Integrity ★ Service ★ Excellence

MBE & the Aircraft Digital Thread

NIST MBE Summit

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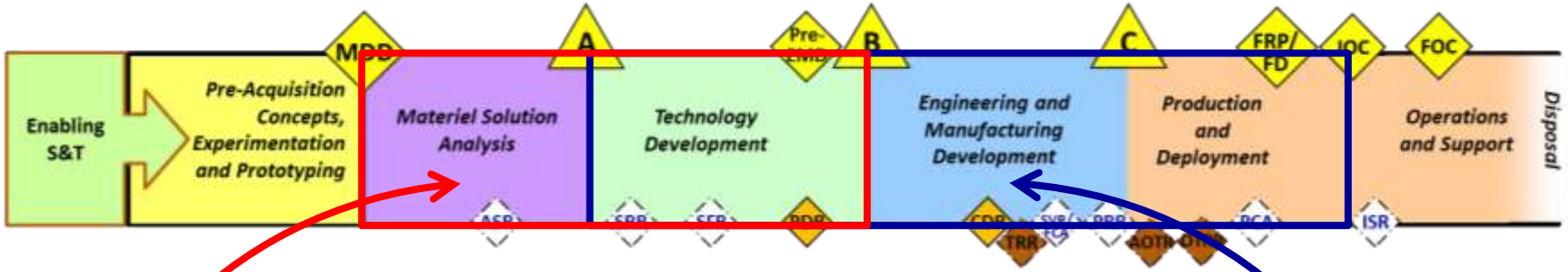
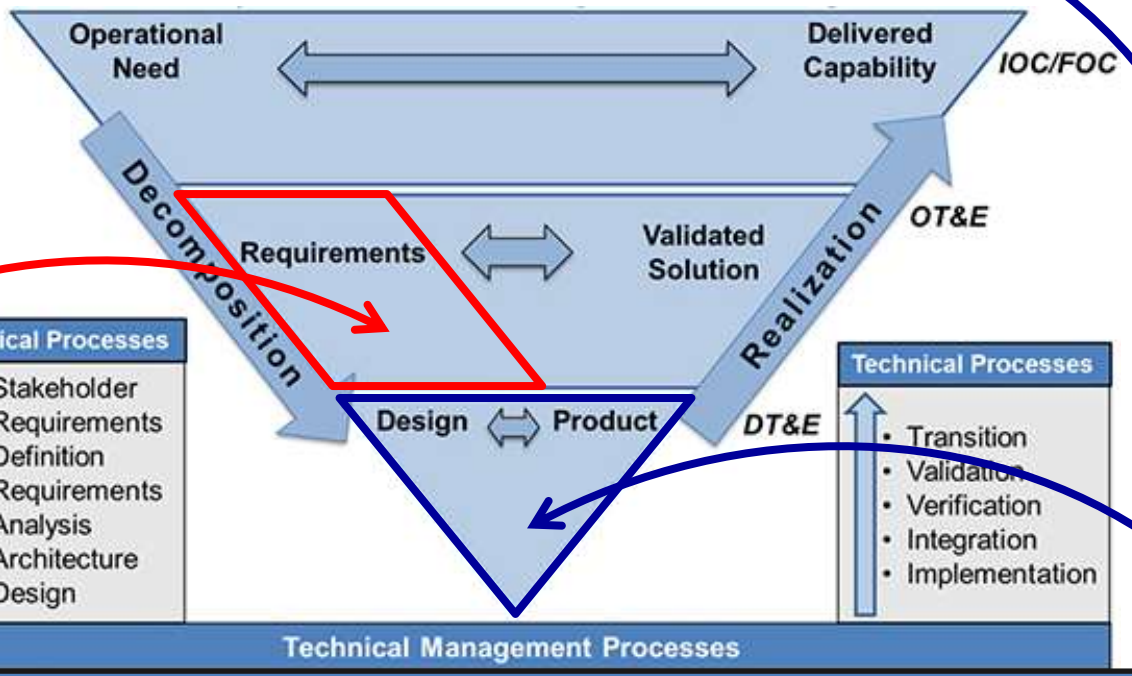
Air Force Research Laboratory

Systems Engineering in DoD:

Where do Materials & Manufacturing Processes (M&P) fit?





Majority of program risk is locked in here.

Majority of M&P activity happens here.

Need to bring M&P into earlier phases of SE, but how?

The Digital Thread


Global Horizons

Global Horizons
Final Report

United States Air Force
Global Science and Technology Vision

AF/ST TR 13-01
21 June 2013

Distribution A. Approved for public release; distributi
SAF/PA Public Release Case No. 2013-0

9. Manufacturing and Materials

9.3 Game Changers

9.3 Game Changers

Exploiting the three game-changing opportunities below will help the AF meet the need for more rapid development and deployment. The recommendations represent the first steps on the path to future game-changers.

