Integrity ★ Service ★ Excellence

Digital Thread Implementation in the Air Force: AFRL's Role

NIST MBE Summit

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Brench Boden, AFRL/RXMS

DoD & USAF Strategic Context: Acquisition/Engineering Focus

Better Buying Power 3.0

Achieving Dominant Capabilities through Technical Excellence and Innovation

Achieve Affordable Programs
- Continue to set and enforce affordability caps

Achieve Dominant Capabilities While Controlling Lifecycle Costs
- Strengthen and expand "should cost" based cost management
- Anticipate and plan for responsive and emerging threats by building stronger partnerships of acquisition, requirements and intelli
- Institutio
- Strengthe

Incentivize Pro
- Align profitability more tightly with Department goals
- Employ appropriate contract types, but increase the use of incentive type contracts
- Expand the superior supplier incentive program
- Ensure effective use of Performance-Based Logistics
- Remove barriers to commercial technology utilization
- Improve the return on investment in DoD laboratories
- Increase the productivity of corporate IRAD

Incentivize Innovation in Industry and Government
- Increase the use of prototyping and experimentation
- Emphasize technology insertion and refresh in program planning
- Use Modular Open Systems Architecture to stimulate innovation
- Increase the return on and access to small business research and development
- Provide draft technical requirements to industry early and industry in funded concept definition
- Provide clear and objective "best value" definition

Eliminate Unproductive Processes and Bureaucracy
- Emphasize acquisition chain of command responsibility, authority and accountability
- Reduce cycle times while ensuring sound investments
- Streamline documentation requirements and staff reviews
- Remove unproductive requirements imposed on industry

onments
nd products from
ncluding more effective use of market research

Improve Tradecraft in Acquisition of Services
- Strengthen contract management outside the normal acquisition chain – installations, etc.
- Improve requirements definition for services
- Improve the effectiveness and productivity of contracted engineering and technical services

Improve the Professionalism of the Total Acquisition Workforce
- Establish higher standards for key leadership positions
- Establish stronger professional qualification requirements for all acquisition specialties
- Strengthen organic engineering capabilities

hnically
mitigate

Cost Cons

ment 1

DoD BETTER BUYING POWER 3.0

Bending the Cost Curve

- AF leadership is committed to maintaining global vigilance, reach and power today and for decades to come
- Weapon system costs are escalating and
- ic agility" in
- Air Force Acquisition Enterprise directive to become the most agile and effective acquisition force in government
- BTCC Initiative launched to work with Industry to foster ideas and take bold transformative actions

SECAF "BENDING THE COST CURVE"

- Strengthen organic engineering capabilities

Focus Area 3: Analysis Capability

Desired End-State: A framework which enables informed decision making, tool interoperability, best practices, training, and authoritative data reuse across the DoD enterprise and industry; resulting in stronger organic engineering capabilities

Headquarters U.S. Air Force

SAF/AQ Priority #3:
"OWN THE TECHNICAL BASELINE"

Acquisition Enterprise Priorities for 2014

October 2014

Priority 3-Tech Baseline

U.S. AIR FORCE

- "Own the technical baseline (OTB) for key programs"
  - Measures: access to tech data, established process, technical staff

Most Relevant DoD-level Activities

DIGITAL SYSTEM MODEL

ODASD(SE) Initiative to build an integrated taxonomy for organizing, tracking, and sharing tech data and associated artifacts across the life cycle

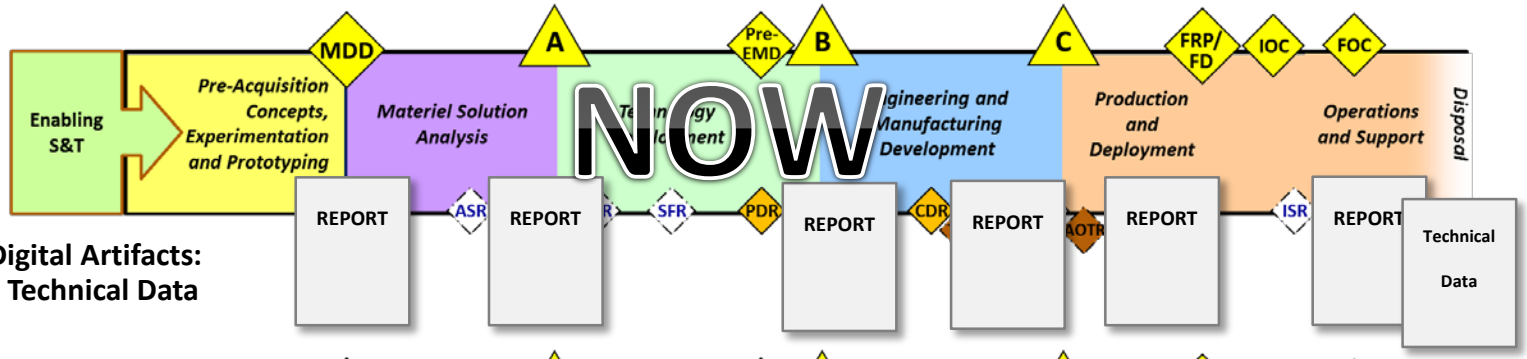
ERS ENGINEERED RESILIENT SYSTEMS DEPARTMENT OF DEFENSE

COI to create engineering concepts, techniques, and tools that lead to the design, development, testing, manufacturing, and fielding of trusted, assured, and easily modified weapons systems

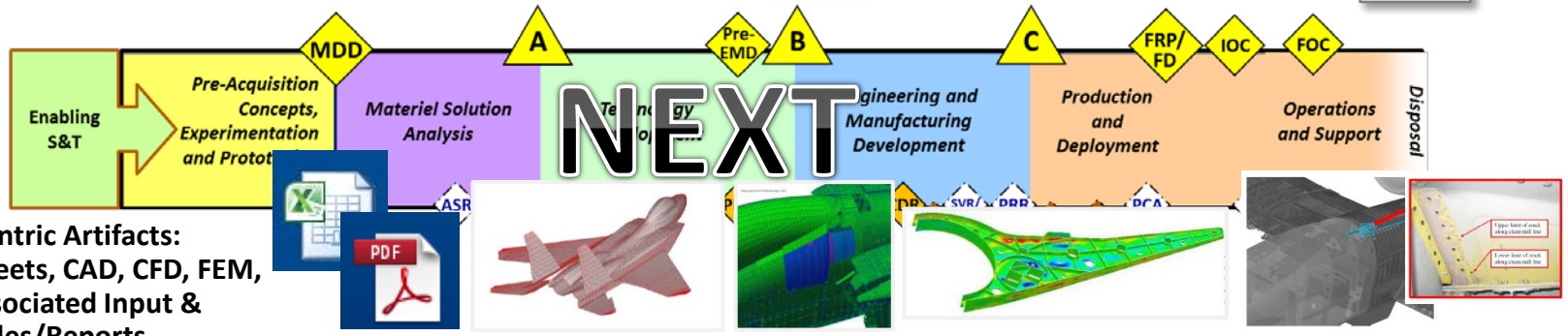
DMDII DIGITAL MANUFACTURING AND DESIGN INNOVATION INSTITUTE

A unique public-private partnership acting as a world-class, first-of-its-kind manufacturing hub and leading US advocate for digital manufacturing

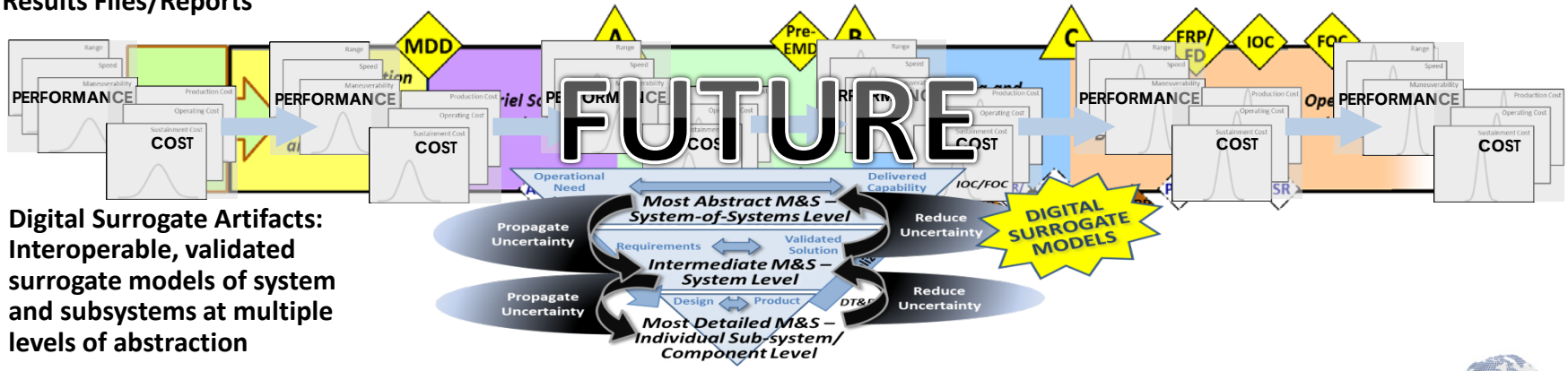
The DT Revolution: From Digital Artifacts to Model-centric Engineering and Beyond



