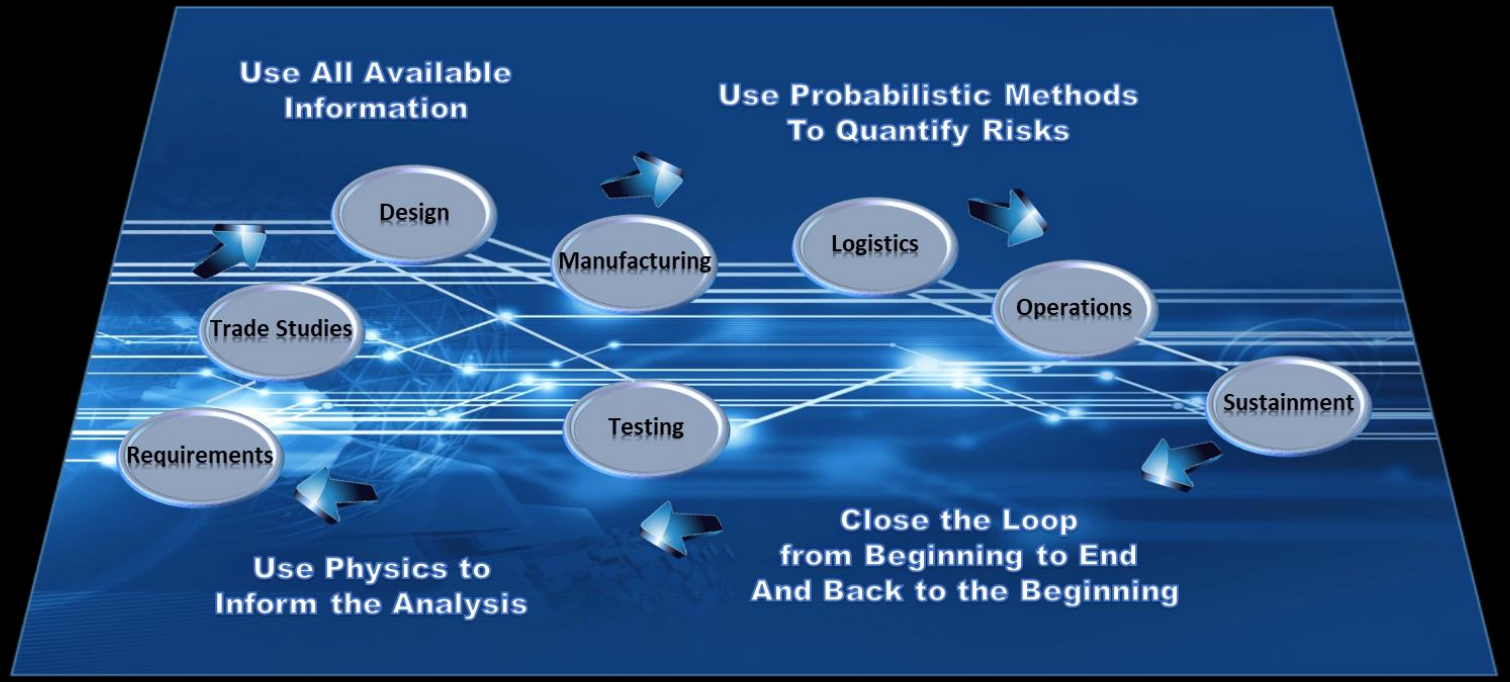
Digital Engineering – a Disruptive Transformation of Aerospace and Defense Tools, Processes, and Culture



Dr. Ed Kraft

Associate Executive Director for Research
University of Tennessee Space Institute

March 20, 2018

The Global Digital Revolution – a Disruptive Transformation of Industry

History of Industrial Revolutions – Always Driven By New Enabling Technologies

End of the 18th Century

1. Industrial Revolution

Introduction of mechanical production plants using water and steam technology

End of the 19th Century

2. Industrial Revolution

Introduction of mass production based on division of labor using electrical power

1970

3. Industrial Revolution

Introduction of electronics and IT to increase the level of automation

Industry 4.0

2015-2020

4. Industrial Revolution

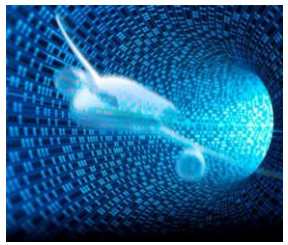
Introduction of the cyber-physics world - Intelligent automation and integration of physical & virtual worlds