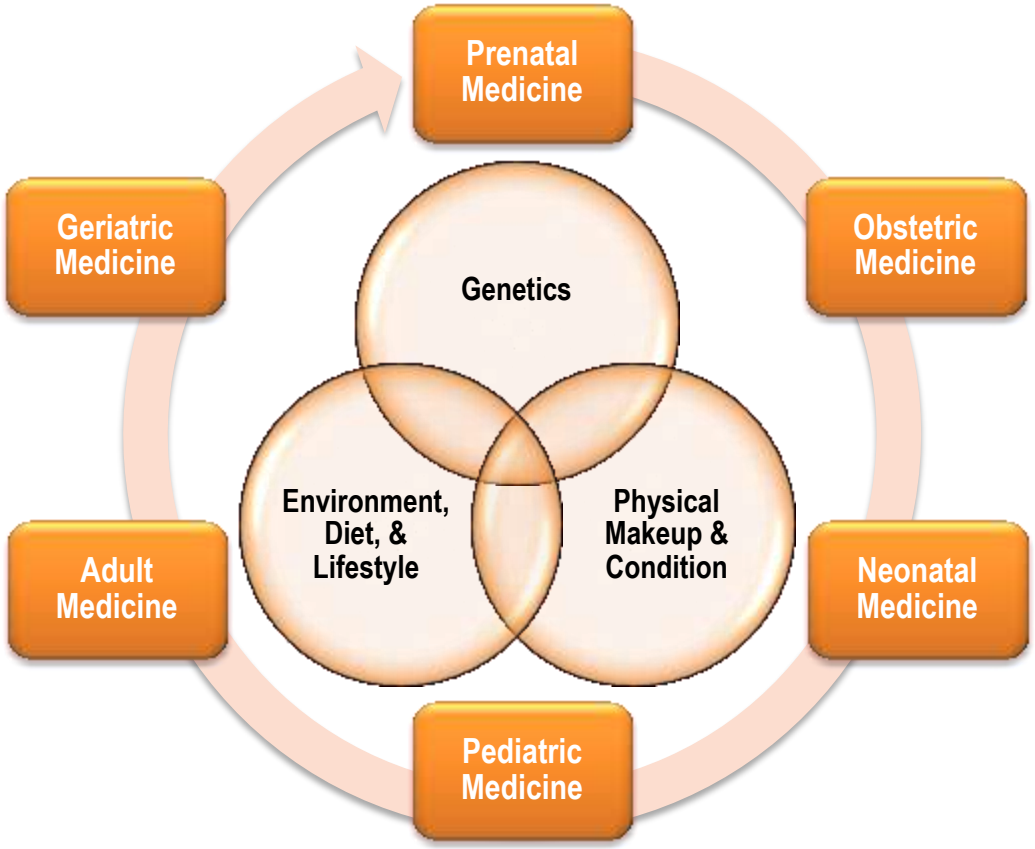
Digital Thread and Digital Twin

Digital Thread and Digital Twin. The concept of a digital thread/digital twin comprised of advanced modeling and simulation tools that link materials-design-processing-manufacturing (Digital Thread) will be the game-changer that provides the agility and tailorability needed for rapid development and deployment, while also reducing risk. State Awareness and System Prognosis advantages will be achieved through the Digital Twin, a virtual representation of the system as an integrated system of data, models, and analysis tools applied over the entire life cycle on a tail-number unique and operator–by-name basis. M&S tools will optimize manufacturability, inspectability, and sustainability from the outset. Data captured from legacy and future systems will provide the basis for refined models that enable component and system-level prognostics. Archived digital descriptions of new systems would greatly facilitate any subsequent re-engineering required in the future. Human performance monitoring will enable adaptation of systems to the "mission capable" state of the operator.

An Analogy: The Future of Healthcare

"TO BE" State:

- Treatments are based on early identification of disease & disease precursors
- Electronic Medical Records & Personal Health Records available to patients & providers
- Preventative medicine & disease treatments are personalized to each patient
- Majority of effort is in predicting, preventing, & managing disease throughout life