Paper or Digital Artifacts: Reports & Technical Data

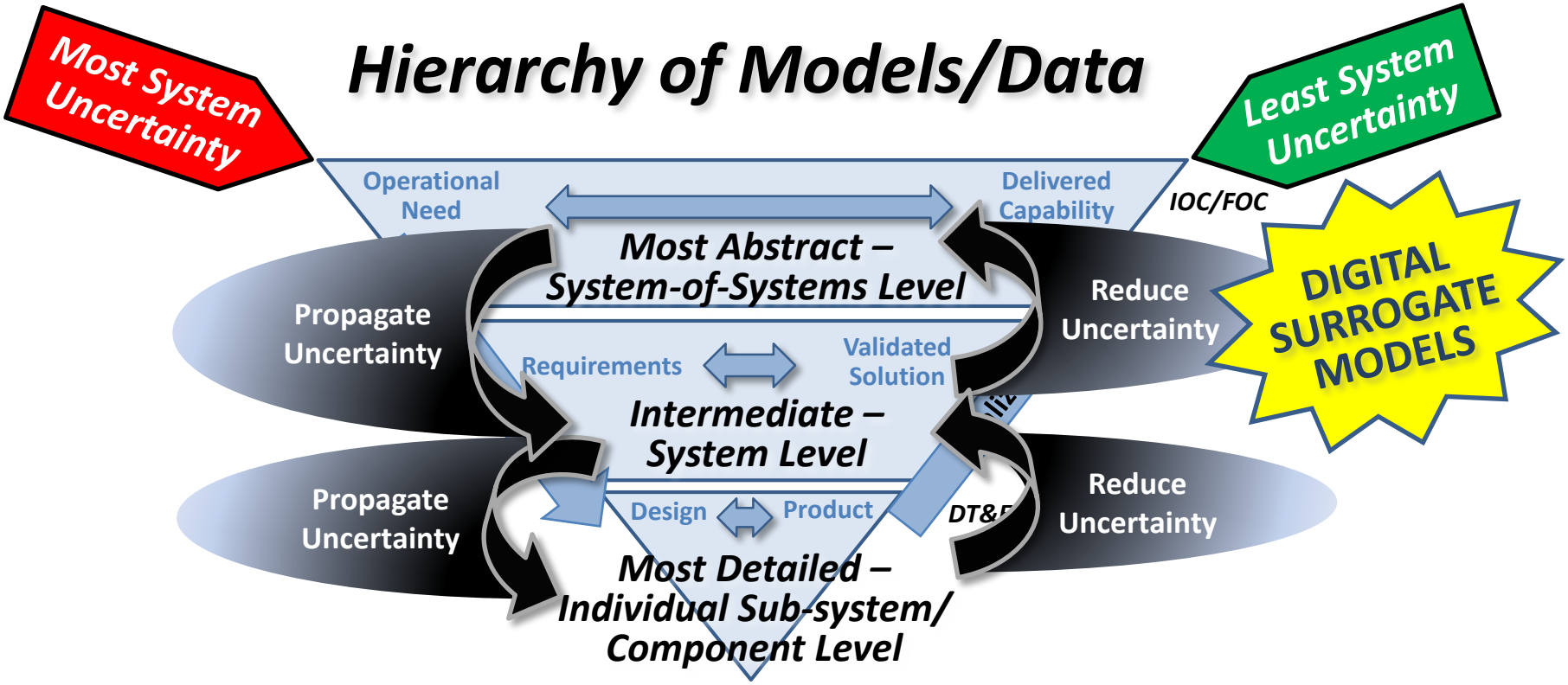


Model-centric Artifacts: Spreadsheets, CAD, CFD, FEM, etc. & Associated Input & Results Files/Reports



Digital Surrogate Artifacts: Interoperable, validated surrogate models of system and subsystems at multiple levels of abstraction

Model-centric Systems Engineering with the Digital Thread

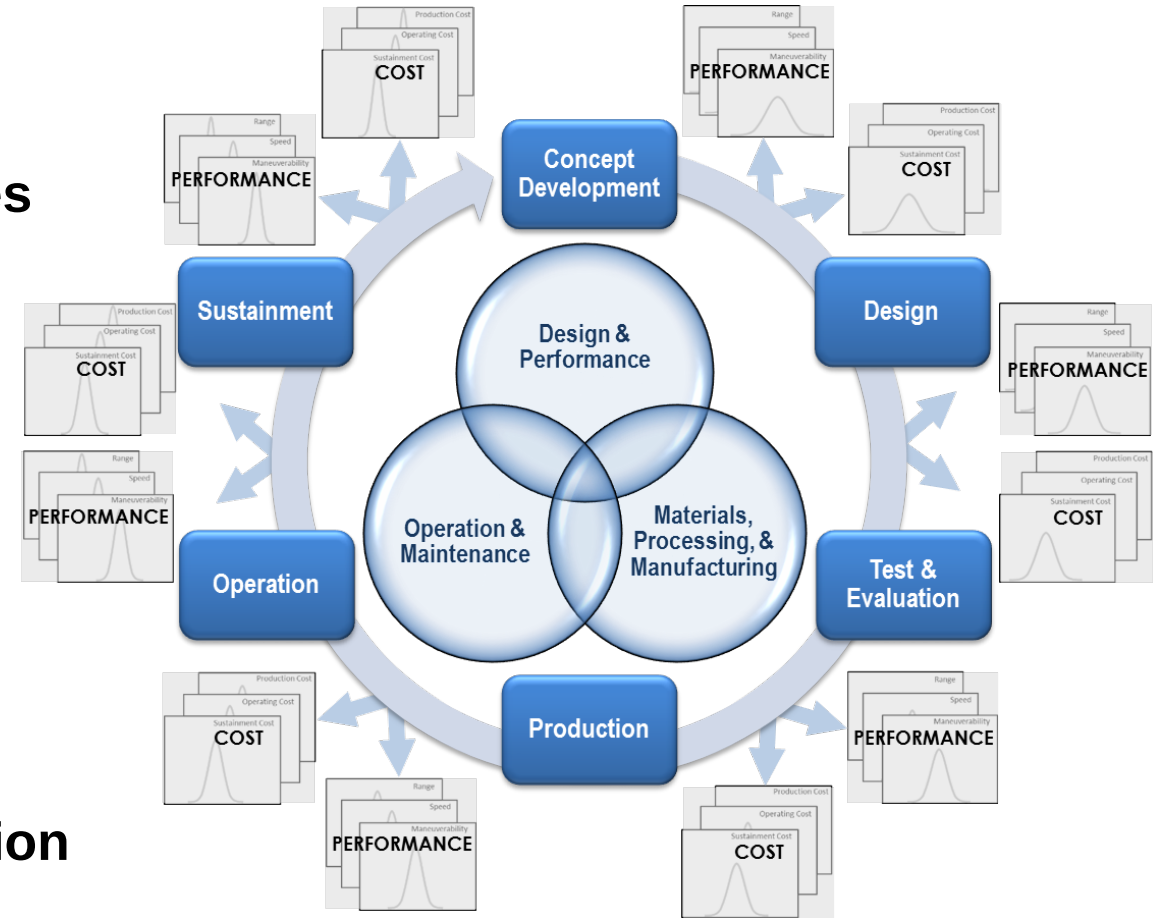


Structure models/data for interoperability AND to quantify, propagate, & reduce uncertainty through the design-build-test-operate-sustain cycle

