21st Century Aerospace and Defense M&S Needs and the Virtual Manufacturing Frontier

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AMEC Charter & Mission

Move Manufacturing to the Left

Advanced Manufacturing

+ =

Engineering Capabilities

Modeling & Simulation

New Design Methodologies

AMEC
Based on 18 month study on current DFM practices*
- Analytical producibility analysis tools lacking
- Many producibility issues inadvertently designed-in
- Current commercial DFM analysis tools inadequate
- Manufacturing M&S a critical missing research area

Roadmap development underway for key focus areas
- Systems engineering trade study and design methodologies
- System integration, assembly, and test modeling
- Enterprise level supply chain design and analysis methods
- Electrical, mechanical, and assembly yield modeling
- Quantitative DFX analyses including complexity characterization
- Life cycle cost modeling including uncertainty and risk impact


Goal is to Influence S&T Investments
Why Focus on Producibility?

• Production cost components
  ➢ Direct material and labor costs
  ➢ Factory overhead/burden costs

• Producer vs. user LCC drivers
  ➢ Low yield & process inefficiencies
  ➢ Manufacturing process complexity
  ➢ Excessive quality specs/controls

• Product cost reduction strategies
  ➢ Post-NPI value engineering
  ➢ Lean out existing processes
  ➢ New material/process technologies

Inadvertently Designed-In Producibility Issues Drive Significant “Hidden” Costs
Role of Systems Engineering

It All Starts with Requirements....
Current Model-Based Approaches

“User” Needs

Systems Eng | Design Engineering | Manufacturing

Requirements Analysis | Conceptual Design | Preliminary Design | CAE/CAD/CAM Based Design | Test & Evaluation | Production & Deployment | Operations & Sustainment

MBSE | MBE | MBM

“Virtual Wall”

“Function Centric”

“Geometry Centric”

“Operation Centric”

Same Problems now Happen Virtually...
Design-Manuf Interdependence

• Early design decisions lock-in cost
  - Trade studies focus on performance
  - Exotic materials used to save weight
  - Design thrown across the “globe”

• Moving manufacturing to the “left”
  - Concurrent engineering teams
  - Early supplier involvement
  - Design for manufacturing (DFM)

• Quantitative analysis tools lacking
  - Manufacturing knowledge mostly tacit
  - High level DFM guidelines/checklists
  - Rule-based CAD/CAM occurs too late

M&S Enabler to Move Manufacturing Left
M&S-Enabled Concurrent Eng

Current State

- Systems Eng: Requirements Analysis, Conceptual Design
- Design Engineering: Preliminary Design, CAE/CAD/CAM Based Design
- Manufacturing: Production & Deployment, Operations & Sustainment

“User” Needs

“Function Centric”
“Virtual Wall”

“Geometry Centric”
“Virtual Wall”

“Operation Centric”

Transforming the Design Space

Future State

“Fit-Form-Function-Operation Centric”

Engineering

- “User” Needs
- M&S-Based Trade Studies
- “Producer” Needs

Manufacturing

“Virtual World” Complex System Design & Development

“Physical World”

“Re-Engineering” Design & Manufacturing
Reliability Engineering Discipline

Reliability Theory

Reliability: Probability that a device will perform its intended function during a specified period of time under stated conditions.

Analytical Basis

\[ MTBF = \frac{1}{\lambda} = \frac{\text{total operating hours}}{\text{number of failures}} \]
\[ R(t) = \int_{t}^{\infty} f(t)\,dt = e^{-\lambda t} \]
\[ f(t) = \frac{1}{\theta} e^{-t/\theta} \quad \lambda = \frac{1}{\theta} \]

Modeling Relationships

\[ R = (1 - R_A)(1 - R_B)(1 - R_C) \]
\[ R = (R_A)(R_B)(R_C) \]

Physics of Failure Analysis

RAMS

Reliability
Availability
Maintainability
Safety

Focus is Early Detection of Failure Modes

Trade Off Evaluations

- Useful Life
- Infant Mortality Period
- Constant Failure Rate Period
- Wearout Failure Period

Physics-Based Failure Prediction

<table>
<thead>
<tr>
<th>Configuration</th>
<th>A₁</th>
<th>MTBF</th>
<th>MₑT</th>
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<tr>
<td>Existing Design</td>
<td>0.961</td>
<td>125</td>
<td>5.0</td>
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<tr>
<td>Alternative 1</td>
<td>0.991</td>
<td>450</td>
<td>4.0</td>
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<tr>
<td>Alternative 2</td>
<td>0.990</td>
<td>375</td>
<td>3.5</td>
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<tr>
<td>Alternative 3</td>
<td>0.991</td>
<td>320</td>
<td>2.8</td>
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</table>
What About Producibility?

**Merriam-Webster.com**

Producibility (noun) \pro(d)(y)üs'abilitē\:
Definition of PRODUCIBILITY
: the character, state, or fact of being producible

**BusinessDictionary.com**

Producibility: Ease of manufacturing an item (or a group of items) in large enough quantities. It depends on the characteristics and design features of the item that enable its economical fabrication, assembly, and inspection or testing by using existing or available technology.