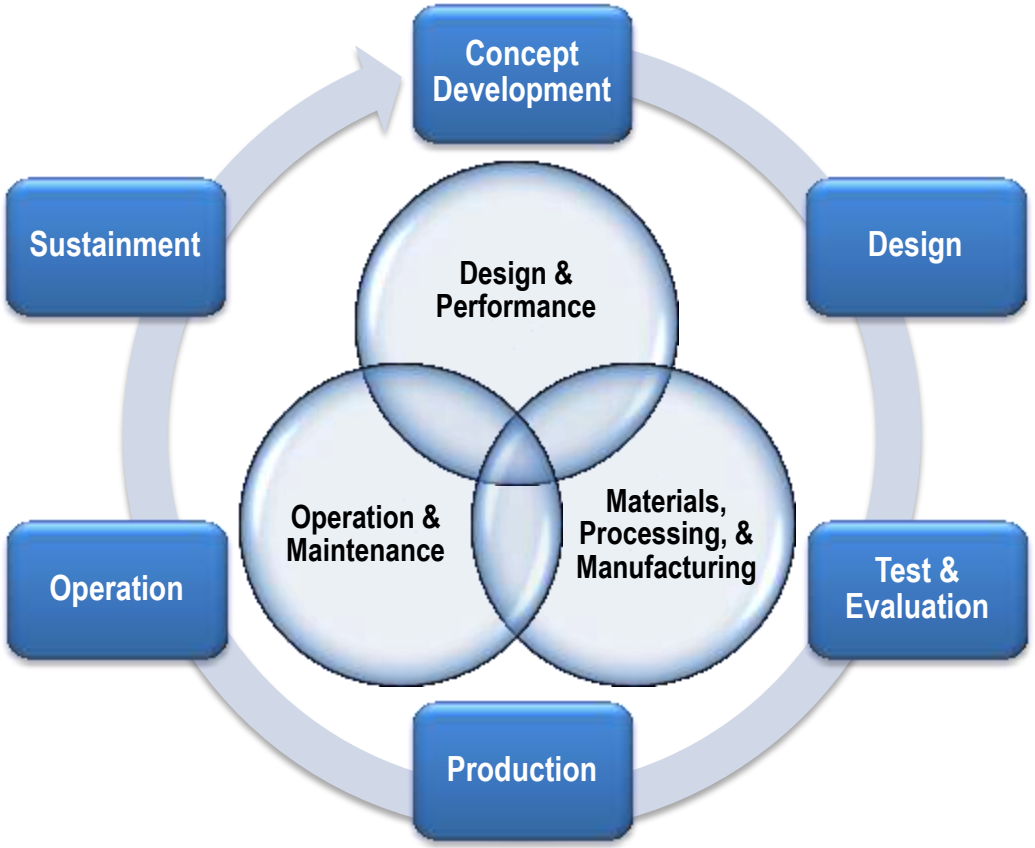


Future Healthcare will be Predictive, Integrated, Personalized, and Preventative

The Future of Aircraft Lifecycle Management

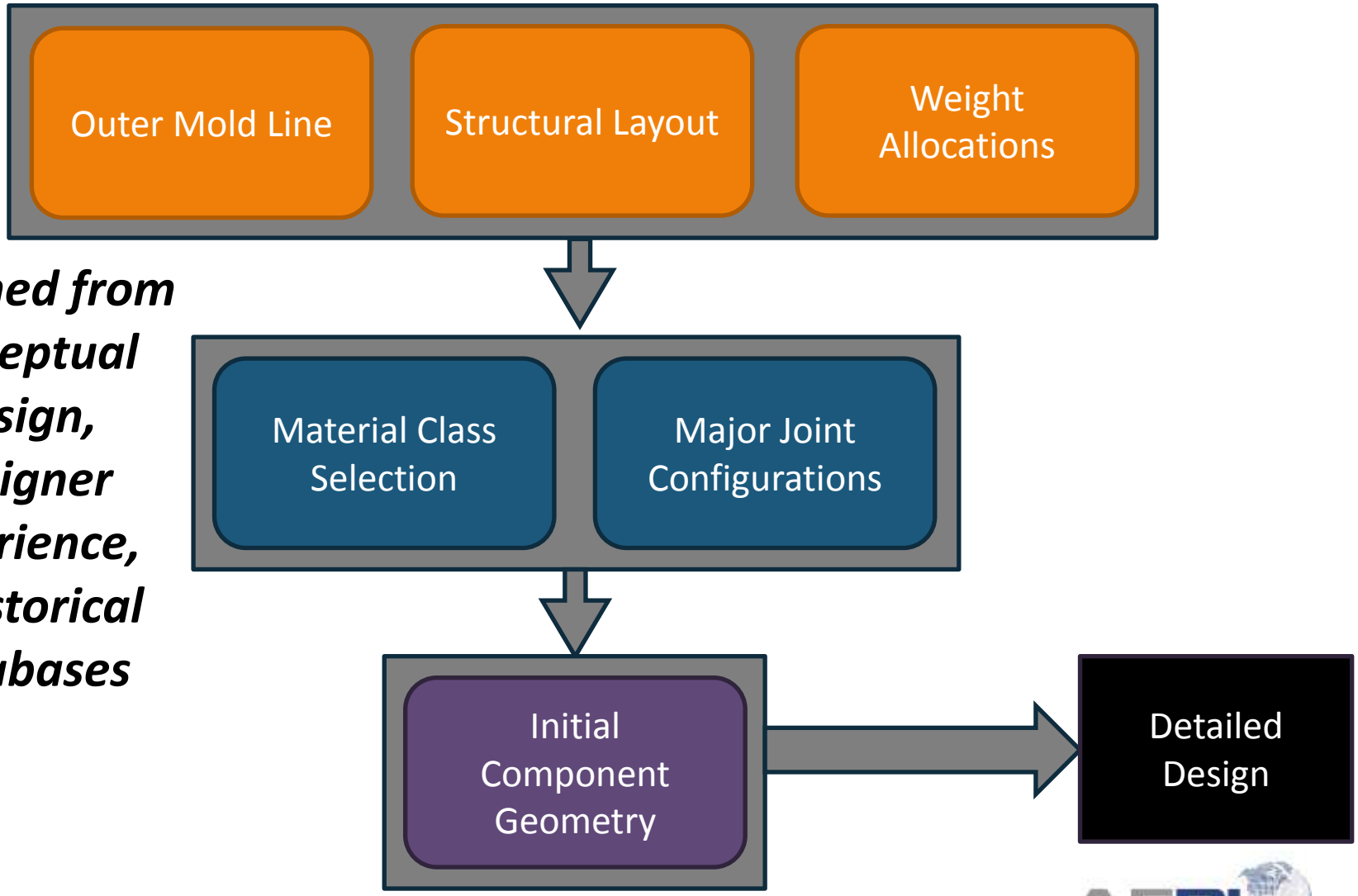
"TO BE" State:

- **Maintenance based on early identification of damage & damage precursors**
- **Individual aircraft history available to operators, maintainers, & engineers**
- **Preventative maintenance & repairs / retrofits are personalized to each aircraft**
- **Majority of effort is in predicting, preventing, & managing damage state throughout life**



Future Lifecycle Management will be Predictive, Integrated, Individualized, and Preventative

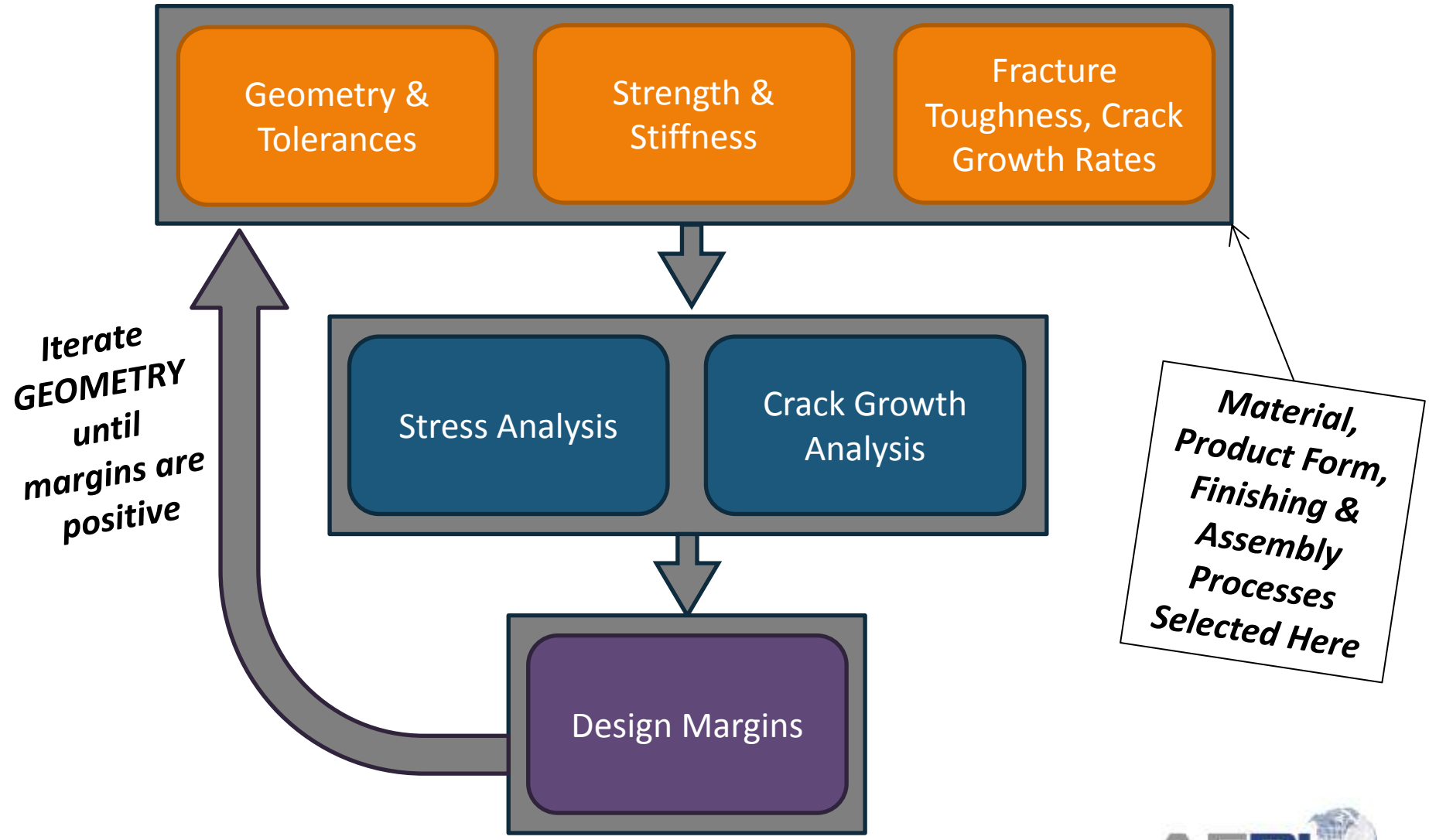
A Simplified View of Structures-related Preliminary Design Activities