Digital Thread Concept

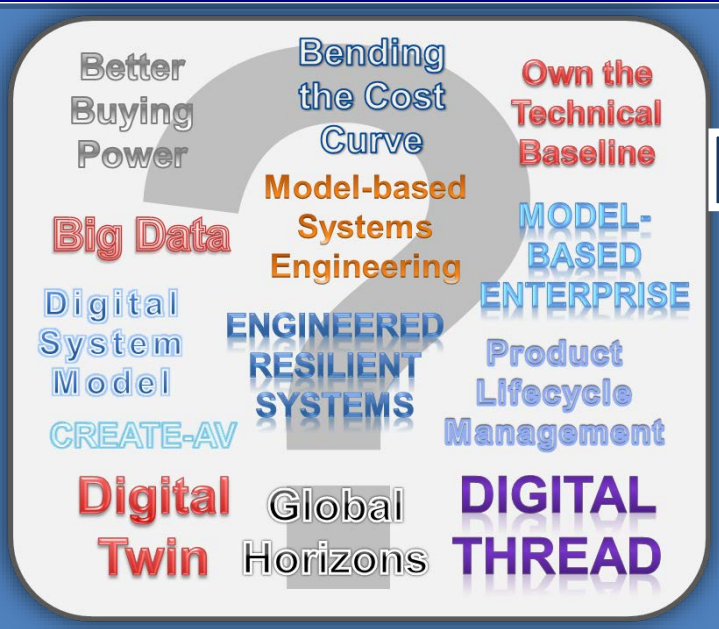
Main Technical Goals:

- Use **ALL AVAILABLE INFORMATION** in analyses
- Use **PHYSICS** to inform analyses
- Use **PROBABILISTIC METHODS** to quantify program risks
- **CLOSE THE LOOP** from the beginning to the end and back to the beginning of the acquisition lifecycle



Make *INFORMED DECISIONS* throughout acquisition

DT/ERS Workshop Results:
4 Big Things



Facilitated Workshop

"4 Big Things"

1) Feedback loop:

- Abstract production / Mx / sustainment data & experience to concept development
- Feed forward production data

2) Interoperability:

- ICMSE, Materials, Model data, Definition (data exchange); MBE
- Mechanism for black-boxing model elements

3) Fail Fast, Learn Fast:

- Define bite-sized, demonstrably useful DT projects
- ID info needs for key decisions
- Reduce the timeline and uncertainty of data for decisions

4) Constraints:

- Access vs deliver
- Formats / standards
- Intellectual Property
- Validation / provenance
- Classification issues
- Legacy
- IT infrastructure
- .com vs. .mil
- Information assurance

Cross-cutting all other items

AFRL Approach

- **Build "case law" to address technical challenges facing broader DT implementation**
  - **Necessary to drive culture change**
  - **Establish momentum**
- **"Fail Fast, Learn Fast" ("use cases")**
  - **Recipe: Decision – Owner – Data ⇒ *measurable impact***
  - **Address interoperability challenges**
  - **Moving data/models: forward for adaptability; backward for better decisions**
  - **Reveal constraints: heritage IT environment and bureaucracies; contracting/acquisition policy; etc.**

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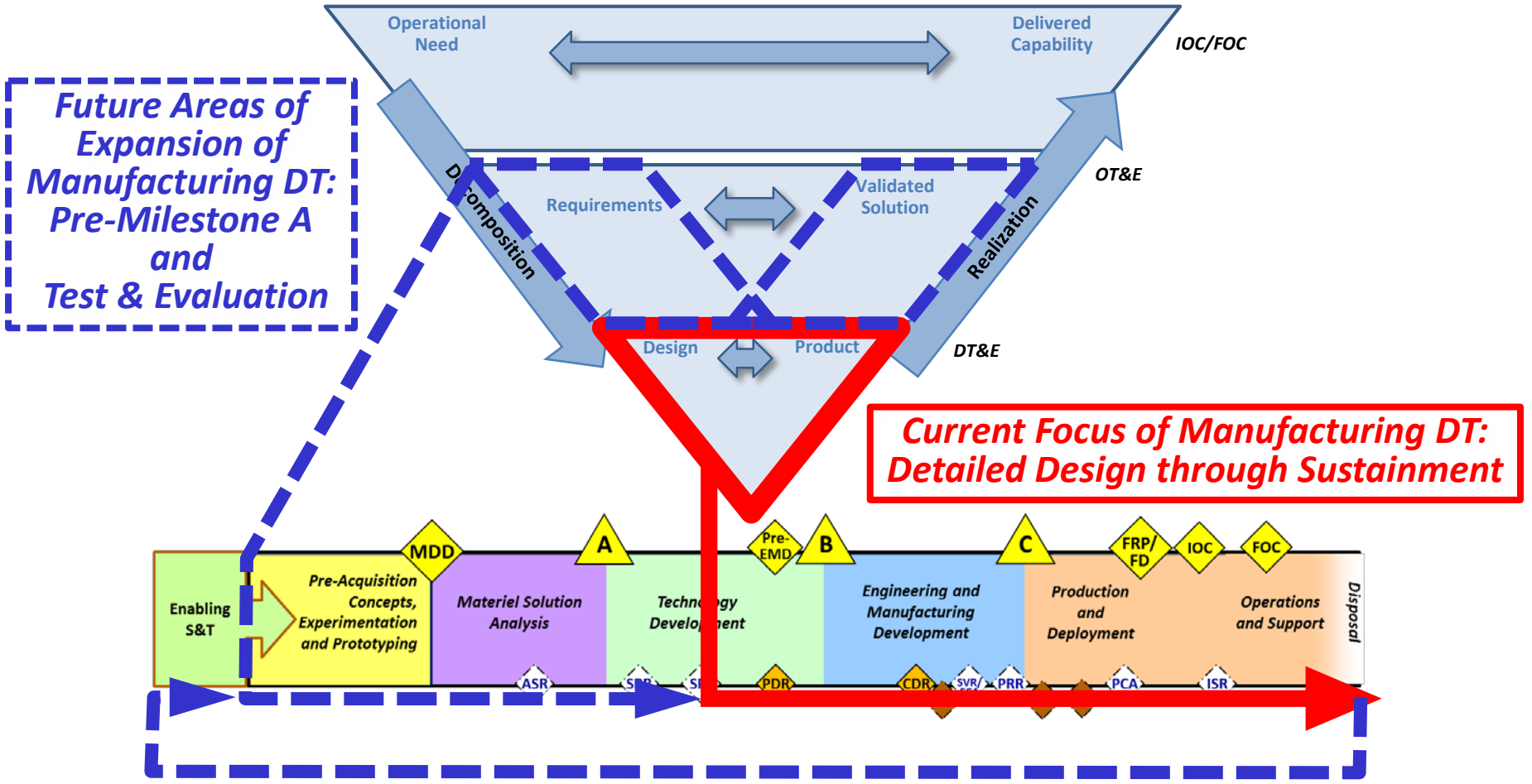
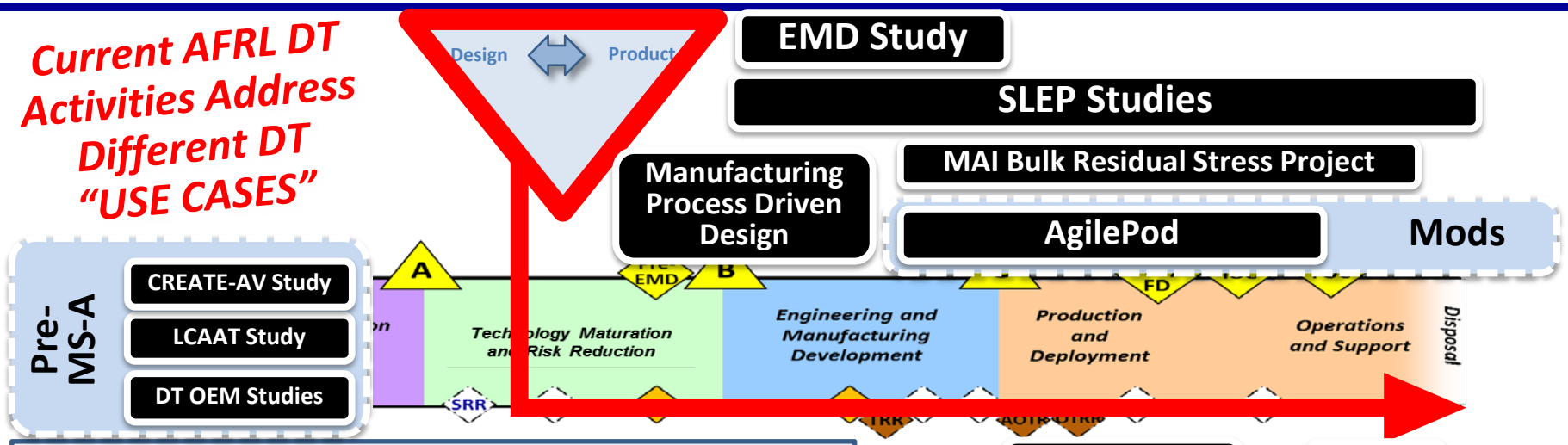
Care and feeding of MANY relationships