Internet of Things

Cloud Computing

Big Data Analytics

Digital Engineering



Digital Manufacturing

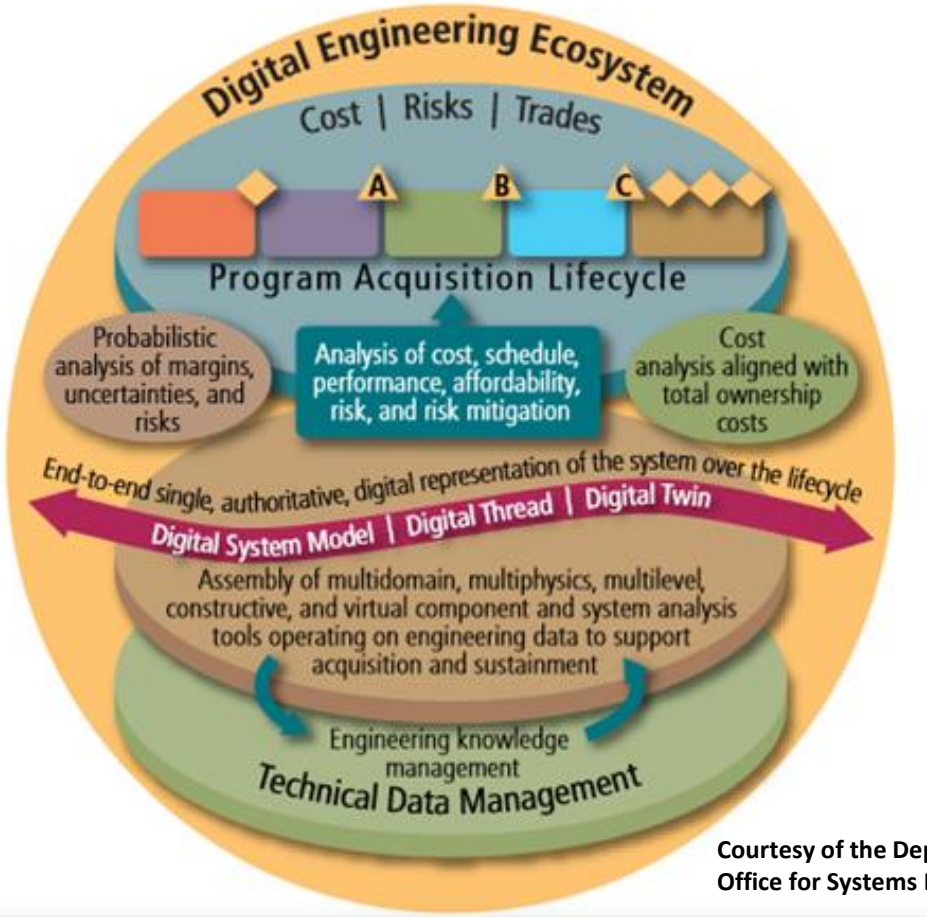
The Digital Revolution is Already Here

The Challenge

- The Aerospace & Defense Industry is investing heavily in Industry 4.0 for their commercial opportunities
- The A&D Industry is at the threshold of developing Digital Engineering Ecosystems to take advantage of the Digital Revolution for defense programs
- Challenges to developing a Government / Industry Digital Environment for Defense Systems include:
  - Technologies and Tools for a cyber-physical world
  - Policies – data rights, intellectual property
  - Processes – moving from document-centric to fully digital model-based processes
  - Culture – education and training in Systems Engineering and Program Management consistent with the Digital Revolution