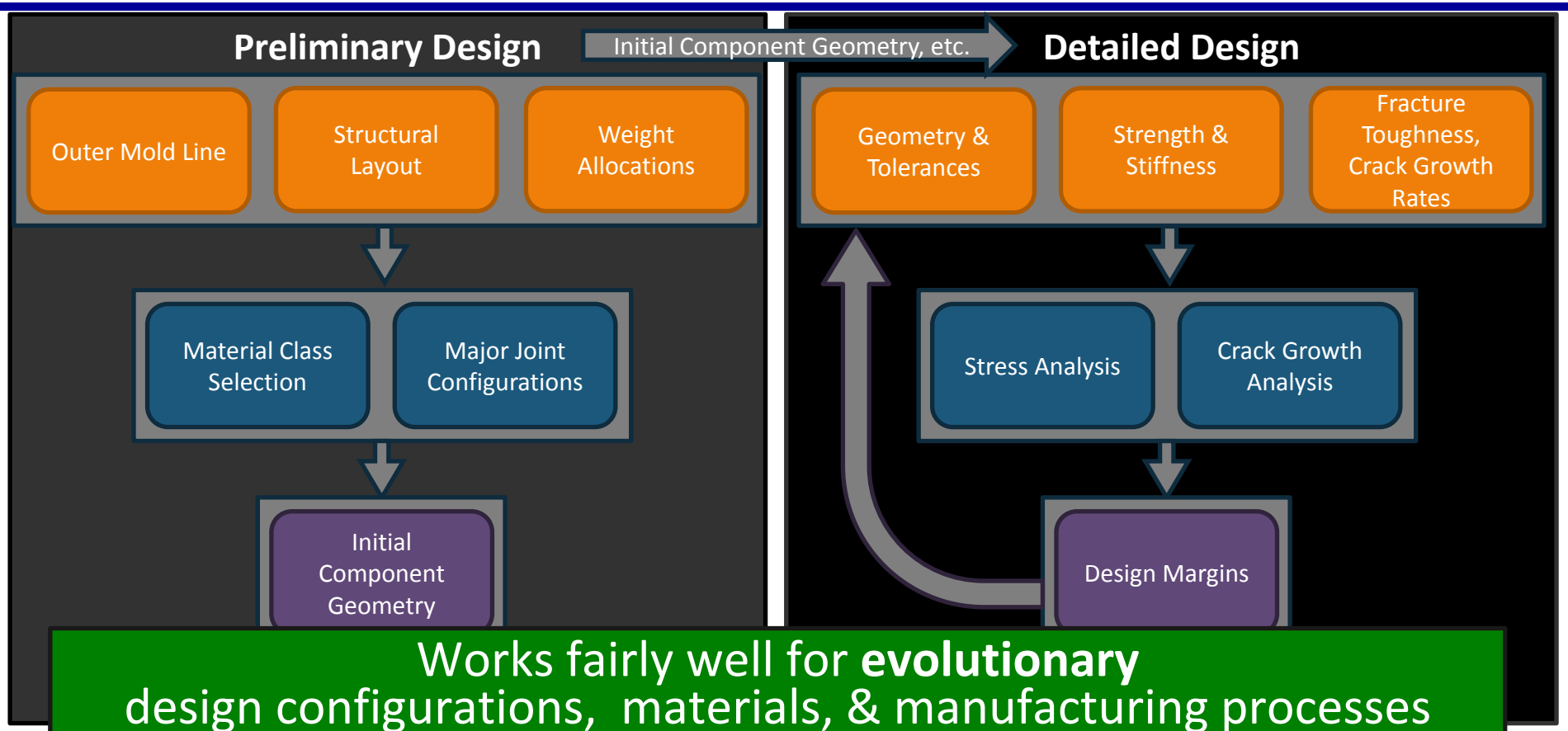
Obtained from Conceptual Design, Designer Experience, & Historical Databases

A Simplified View of Component-level Detailed Design Analyses

Obtained from handbooks, specifications, historical databases, and building-block testing programs



The Aircraft Systems Engineering Game:
One-way Requirements Flow



Works fairly well for **evolutionary** design configurations, materials, & manufacturing processes

Works poorly for **revolutionary** design configurations, materials, & manufacturing processes