AFRL DT/DTw Activities:
Relationship to DoD Systems Engineering

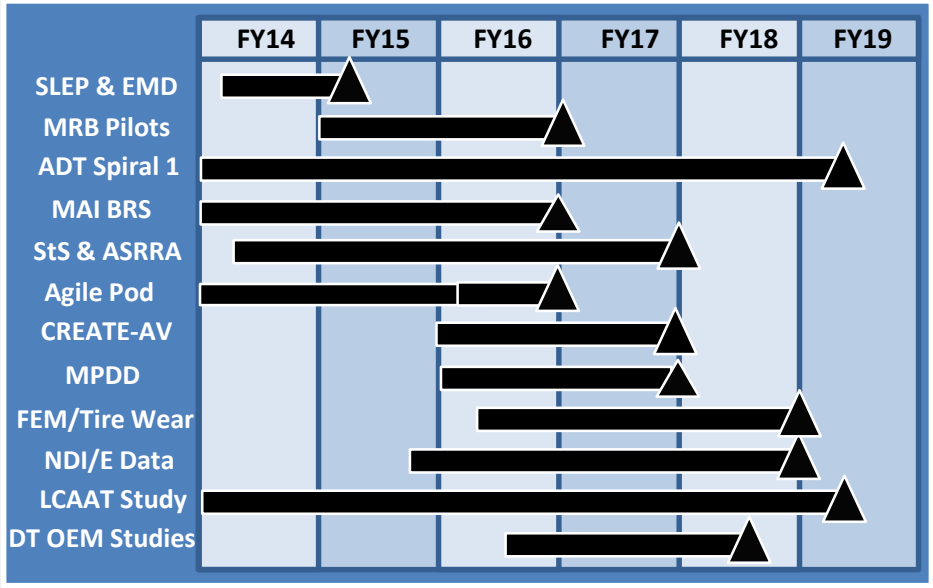


Current & Imminent AFRL DT/DTw Projects: Touching the Entire Acquisition Lifecycle

Current AFRL DT Activities Address Different DT "USE CASES"



Demonstrating the VALUE of the Digital Thread



MRB Pilots → ADT

Sustainment
- NDI/E Data Capture & Analysis
- Stick-to-stress Analysis Enhancements
- Aircraft Risk & Reliability Analysis Enhancements
- Strain-gage Calibration
- Spare Parts

T&E
- FEM Correlation

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NUMEROUS technical challenges: data / model exchange standards; ontology development; analytical software

AFRL Approach

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IT enterprise integration; program-specific IT solutions, engineering tools, datasets; etc.

AFRL Approach

- **Build "case law" to address technical challenges facing broader DT implementation**
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Material Review Board Example

Airframe Digital Twin Example

The "Digital Thread for Material Review Board Processes" Use Case

The Material Review Board

- Decision-making Authority for Engineering Disposition of Non-conforming Articles during Production
- Convened when material non-conformances are discovered after significant value has been added to the manufactured article
- Dispositions require an assessment of the impact of the nonconformance and potential rework/repair actions on the performance of the article
  - Information gathering, engineering analysis, repair development
  - Impact to production schedule and cost

Scope of the "Digital Thread for MRB" Use Case:

- Acquisition Activity: Manufacturing/Production
- "Performance" Parameters: Key Characteristics
- Applicability: Nonconforming Articles

"The Digital Thread for Material Review Board Processes" Use Case

Background: Digital Thread for Material Review Board Processes aims to modernize engineering dispositions of nonconformances in production by integrating data, models, and analysis tools to provide engineers with actionable information for rapid dispositions, process re-engineering, and serial-number-specific lifecycle management.

- DT for MRB Infrastructure
- DT for MRB Tech Data Package Standards
- DT for Enhanced MRB Efficiency
- DT for Reduced MRB Occurrences
- DT for MRB Metrics & Business Cases

Tech Development Approach

Collaborate w/ Industry to develop & demo Technology and Business Case for DT for MRB Processes

RJ Lee Group

Pratt & Whitney
A United Technologies Company

NORTHROP GRUMMAN

Etegent
TECHNOLOGIES ltd

Program Schedule & Status

- **Two 24-month 6.3 Programs underway**
  - RJ Lee Group w/ Pratt & Whitney
  - Northrop Grumman w/ Etegent
- **Conclude at end of CY2016**
- **Focusing on different types of products & associated nonconformances**
- **Complementary approaches**
- **Revealing enormous business case opportunities**

RJ Lee Group Approach

- Crawl the data sources
  - Part Geometry
  - Quality Notification Events
  - Engineering Studies
  - Design Models and Specifications
- Extract information about the non-conformant parts and processes
- Analyze similarities in non-conformances
- Simulate predicted performance
- Provide access and guidance to decision support staff (MRB)

RJ Lee Group Approach

- Crawl th… urces
  - –
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  - Design … pecifications
- Extract informatio… non-conformant parts an…
- Simulate p…
- Provid… port

