inclusion of analysis of digital surrogate truth sources and QMU of requirements at critical decision points
Ecosystem	• MBSE Language standards • Collaborative Knowledge Mgt System • Data/Truth Source Taxonomy • Common toolsets, common interests • Preservation of decision meta data • Interfaces with other functional areas, e.g., CAPE/CADE • Not Program dependent	• Governance of authoritative truth sources • Common data as the connective tissue between govt and industry • Govt data accepted is govt data and part of the authoritative truth source • Protection of proprietary data • Security Classification Guides	• Continuity of authoritative digital knowledge with Production, Delivery, Training, Operations and Sustainment • Post MS C - Capture manufacturing, operations, and sustainment data in digital surrogates, apply big data analytics to relate initial requirements setting and design decisions to operational performance and total ownership costs
T&E Processes	• Resourced pre MS A govt DT&E SMEs to address requirements/testability • Apply MBE tools to develop initial modeled truth source/digital surrogate • Quantify acceptable uncertainty budgets for test information vs requirements – ID capability gaps • Apply initial modeled truth source to guide optimum test campaigns, include in MS A TEMP along with uncertainty budgets	• OEM apply advanced MBE tools to design integrated system • Update modeled performance truth source with current design, data from prototypes and experimentation • Quantify margins/uncertainties (QMU) against documented requirements, include in PDR assessment • Update approach to optimum test campaign – include in RFP • Evaluate proposed systems, update MS B TEMP with current truth sources	• Update/deploy optimum WT campaign, incorporate flight data with modeled and ground test data to update truth sources • Provide QMU for decision support at CDR, FRR • Apply updated digital surrogate to define an optimum flight test campaign • Update authoritative truth source with flight data to provide the “as flown” authoritative digital surrogate • Provide QMU for decision support at LRIP

Seeding Some Technical Thoughts

- Earlier, model-based integrated design, e.g., airframe/ structure, airframe/propulsion, airframe/weapons, etc followed by improved test techniques for <u>integrated</u> systems
- Collaborative govt/industry authoritative digital surrogate to quantify KPPs/KSAs and develop uncertainty budget for tests
- Application of a load-bearing WT model framework with adaptive manufacturing surface elements to arrive at a final OML quicker
- Reduced wind tunnel entries using remotely actuated control surfaces, auto-trimming features to produce aero, S&C, trim loads in single, final entry.
- Integration of authoritative digital surrogate for weapon performance with digital authoritative surrogate for the air-vehicle environment for weapons carriage / release
- Use reduced order response surfaces and adaptive learning Bayesian techniques to minimize flight test sorties
- Decouple software regression from flight testing using open modular architectures and virtual SILs