Works less well when aircraft mission profiles & retirement dates **change**

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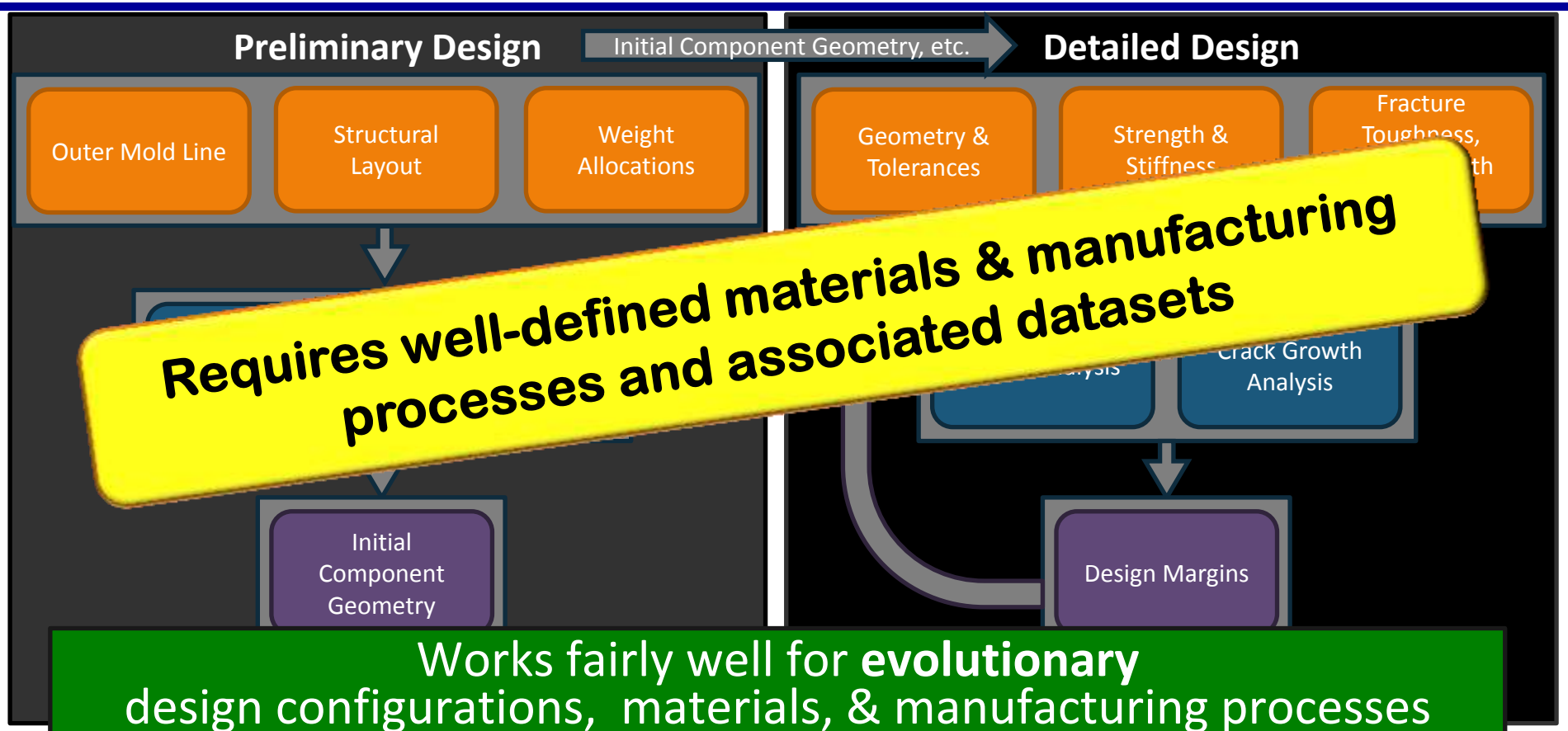

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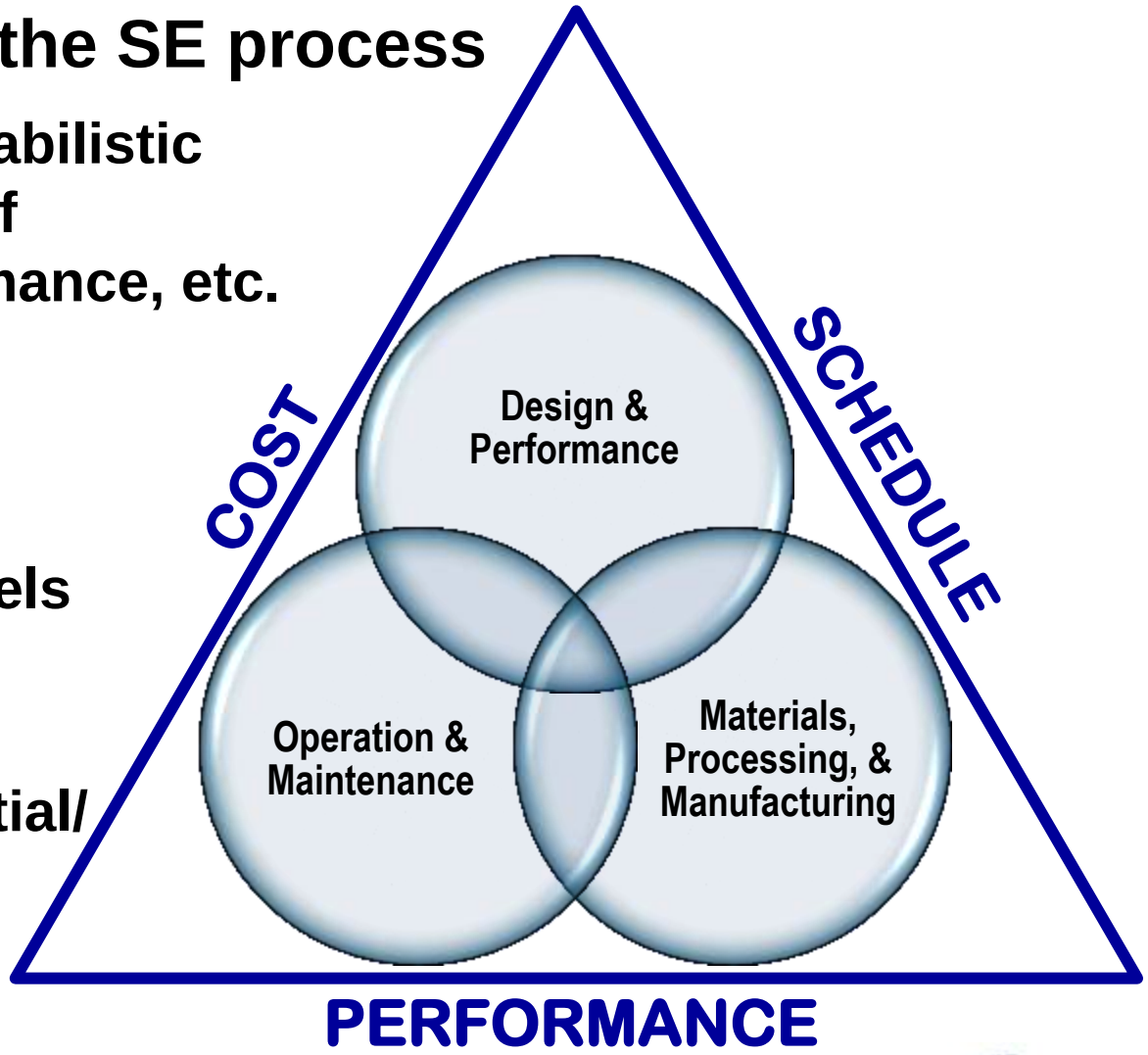
How might Digital Thread change this game?