Data

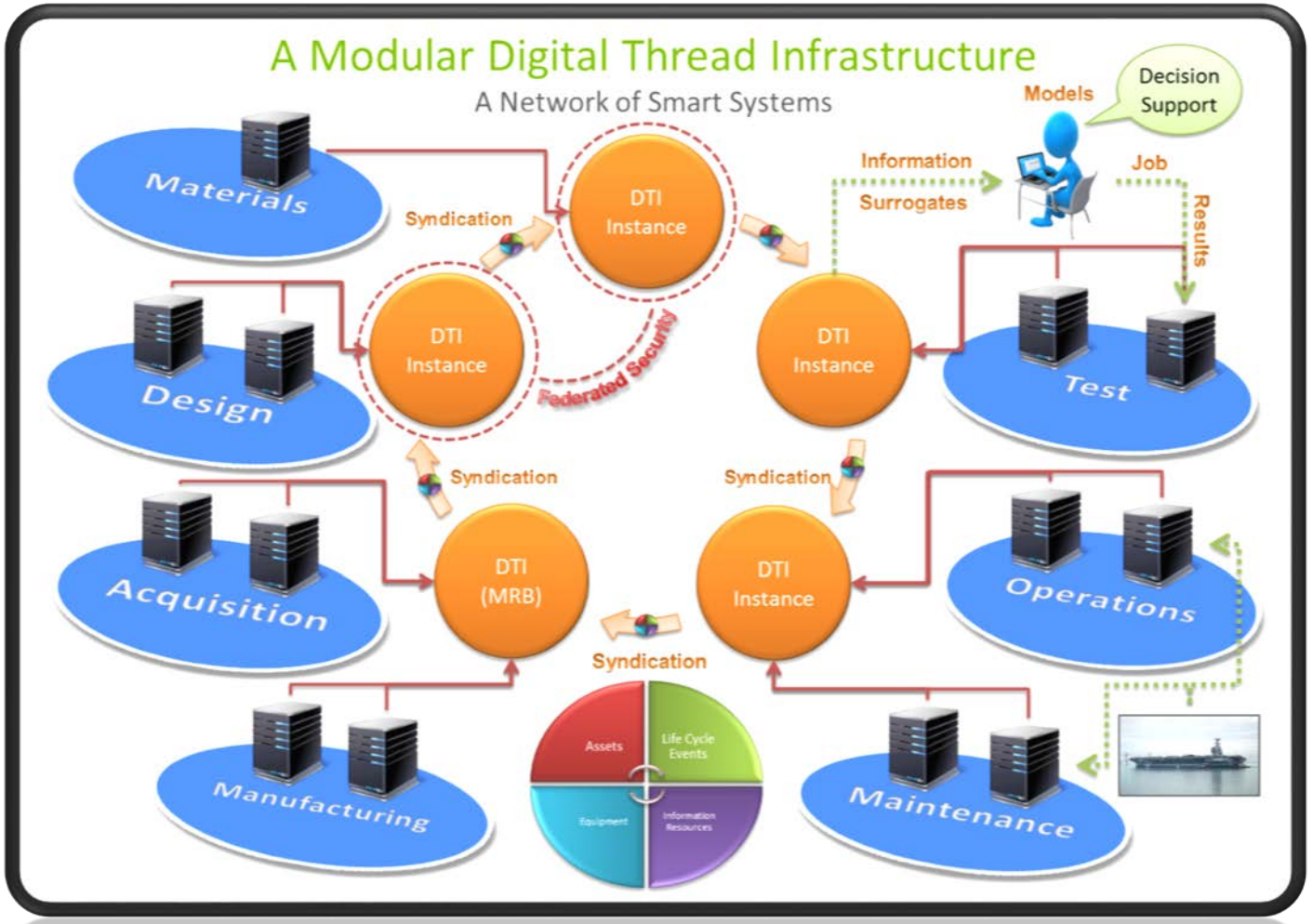
Modelling, Simulation, & Analysis

Decisions

RJ LEE GROUP

Pratt & Whitney
A United Technologies Company

RJ Lee Vision: Modular Infrastructure



RJ Lee Solution

The SEAMS Platform Solution for Digital Thread

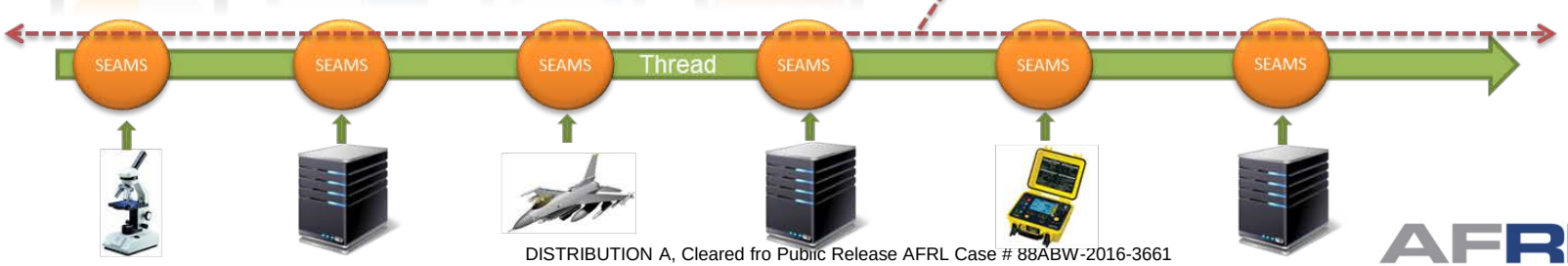
Aggregate → Analyze → Answer

Answer Engine and Search Appliance

Forward Cache and Semantic Object Store
for Aggregation and Distribution

Distributed Analytics Engine
for Transformation, Computation, Metadata Extraction, Inferencing, and Syndication of Scientific Data

Common Federated Security Framework



Northrop Grumman Approach

NORTHROP GRUMMAN

Etegent TECHNOLOGIES ltd

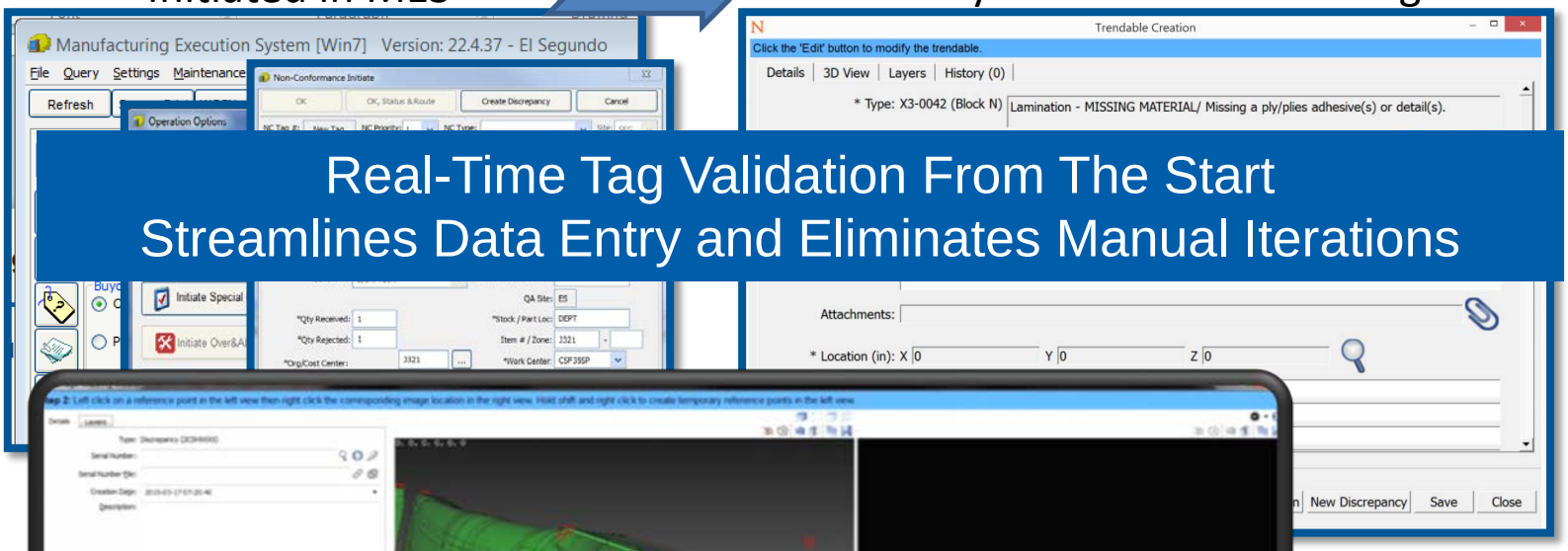
- Veri-tag Solution
  - Deploy tablet application at point of inspection
  - Reduce time required to create initial Tag (NC)
  - Add structure to captured data to support automated research
  - Reduce number of Tag Rejections
- ANCR (Automated Nonconformance Research) Solution
  - Central database with links to all relevant data
  - Structured data customized for each type of defect
  - Automated generation of common queries
  - 3D visualization of reference and historical data
- Enhanced Technical Data Package (TDP+)
  - Contains current Technical Data Package: As-Designed data
  - Enhanced with As-Built data
  - Extensible in the future to contain As-Used data and As-Maintained data