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

Digital Engineering Ecosystem

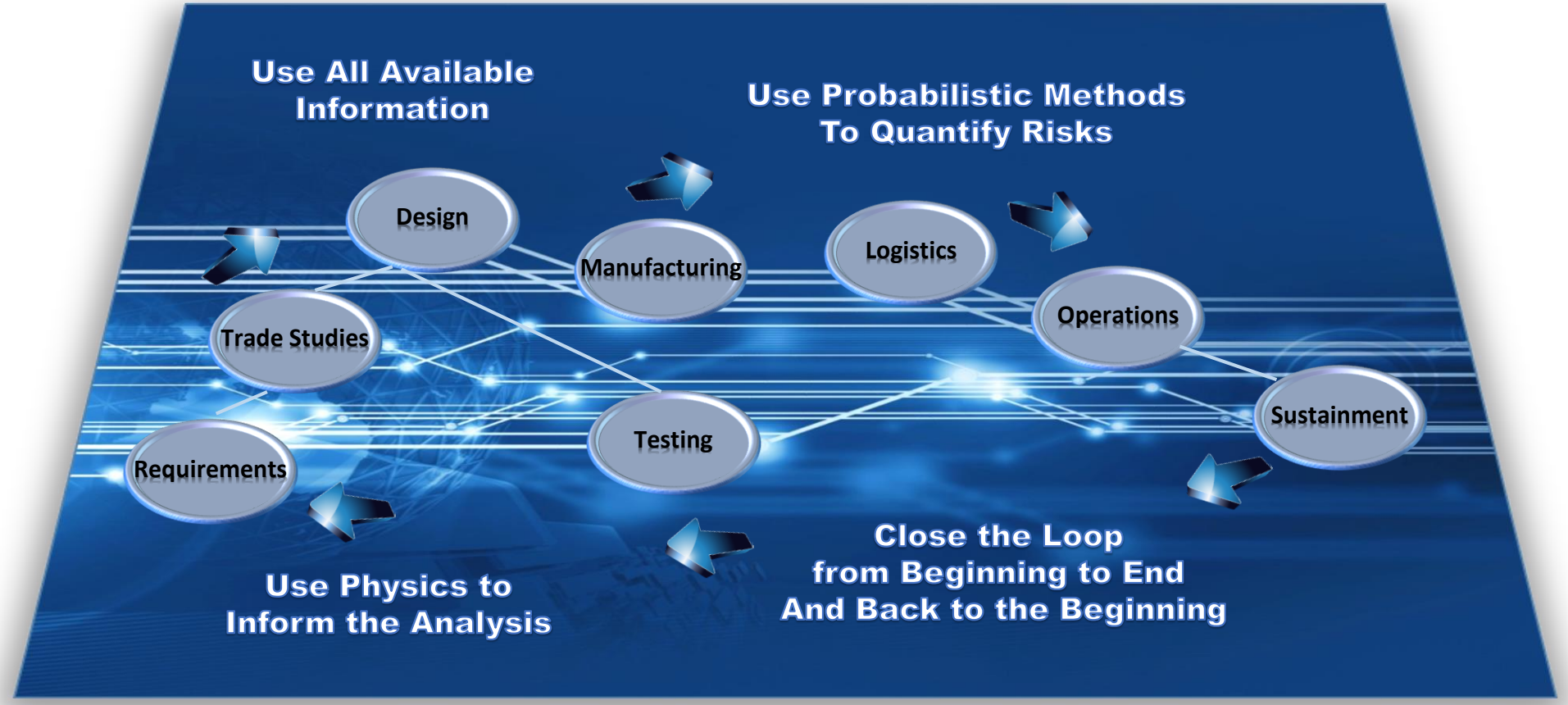


Courtesy of the Deputy Assistant Secretary of Defense
Office for Systems Engineering

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



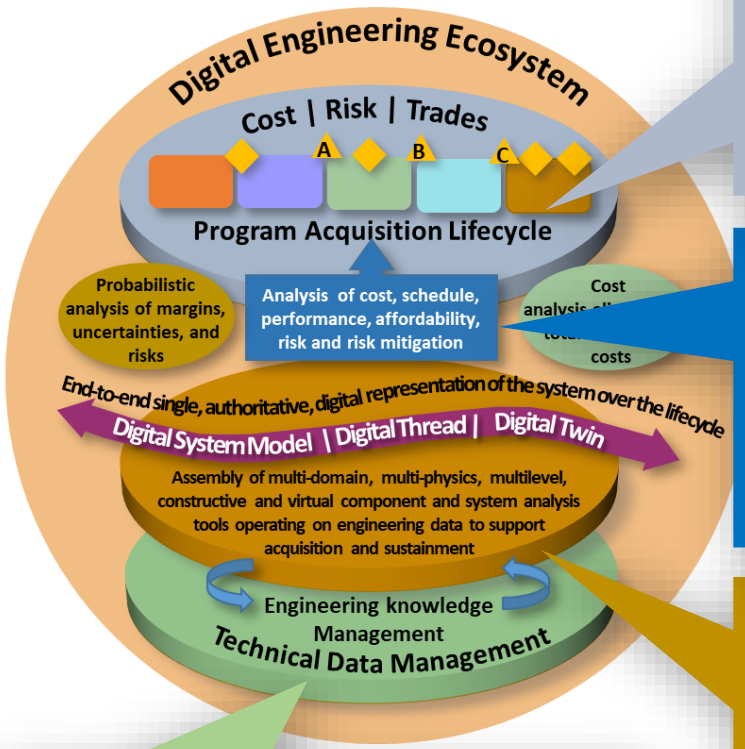
Make Informed Decisions Throughout the Lifecycle

Tenets of the Digital Thread/Digital Twin

- 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

Decision Analytics



Sources of Record

Prescriptive Analytics:

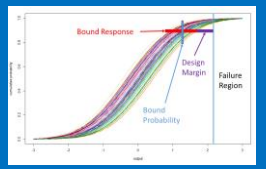
Used to understand what should be done or to recommend the best course of action for any pre-specified outcome

Risk = {Failure Scenario, Probability, Consequence}

Do

Predictive Analytics:

Probabilistic analysis of system state, used to forecast what might happen or could be accomplished – quantified margins and uncertainties



Think

Descriptive Analytics:

Application of Model Based Engineering analysis tools to transform technical data into system state technical information – the authoritative digital surrogate "truth source".

See

Risk – Uncertainty with Consequences

UQ – The Connective Tissue Between Analysis and Decisions

Descriptive Analytics
A Single, Authoritative Digital Surrogate "Truth Source"

INSTITUTE

Predictive Analytics

- Publish
- Syndicate

- Access Security Management
- Interface, Analyze, Support Predictive Analytics
- "Truth Source" Quality Metrics