- **Integrate M&P with the SE process**
  - **M&P-informed, probabilistic parametric models of cost, weight, performance, etc.**
  - **Physics-informed, probabilistic models of M&P**
  - **Linking of M&P models with detailed design analysis models**
  - **Automated experiential/ evidentiary updating of models**



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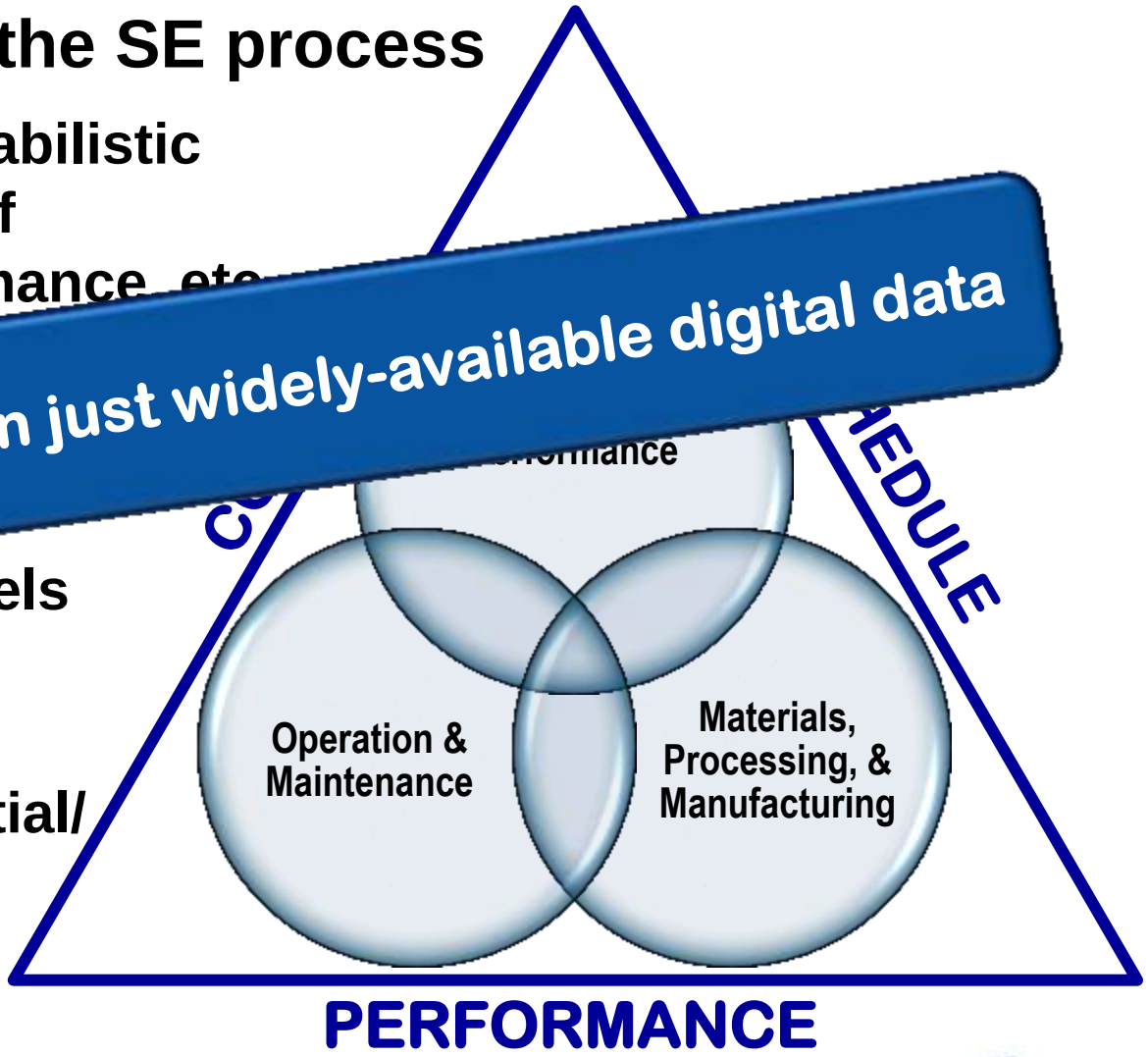
Requires more than just widely-available digital data

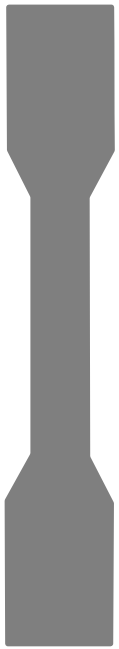


Integrating Engineering Disciplines in a Model-Based Enterprise

An Example:

How do different engineering disciplines see a Tensile Bar?

Design Engineer:
Dimensions



Processing Engineer:
Producibility, variability in mechanical properties

Quality Engineer:
Acceptance testing methods & criteria

Design Analyst:
Tables of mechanical properties & design criteria

Materials Engineer:
Chemical composition, microstructure, texture

How do these differences impact model formulation and validation choices?

Integrating Engineering Disciplines in a Model-Based Enterprise

An Example:

How do different engineering disciplines see a Tensile Bar?