AFRL

Data Generation & Capture

Initiated in MES

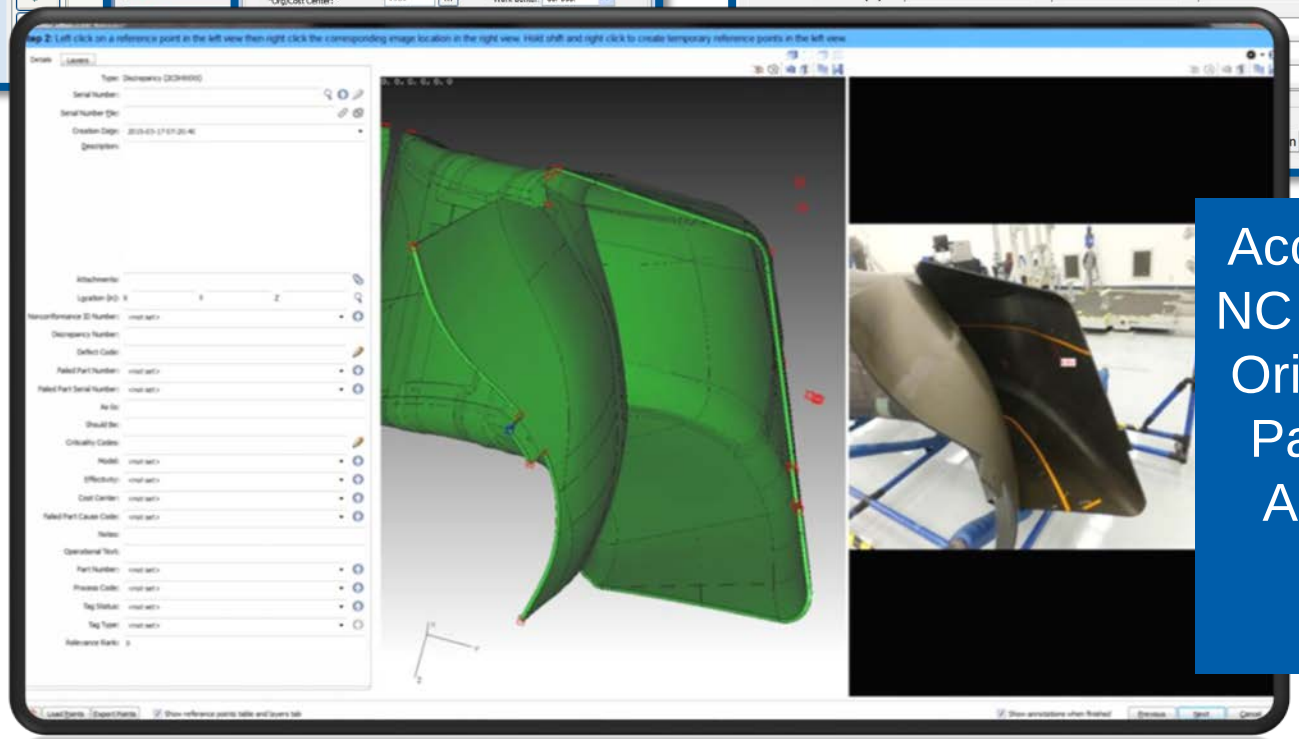
Accurately Described within NLign



NLIGN ANALYTICS

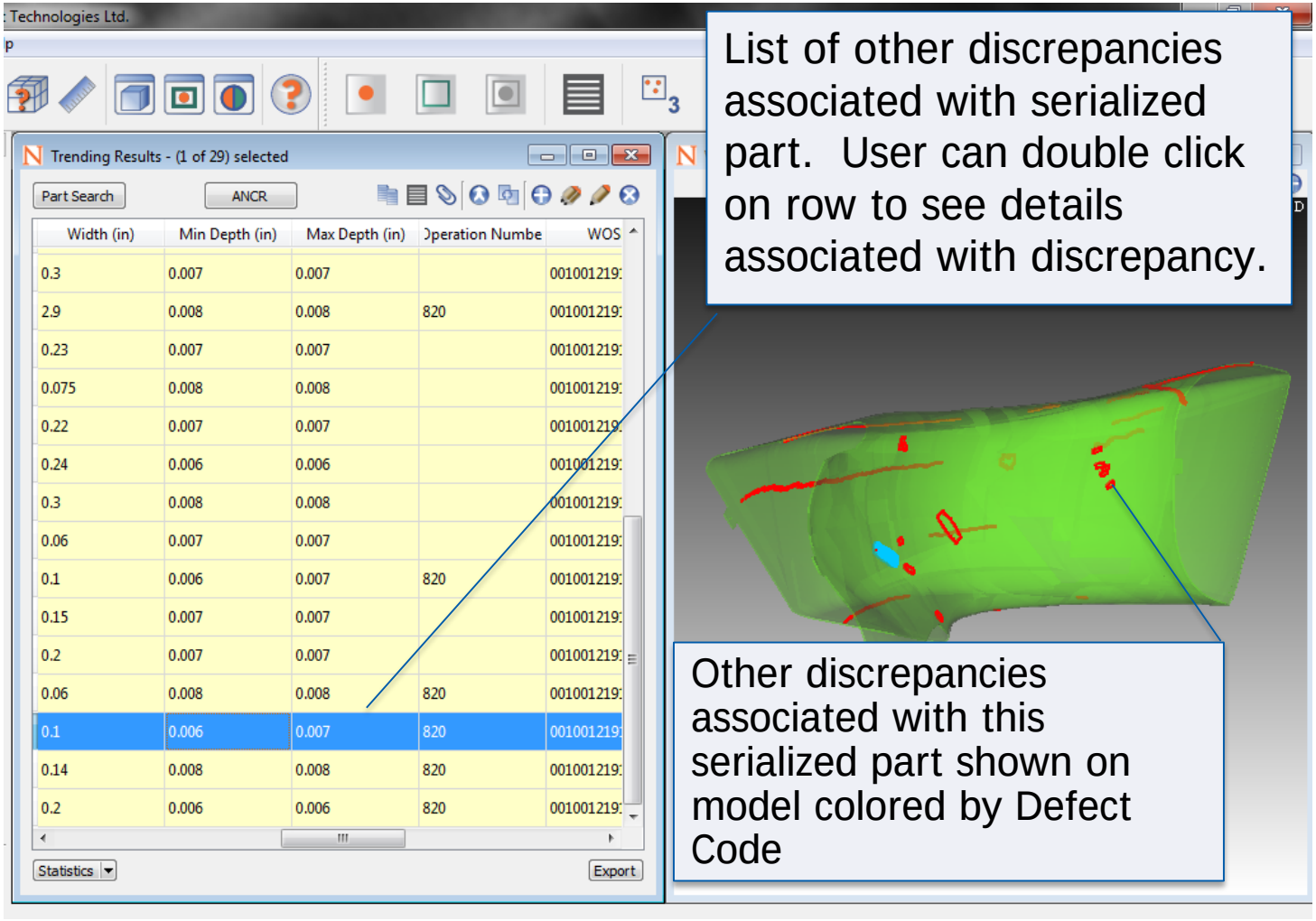
Real-Time Tag Validation From The Start
Streamlines Data Entry and Eliminates Manual Iterations

Returned back to MES



Accurate Registration of NC into the 3D Database Orients the Adjudicating Party, Providing Quick Access to Necessary Information for Disposition

Data Retrieval, Analysis, & Decisions



- Searchable data knowledgebase referenced by salient features: Location, Damage Type, Serial Number, Aircraft Tail Number, Left/Right Hand, and/or any other user defined criteria

Automated NC Research Streamlines & Enables Data Driven Decisions

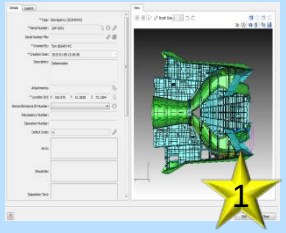
DT for MRB Processes Business Case

- Capture of disparate data sources from manufacturing, inspection, MRB disposition, as-manufactured geometry from suppliers, and engineering analysis will enable preemptive detection of manufacturing issues and lead to faster MRB disposition times.
- Enabling performance-based product definition through the use of uncertainty quantification and a Design for Variation (DFV) framework the Digital Thread (DT) will reduce scrap and rework.

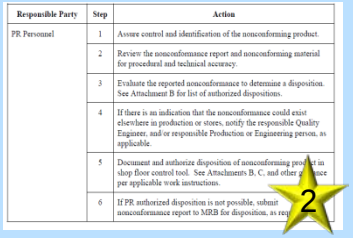
Total potential savings from implementation and use of DT up to ~ $42M/year

Note: This savings is only for two turbine engine component classes @ P&W

NC Report (NR)/Veri-Tag

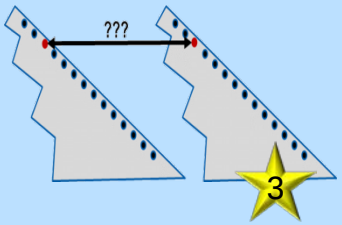


Preliminary Review (PR)



Responsible Party	Step	Action
PR Personnel	1	Assure control and identification of the nonconforming product.
	2	Review the nonconformance report and nonconforming material for procedural and technical accuracy.
	3	Evaluate the reported nonconformance to determine a disposition. See Attachment B for list of authorized dispositions.
	4	If there is an indication that the nonconformance could exist elsewhere in production or stores, notify the responsible Quality Engineer, and/or responsible Production or Engineering person, as applicable.
	5	Document and authorize disposition of nonconforming product in shop floor control tool. See Attachments B, C, and other guidance per applicable work instructions.
	6	If PR authorized disposition is not possible, submit nonconformance report to MRB for disposition, as req

ANCR/Reference Data



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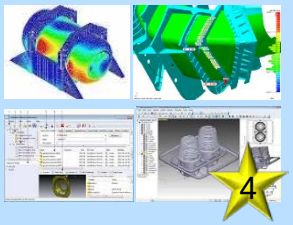
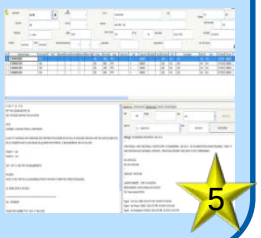


MES



Veri-Tag & ANCR Have Been Estimated to Save 33% of MRB Labor Hours

What is a 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."