- Data Governance
- Equities of Stakeholders
- Data Quality
- Data Security

Authoritative Source of Truth

SMARTUQ®

Model Based Systems Engineering

Engineering Design and Analysis

Data Transformation Into a Digital Surrogate

Data Validation, Verification, and Uncertainty Quantification

Data Servicing and Analytics

- Analyze
- Compute
- Transform
- Document
- Store

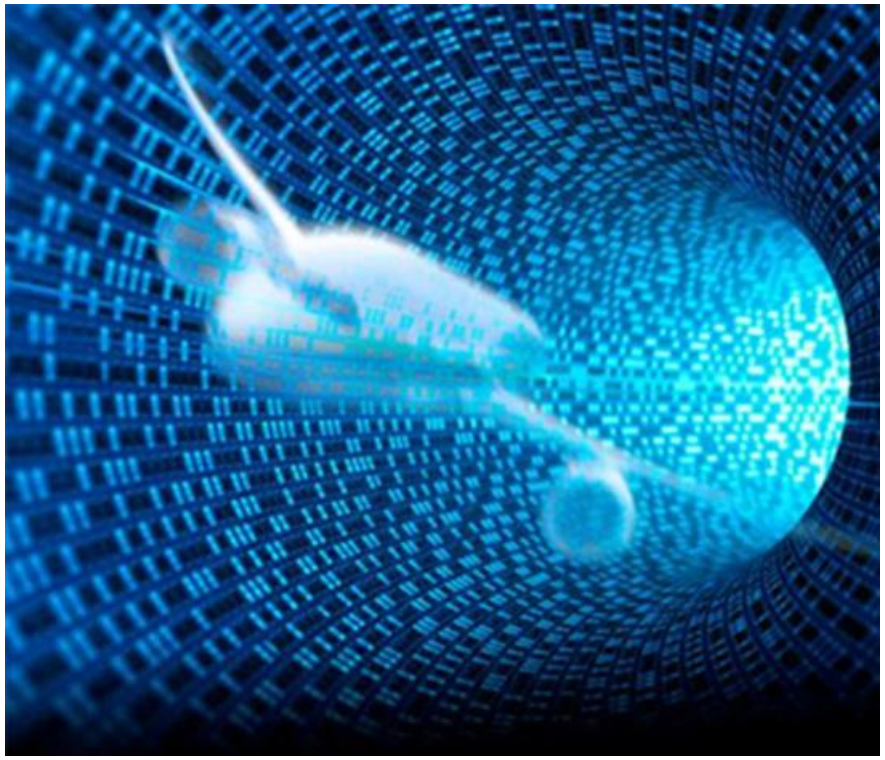
- Semantic Data / Tools Search and Discovery
- Data Formatting
- Meta Data
- Data Management
- Source Security Management

PLM | Test Data | Models | Analysis Tools | Truth Source

- Configuration Management
- Pedigree
- Provenance

Distributed Sources of Record

Thinking Digitally - Targets of Opportunity



Shifting from linear, document-centric system lifecycle process towards a dynamic, connected, digital model-centric ecosystem enables disruptive transformations including

- **Digital TEMP – dynamically coupled to requirements, employs model based engineering and uncertainty quantification to develop an optimum T&E campaign, minimize defects**
- **T&E as key to the validation of an Authoritative Digital Surrogate Truth Source**
- **Digital Critical Design Review – Use Surrogate Truth Sources to quantify margins and risks, project optimum course of action**

The Digital Revolution

Physical Science + Data Science + Learning System = Velocity

Integrated Test Team - Stuck in a Document Centric Mode…

Current TEMP as required by the DODI 5000.02

- Represents a linear, document-centric, positional approach
- Not connected to changing Requirements
- Does not use all of the available knowledge / information
- Doesn't readily support optimization of T&E campaign
- Does not address generating the authoritative truth source through an integrated application of UQ

Test and Evaluation Master Plan (TEMP) requires 12 months to prepare and 10 months to review with up to 56 organizations at 8 levels involved in the review.

GAO-15-192, February, 2015

. . . and the next day someone changes a requirement and it is obsolete!

… Moving to a Digitally Connected ITT, Digital TEMP

Use early model-based authoritative digital surrogates combined with requirements and uncertainties to develop an optimum test campaign to reduce time/costs and assure requirements are met

A Digital TEMP will

- **Provide a model-centric approach <u>dynamically coupled</u> to digital Requirements**
- **Apply digitally captured system performance parametric sensitivities from trade studies to quantify T&E requirements**
- **Use digitally captured MRTFB capabilities / performance maps / schedules to identify gaps for investments to meet requirements**
- **Employ digitally captured quantified epistemic and aleatory uncertainties for MRTFB test capabilities and processes to allocate uncertainty reduction budgets to particular tests – learning when you have to iterate the design or move on to the next level of testing**

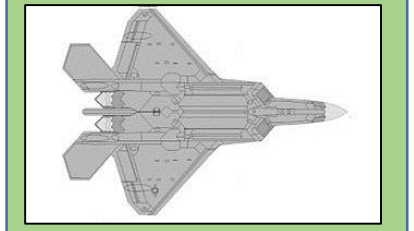
T&E – Moving Beyond Statistically Defensible Testing to Validation and Calibration of the Authoritative Truth Source