How do these differences impact model formulation and validation choices?

Aircraft Digital Thread

NOW

- Integrated Computational Materials Engineering (ICME) for component manufacturing
- **Local** material properties integrated into **local** engineering analyses
- Knowledge base for Material Review Board **dispositions**
- Uncertainty Quantification w/ M&P variations for **local** engineering analyses

NEXT

- Probabilistic ICME models of components linked to manufacturing data for **automated model calibration**
- Local engineering analyses w/ **as-built local dimensions**
- Uncertainty Quantification w/ M&P variations for **global** engineering analyses
- ICME for aircraft **assembly**
- Dimensional tolerances developed based on impact to **performance**

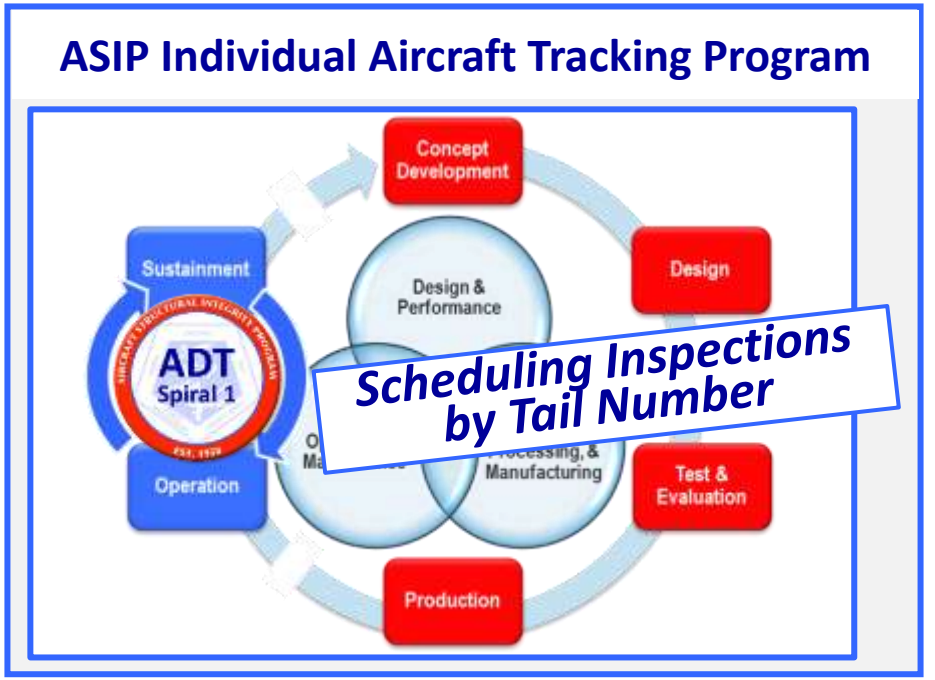
FUTURE

- **Local** material properties integrated into **global** engineering analyses
- M&P variations in engineering analyses updated based on **as-built & as-maintained manufacturing data**
- Manufacturing knowledge base informing design decisions **interactively**
- Manufacturing knowledge base mined to develop **improved parametric models** for conceptual & preliminary design

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

Two "Probabilistic & Prognostic IAT" ADT Spiral 1 6.2 Contracts Underway

USE ALL INFO
FDR Data
NDE Data

USE PHYSICS
Fluid Dynamics
Structural Mechanics
Materials Sci & Eng'g

USE PROBABILISTIC ANALYSIS

CLOSE LOOP
Automated Probabilistic Updating

GE

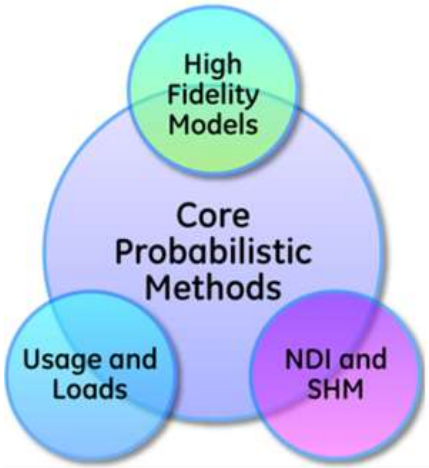
LOCKHEED MARTIN

VANDERBILT

wyle

SAFER-P²IAT

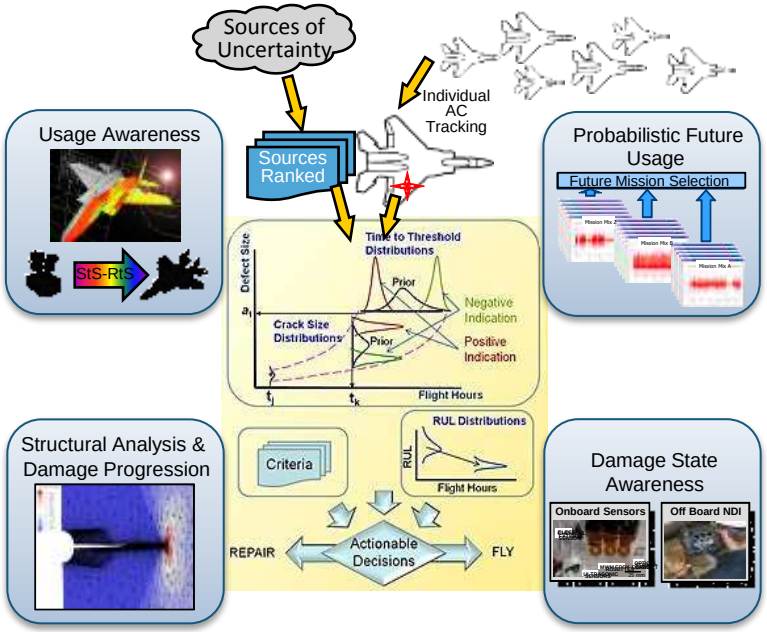
Scalable
Accurate
Flexible
Efficient
Robust



NORTHROP GRUMMAN

UTSA

Open
Flexible
Extensible
Maintainable



https://www.fbo.gov/index?s=opportunity&mode=form&id=0b10f8d15837d4ad47ca81da9e97cfcd&tab=core&_cview=1