(source: DAU Glossary of Defense Acquisition Acronyms and Terms)

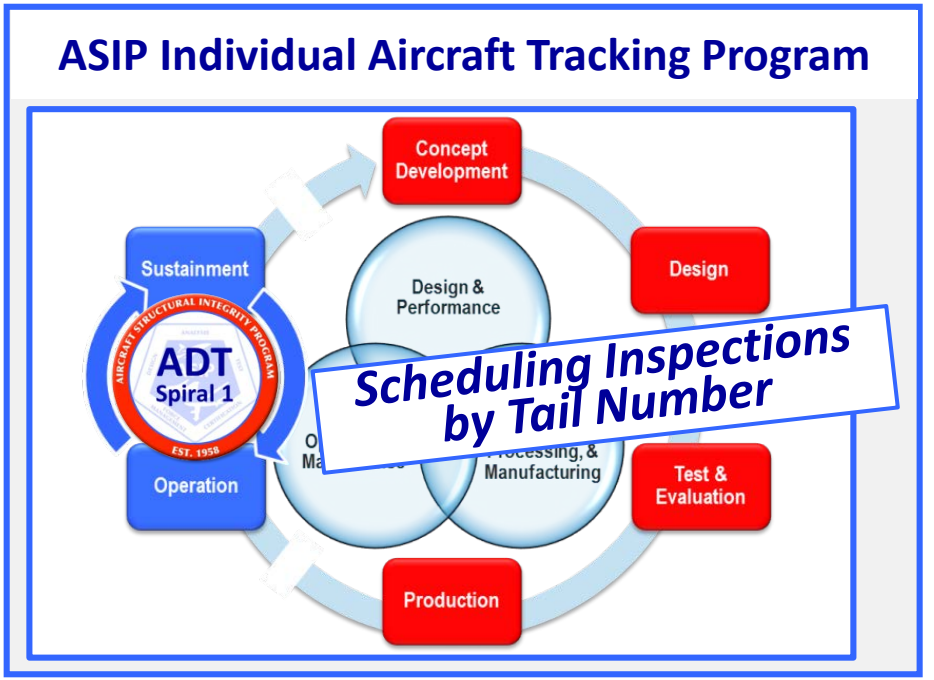
A Digital Twin is **NOT:**

- a Digital Tool for Configuration Management
- a 3D Geometric Model of an As-Built System
- a Model-based Definition of an As-Built System

The "Airframe Digital Twin for Individual Aircraft Tracking" Use Case

Individual Aircraft Tracking Program (IATP)

- Required by MIL-STD-1530C
- Used to adjust structural inspection, modification, overhaul, and replacement times based on the actual, measured usage of the individual aircraft
- Used to forecast when aircraft structural component life limits will be reached
- Requires development of analysis methods and collection of actual usage data



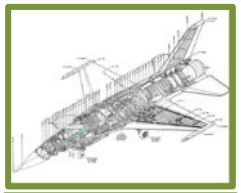
Scope of the "ADT IATP" Use Case:

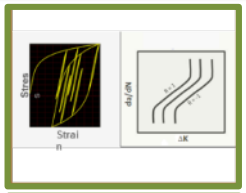
- Acquisition Activity: Operation & Sustainment
- "Performance" Parameters: Structural Life Predictions
- Applicability: Airframe Structures

Airframe Digital Twin

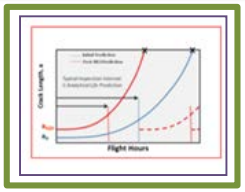
Background: Airframe Digital Twin aims to modernize lifecycle management of airframe structures by integrating data, models, and probabilistic analysis tools to provide actionable output for tailoring airframe maintenance by tail number.


Flight Data

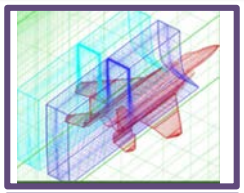

Tail Number Specific Geometry


Material Properties


Inspection & Maintenance Data


Damage Growth Models


Finite Element Model

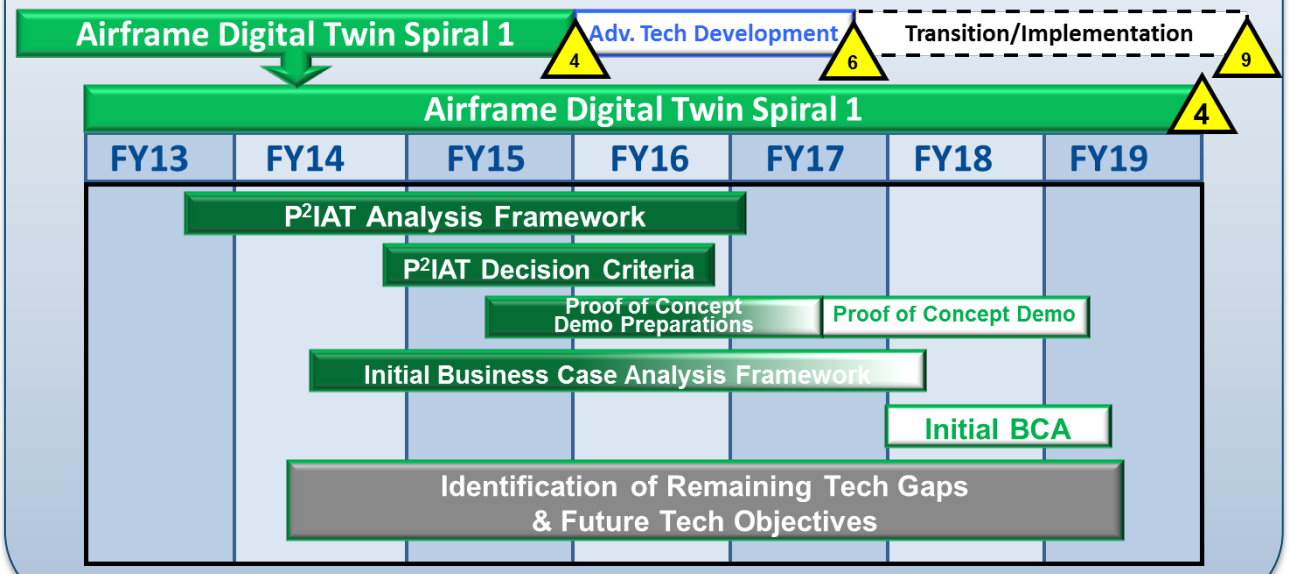

Aerodynamic Model

Tech Development Approach

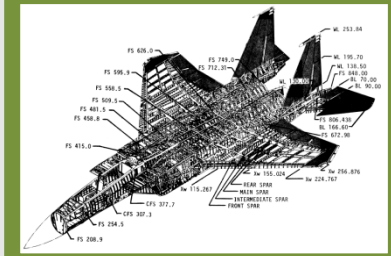
Collaborate w/ Industry to develop & demo Analysis Framework and Business Case for Probabilistic & Prognostic Individual Aircraft Tracking

NORTHROP GRUMMAN
LOCKHEED MARTIN
UTSA
AEROSPACE SYSTEMS DIRECTORATE
GE
VANDERBILT
wyle
Booz | Allen | Hamilton
MERC MERCER ENGINEERING RESEARCH CENTER
An Operating Unit Of Mercer University

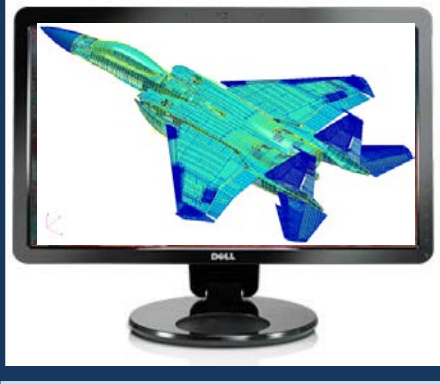
Program Schedule & Status



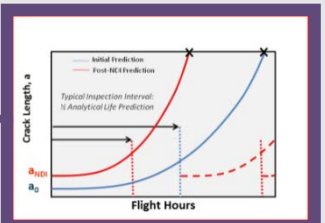
Integrating Data with Engineering Models