SPACE INSTITUTE

Expanded Impact of T&E Results Leading To →

Authoritative Truth Source

Sources of Record



CAD Geometry File

- Operating Conditions Library
- Test Data
- Validated Models
- Reports

SysML System Requirements

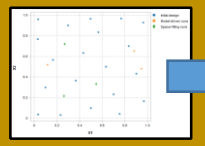
Testing and Operations

Code Validation

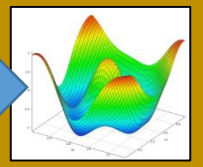
Select Calibration / Training Points

Minimize the Number of Experiments / Tests

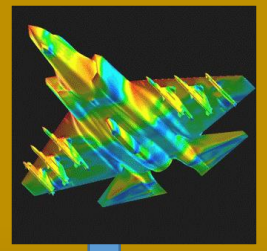
Optimum Experimental DOE



Calibrated Response Surface Model



High Fidelity Model

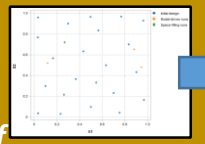


Enhanced Numerical Solutions

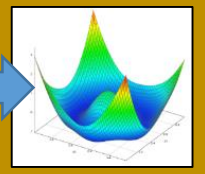
Select Calibration / Training Points

Minimize the Number of High Fidelity Modeling Computations

Statistical Calibration

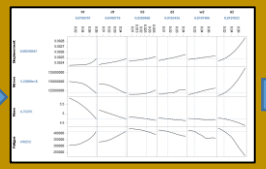


Adaptive DOE

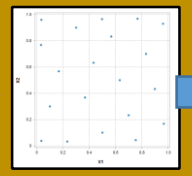


Intermediate Response Surface Model

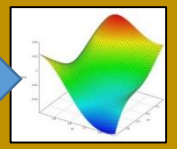
Lower Fidelity Model



Parametric Sensitivity Study



Design of Experiments



Initial Response Surface Model

Engineering Design & Analysis

Trade Studies

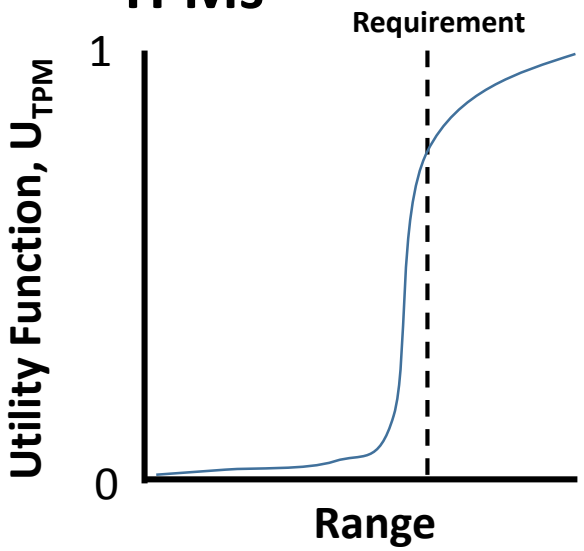
Response Surface Development & Calibration

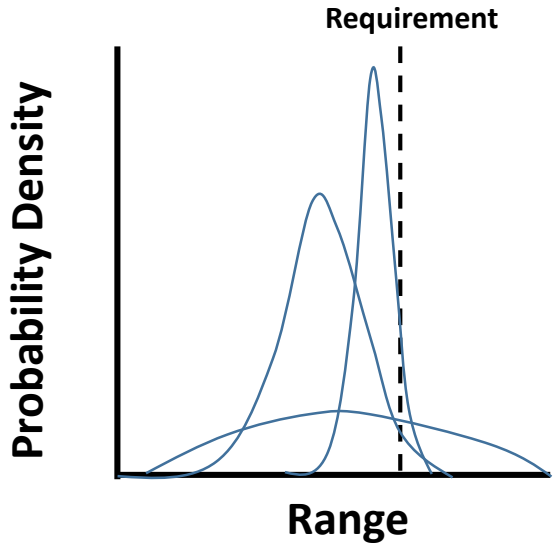
Calibrated Response Surface Digital Surrogate

Updated with Additional Test and Operational Data Over the System Lifecycle

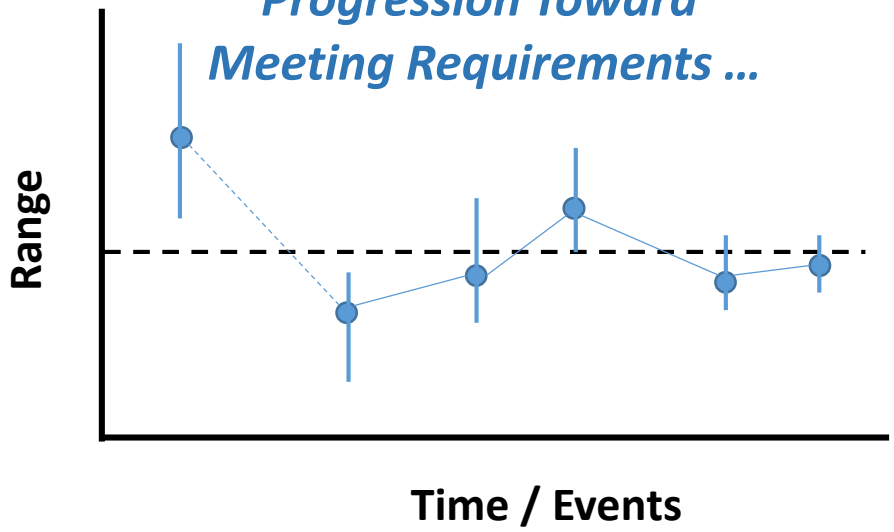
Prescriptive Analytics
Technical Performance Measures (TPMs) and Military Utility Risks