**Air Force Research Lab**

Producibility: A design characteristic which allows economical fabrication, assembly, inspection, and testing of an item using available manufacturing techniques. The relative ease of manufacture of an item or system.

**Defense Acquisition University**

Producibility: The measure of relative ease of manufacturing a product. The product should be easily and economically fabricated, assembled, inspected, and tested with high quality on the first attempt that meets performance thresholds.

Analytical Basis needed for Producibility
State-of-the-Art DFMA Analysis

Reduce part counts…
Standardize components…
Simplify assembly operations…

“As Is” Design
• 29 Total Parts
• Assy Time 204 sec

“To Be” Design
• 11 Total Parts
• Assy Time 88 sec

“As Is” Design
• 33 Total Parts
• Assy Time 233 sec

“To Be” Design
• 13 Total Parts
• Assy Time 91 sec


Simple DFMA Approaches Work for Simple Products
A&D Producibility Analysis Needs

• Aerospace producibility challenges
  ➢ Maximum functionality in smallest package
  ➢ Highly 3-D shapes with intricate features
  ➢ Exotic hard to machine/fabricate materials
  ➢ Tightly controlled dimensions & tolerances

• Producibility is a “design characteristic”
  ➢ Ease and economy of making item(s) at rate
  ➢ Drives manufacturing inefficiencies and risk
  ➢ F(fit, form, function, complexity, capability,..)

• Need quantitative analytical design tools
  ➢ Make “hidden factory” costs & risks visible
  ➢ Shape design vs. verify rule adherence

M&S Enabler for Producibility Prediction
**Example Producibility Impact**

**Aero Producibility Improvement Initiative**

- Legacy product producibility improvement focus areas
  - High COPQ (scrap & rework) both planned and unplanned
  - Repetitive QN and/or MRB activity due to non-conformance
  - Low first pass yield during component/part manufacturing
  - Low first pass yield during system final assembly and test
  - Excessive NVA activities in value stream map and routing
  - Non-optimal manufacturing processes that inhibit throughput

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### Financial Savings Dashboard

<table>
<thead>
<tr>
<th></th>
<th>2009-2011 Producibility Improvement Savings</th>
<th>One Year Forward Looking Financials</th>
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</thead>
<tbody>
<tr>
<td>NUMBER OF PROJECTS</td>
<td>2009: 49</td>
<td>AVE YIELD IMPROVEMENT: 21.0%</td>
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<tr>
<td></td>
<td>2010: 57</td>
<td>TOTAL SAVINGS: $25,765,469</td>
</tr>
<tr>
<td></td>
<td>2011: 82</td>
<td>AVERAGE ROI: 9.9</td>
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<td>Cumulative: 188</td>
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**Savings Breakdown**

- $22.0M: 38%
- $14.4M: 24%
- $7.4M: 13%
- $9.9M: 17%
- $1.7M: 3%
- $58,314,310: 7.6%
- $50.8M: 1%
- $2.2M: 4%

**Prodicibility Impacts Factory Operating & Support Costs**

Example Producibility RCCA

Producibility Driver Root Cause Analysis

- Producibility issues drive significant factory inefficiencies
  - Over 75% of producibility issues found to be non-6σ driven
  - Majority of defects uncovered during later processing activities

- Current DTC/DFM tools inadequate to predict factory impact
  - Product complexity drives low yield and process complexity
  - Design methods & tools needed to product/process interactions

Total Financial Savings: $58.3M

Root Cause Driver Breakdown

Significant ROI Associated with Development of M&S Tools

Summary and Key Take Aways

• Producibility issues drive significant “hidden” costs
  ➢ Neglected “ility” due to lack of analytical predictive tools
  ➢ Analytical basis needed for producibility similar to reliability
  ➢ M&S capabilities needed to move manufacturing to the left

• Advanced manufacturing M&S a critical research area
  ➢ Quantitative analyses to predict product-process interactions
  ➢ Supply chain analysis tools to predict industrial base behavior
  ➢ Design methods integrate manufacturing into SE trade space

• Vision is to create a “virtual manufacturing” environment
  ➢ M&S-enabled concurrent engineering and product realization
  ➢ Producibility predicted, quantified, and traded as design evolves
  ➢ Manufacturing enterprises designed in parallel to the product

M&S is a Transformative Technology for the Advanced Manufacturing Discipline
Underlying Research Themes

• Producibility metrics, measures, and leading indicators
• Analytical basis and models for producibility prediction
• Reduced order modeling of product-process interactions
• Design methodologies that manage uncertainty and risk
• Conceptual design decision aides and knowledge advisors
• Scenario analysis frameworks and life cycle planning tools
• Technologies for automated model generation & verification
• Immersive visualization and virtual reality environments
• Benchmark experimental data sets to validate M&S tools
Thank You
Questions?