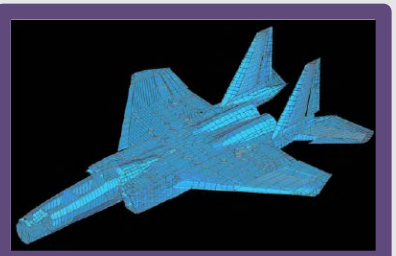
Tail Number Specific Geometry



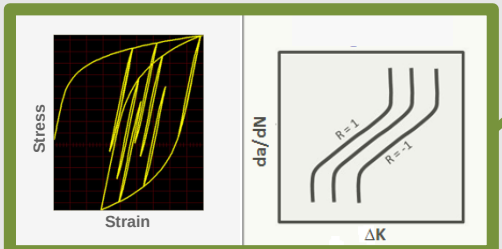
Airframe Digital Twin



Damage Growth Models



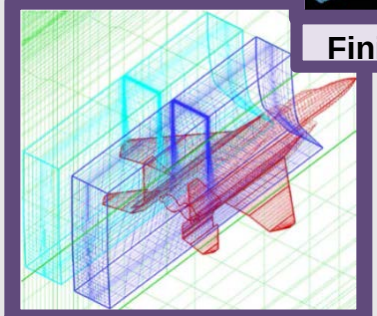
Finite Element Model



Material Properties

Flight Data

Inspection & Maintenance Data



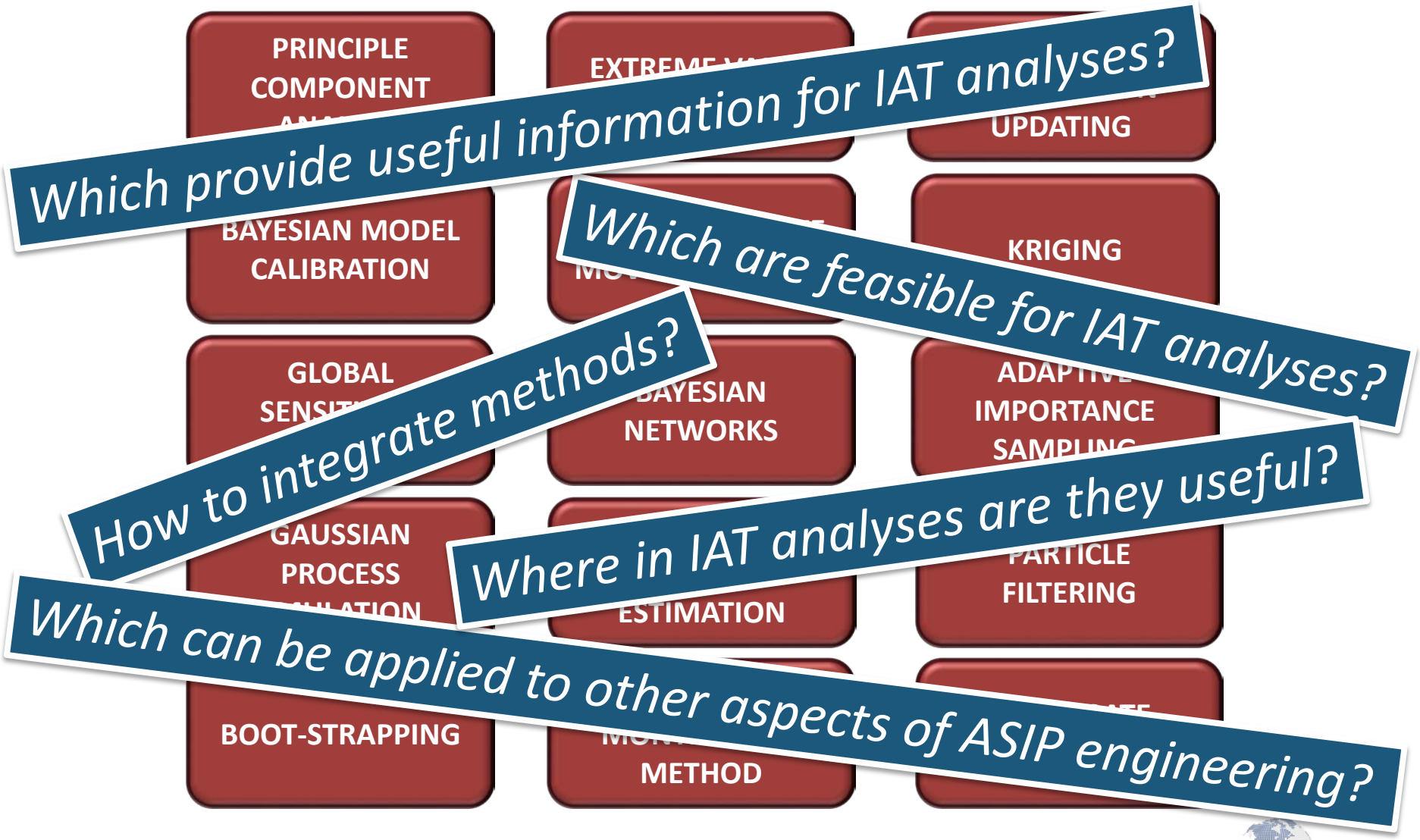
Aerodynamic Model

Digital Twin requires **DATA** and **MODELS** from Digital Thread

Identifying & Integrating Useful Probabilistic Methods

PRINCIPLE COMPONENT ANALYSIS	EXTREME VALUE THEORY	PROBABILITY DISTRIBUTION UPDATING
BAYESIAN MODEL CALIBRATION	AUTO-REGRESSIVE MOVING AVERAGE	KRIGING
GLOBAL SENSITIVITY ANALYSIS	BAYESIAN NETWORKS	ADAPTIVE IMPORTANCE SAMPLING
GAUSSIAN PROCESS EMULATION	CONFIDENCE BOUND ESTIMATION	PARTICLE FILTERING
BOOT-STRAPPING	MARKOV CHAIN MONTE CARLO METHOD	SURROGATE MODELING

Identifying & Integrating Useful Probabilistic Methods

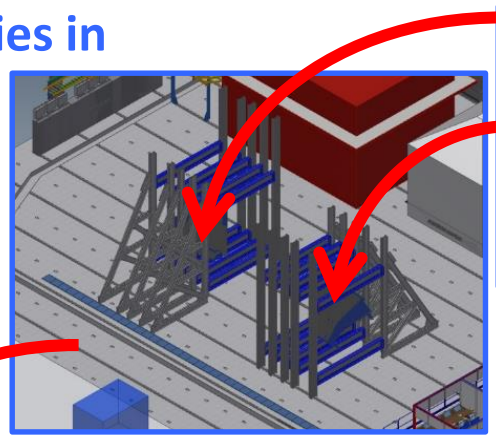


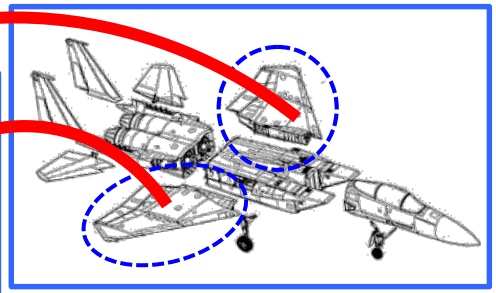
Demonstrating on Surrogate Aircraft

DEMONSTRATE P²IAT BY MANAGING "SURROGATE AIRCRAFT"

(i.e., ground-based fatiguing of ACTUAL AIRCRAFT STRUCTURE)

- **Exercise P²IAT on two F-15C Wings**
  - Inspect/modify/instrument retired wings
  - Simulate two different flight histories in AFRL Full-scale Structural Test Facility
  - Schedule inspections based on P²IAT results
- **Compare P²IAT to Conventional IAT**





NOTE: Loads will be applied quasi-statically.

- **Generate probabilistic life predictions for 10 locations**
- **Demonstrate:**
  - Automated analysis/updating from simulated flight & inspection records
  - Increasing prediction confidence w/ updating
  - Application of decision criteria

Revealing Digital Thread Challenges & Opportunities

- **Collecting & Modifying Existing Tech Data**
  - Drawings
  - Tech Orders
  - Analysis Reports
  - Test Reports
  - Teardown Reports
  - Flight & Mx Records
  - Air Vehicle FEM
  - 6DoF Dynamic Flight Simulator
- **Generating New Tech Data**
  - CAD
  - Detailed FEM
  - Local Damage Models
  - NDI POD Curves
  - NDI Procedures
  - Baseline Flight Spectra
  - Model Input Data
- **Planning & Executing Full-scale Ground Tests**
  - Metrology Data
  - Test Execution Plans
  - Strain Surveys
  - Actuator Data
  - Sensor Data
  - NDE Data
  - Repairs
  - Teardowns
- **Ground Test Articles treated like Flying Assets**
  - Unique test spectrum for each wing
  - Tracked using ADT's P^2IAT
  - NDI planned using P^2IAT results
  - Repairs conducted as necessary
  - New tracking locations added as necessary

Summary

- **Digital Thread movement continues to build momentum**
- **Digital Thread is about making better decisions faster**
- **Strong ties to DoD Engineering & Acquisition**
  - BBP3.0, USAF BtCC & OtTB
  - DSM, ERS, DMDII
- **AFRL has articulated a vernacular for DT/DTw**
  - Pinwheel Diagram
  - 4 Tech Goals
  - 4 Big Things
- **AFRL has a common approach for DT/DTw projects**
  - Build “case law” to address technical challenges facing broader implementation
  - “Fail Fast, Learn Fast” (“use cases”)
- **Integration & Implementation remain challenging**
  - Science & Technology can address many gaps as they are revealed