- TPMs can be related to measure of Military Utility and change as the development risk reduction processes progresses
- TPMs are estimated early in the requirements setting and design process and are refined based on data from analyses, simulations, prototypes, demonstrations, etc
- Performance risk is the product of probability and impact on utility
- Overall performance risk is the weighted sum of the risks for all associated TPMs

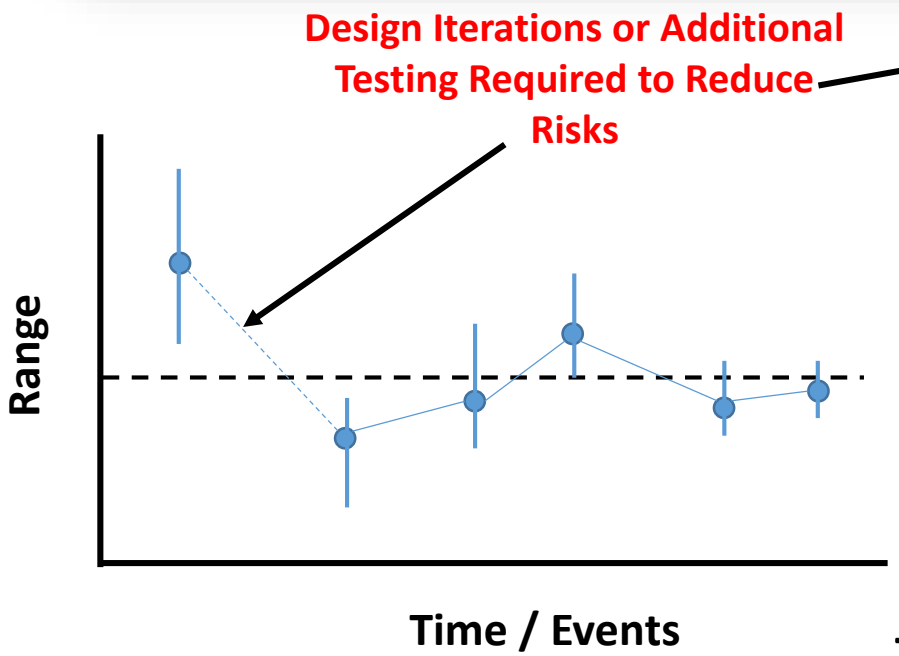




UQ is the Measure of Progression Toward Meeting Requirements …



Prescriptive Analytics
Risk Reduction/Mitigation Strategies Impact On Value Objective



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

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

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

± Impact on Performance, Cost, Schedule, and # Systems Produced

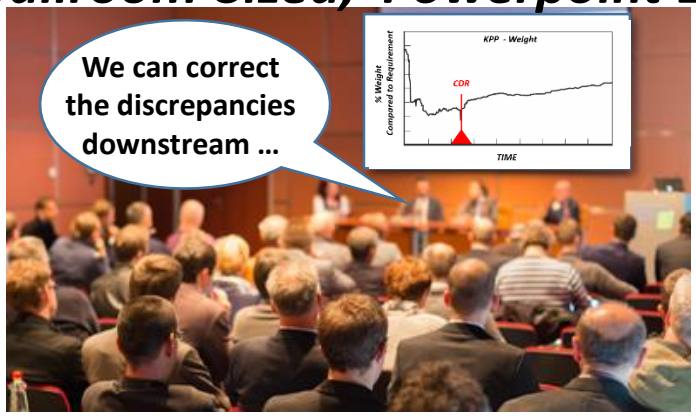
$$Value = Military\ Utility \cdot Availability \cdot (Total\ Ownership\ Costs)^{-1}$$

UQ Becomes an Inherent Bayesian Process that Not Only Quantifies Progression Toward Objectives But Projects Next Best Activity to Mitigate Risk

Deyst, John J. "The Application of Estimation Theory to Managing Risk in Product Development" MIT Report

A Digital Critical Design Review (CDR)

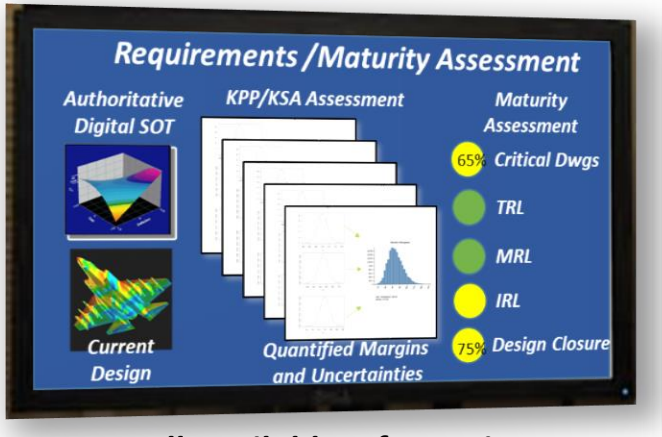
Moving From a Calendar-Driven, Ballroom-Sized, Powerpoint Event . . .