AFRL

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

Two "DT for MRB Processes" 6.3 Contracts Awarded

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

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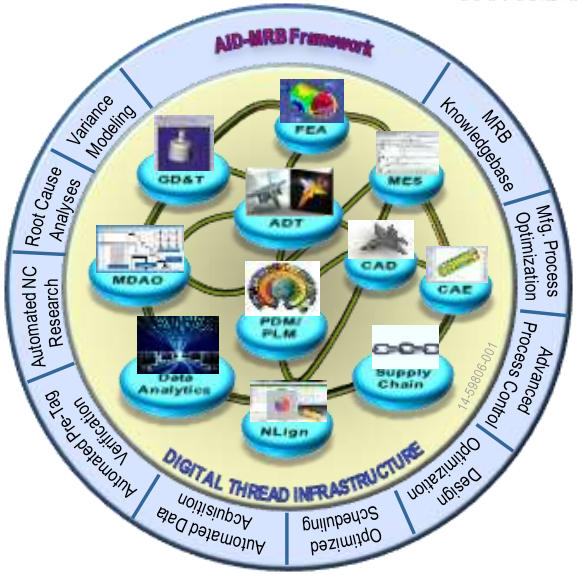
Etegent

NLIGN ANALYTICS



RJ LEE GROUP

Pratt & Whitney
A United Technologies Company

https://www.fbo.gov/index?s=opportunity&mode=form&id=31b783542ca9a65f06fc8ee98f5a379d&tab=core&tabmode=list&=

AFRL

The "Component Lifing w/ Forging Residual Stress" Use Case

Component Lifing

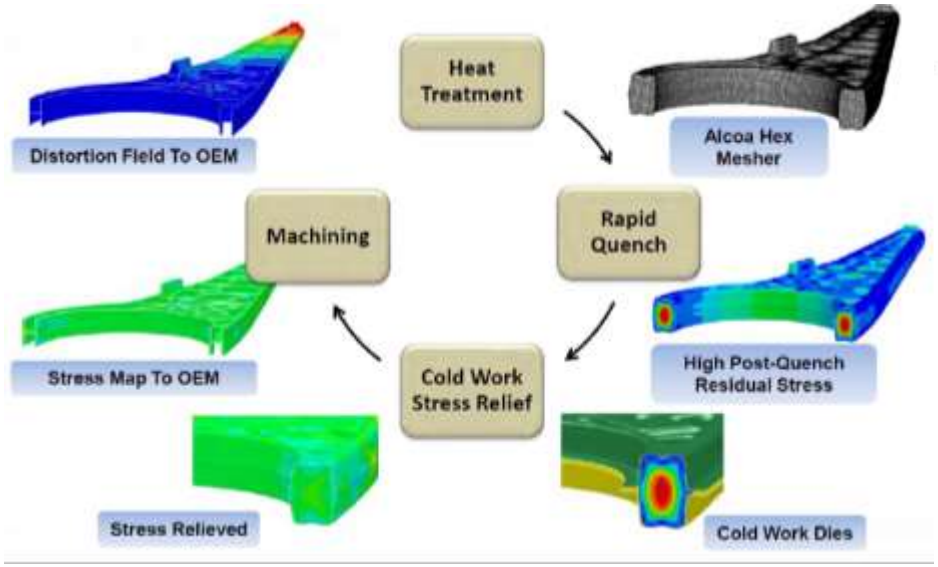
- Engineering analyses of durability & damage tolerance of design features on a component
- Models of fatigue crack initiation and crack growth
  - Boundary conditions extracted from of a series continuum mechanics models
  - Material properties developed from coupon testing
- Design feature geometry iterated until design life criteria are met

Scope of the "Component Lifing " Use Case:

- Acquisition Activity: Design
- "Performance" Parameters: Residual-stress-informed life analyses
- Applicability: Detailed Component Design

Metals Affordability Initiative Project Nearing Completion

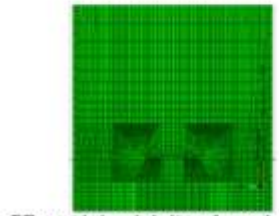
Process Modeling & Validation



REF: D. Ball et al, AIAA SciTech2015

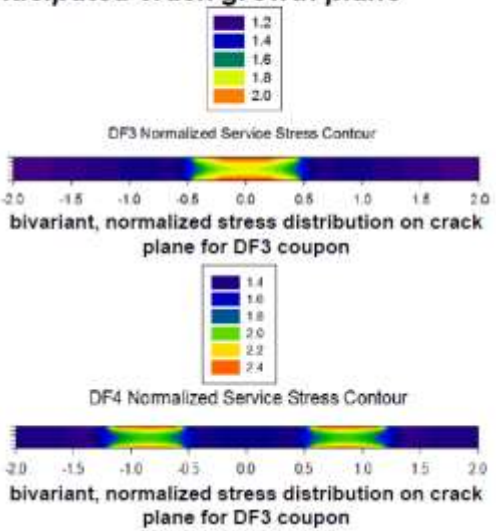
Fatigue Cracking Modeling & Validation

- Finite element analysis used to determine
  - *local stress at anticipated crack initiation site*
  - *stress distribution on anticipated crack growth plane*



FE mesh in vicinity of crack plane for DF3 coupon

FE mesh in vicinity of crack plane for DF4 coupon



New paradigm forces new Tech Data Packages, new relationship between designer & supplier, new acceptance testing requirements, and new engineering analysis model formulation

Parting Thoughts for the MBE Community

- **Multidirectional flow of data will be important**
  - Impact to Customer, OEM, & Supply Chain
    - Data Protection issues will multiply
    - Supply Chain to be linked to design much earlier
- **Continuous model/design system validation will be critical to success**
  - Need to consider design system validation during prototyping
  - Need to calibrate & update models with real data
- **Methods required to translate lessons learned into all phases of design & associated program planning**
  - Quantitative design of building block test programs for early risk reduction
  - Evolutionary Rules of Thumb converted to interactive design guidance
    - Can I make it?
    - What are the cost implications of making it this way?
  - Quantitative consideration of maturation risks for revolutionary designs/manufacturing processes/materials
  - Quantitative consideration of engineering resiliency
    - Impact of design/manufacturing/materials on robustness to future usage changes