…to a Digitally Current, Quantified Risk Assessment to Support Better Decision Making

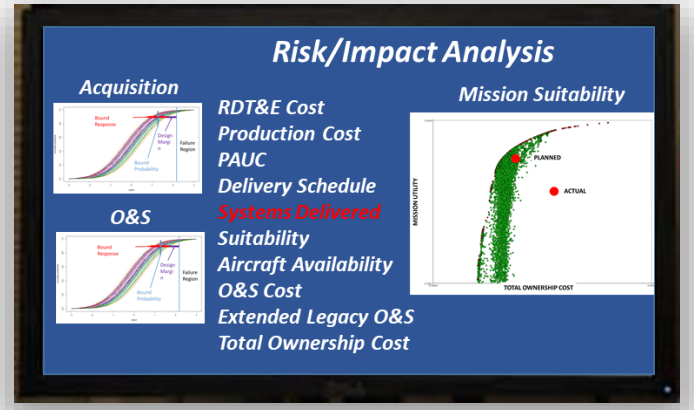
- ***See*** – bring all authoritative digital surrogate truth sources to understand the performance of the system at CDR vs requirements – target 90% confidence level in design closure
- ***Think*** – use data analytics/probabilistic analyses to assess risk, impact on military utility, and total ownership cost of any requirements gaps
- ***Do*** – analyze multiple decision scenarios to select the best value course of action including data-driven mitigation strategies

See



Use All Available Information

Think



Use Probabilistic Analysis to Inform

Do

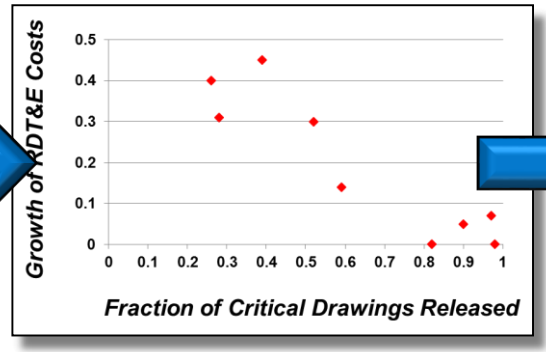
Select Best Value COA

Risk = Uncertainty with Consequences

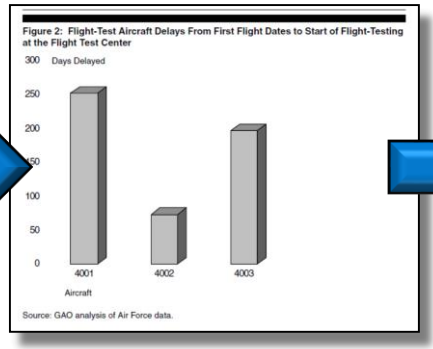
Value of a Digital CDR
Connecting Critical Decisions to Lifecycle Value

Previous Knowledge
- Requirements Volatility
- % Design Closure at PDR
- TRL at MS B

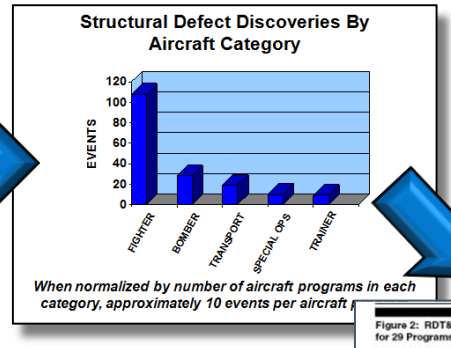
Close the Design at CDR…



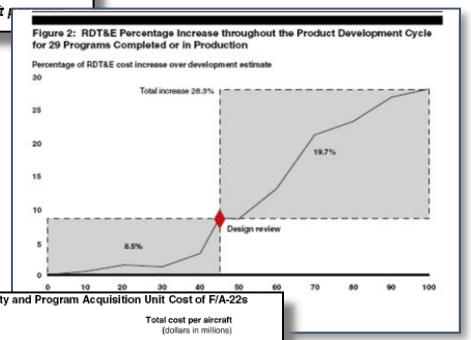
Deliver FF Vehicle On Time…



Minimize Late Defects

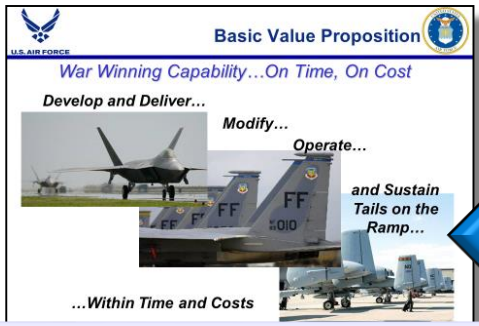


Minimize RDT&E Overruns

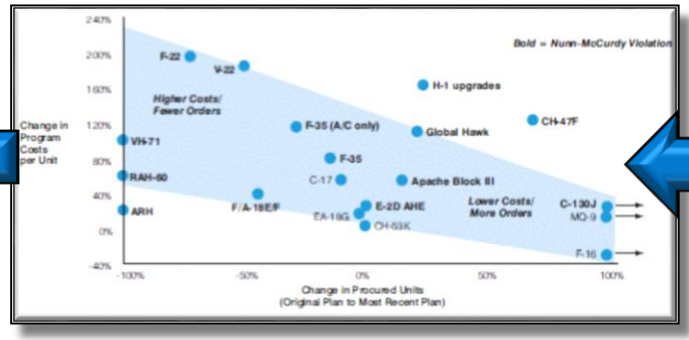


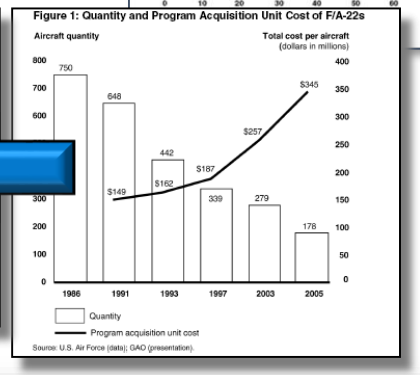
It All Starts with Quantified Performance Margins and Uncertainty Assessments at CDR

Maximize RDT&E Impact on Lifecycle Value



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





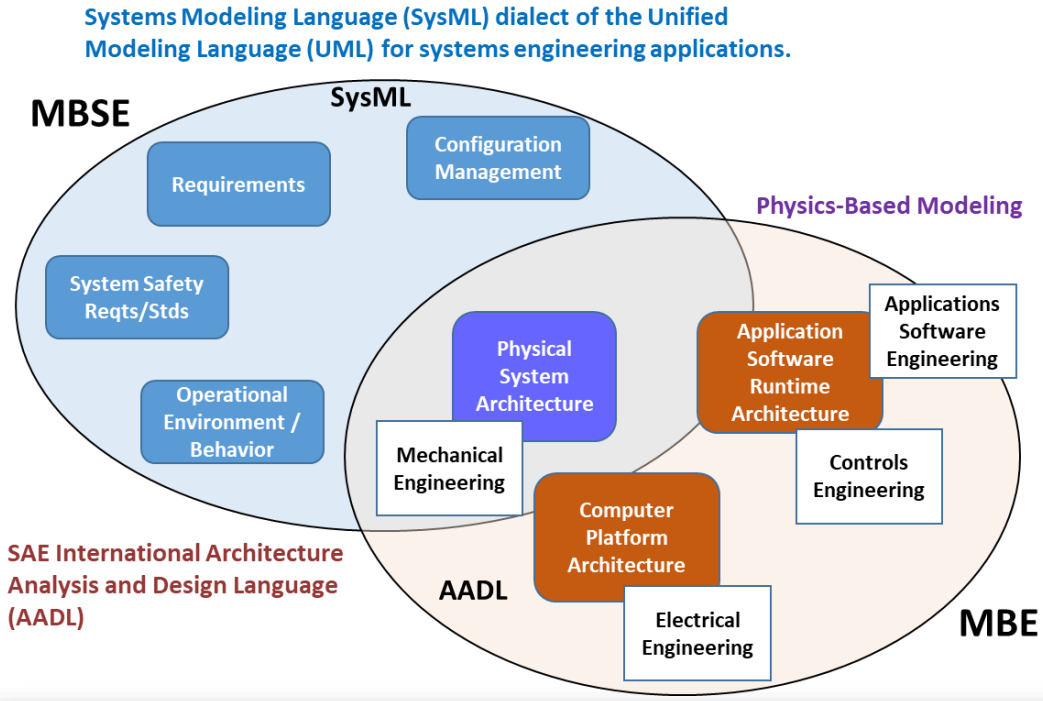
Deliver Contracted Number of Systems on Time/Cost

Consequence of implementing DODI 5000.02 as a <u>positional</u> vice an <u>intentional</u> process has lead to a cascade effect of unconnected decisions not supported by quantified risk assessments

The Next Generation of Digital Systems Engineers Training/Education

- Trained in Digital Modeling
  - Systems Modeling Language (sysML)
  - Architecture Analysis and Design Language (SAE AADL)
  - Physic-Based Modeling
  - Uncertainty Quantification / Risk Analysis
  - Systems Thinking / Systems Dynamics
- Translate traditional Case Study reports to scenario emulators for a digital engineering ecosystem
- Train on Systems Engineering / Program Manager "Flight Simulators" with real world consequences for decisions made
- Use the Digital Engineering Ecosystem to "See-Think-Do"
- Capstone projects focused on streamlining digital processes to increase value

Move from a Build-Test SE paradigm to a new Integrate-Analyze-Build SE Paradigm



Early SE analysis of the total system including the architecture for software intensive systems will be essential for cyber and autonomous systems

Summary

- The Digital Revolution is reshaping the development, fielding, and sustainment of aerospace and defense systems
- The DoD is at the front end of a significant journey toward a Digital Engineering transformation mandated by the need to maintain technical dominance over adversaries
- The Keys to Success encompass
  - Connecting tools and technologies to support a Digital Engineering Ecosystem
  - Establishing policies to enable a public/private partnership while respecting data rights and intellectual property
  - Moving from positional document-centric to fully digital, model-based, intentional processes
  - Educating and training Systems Engineers and Program Managers to lead the Digital Revolution

The Value of the Digital Revolution to the Development, Operation, and Sustainment of DoD Systems Seems Self-Evident But Must Be Proven at Each Stage of Implementation

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Upcoming Related Webinar

- “Uncertainty Quantification and Decision Analytics for Aerospace and Defense"
- Thursday, March 29, 2018 1:00 PM - 2:00 PM CDT
- Sponsored by SMARTUQ
- You can register for the free Webinar at https://www.smartuq.com/