Accelerated Insertion of Materials - Composites

Presented at SAMPE
by Gail Hahn
Boeing Phantom Works
314-233-1848
gail.l.hahn@boeing.com
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Report Documentation Page

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<th>c. THIS PAGE</th>
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Accelerated Insertion of Materials Goals

**Transform** traditional materials database and qualification practice into an efficient and interactive process fully integrated into the available design tools and design community that retains/improves upon the robustness and reliability of traditional practice.

Use the **right** source (model, experiment, experience) to fill in the data.

Reach for **robustness** not precision. Know the confidence in the data when needed.

Models can (and will) evolve – confidence in the knowledge of errors and uncertainty is what is needed.
Specific Objectives for Phase I

Establish a *methodology* for accelerated insertion of materials into defense structures.

- Phase I
  - Establish a designer knowledge base (DKB) for a currently employed material
  - Populate with data from models and/or experiments directed by the new methodology
  - Fully integrate into design tools
  - Validate against known material database
  - Demonstrate reduction in insertion time

**AIM-C is on track to meet all AIM Phase 1 Objectives**
The Objective of the AIM-C Program is to Provide Concepts, an Approach, and Tools That Can Accelerate the Insertion of Composite Materials Into DoD Products

AIM-C Will Accomplish This Three Ways

**Methodology** - *We will evaluate the historical roadblocks to effective implementation of composites and offer a process or protocol to eliminate these roadblocks and a strategy to expand the use of the systems and processes developed.*

**Product Development** - *We will develop a software tool, resident and accessible through the Internet that will allow rapid evaluation of composite materials for various applications.*

**Demonstration/Validation** - *We will provide a mechanism for acceptance by primary users of the system and validation by those responsible for certification of the applications in which the new materials may be used.*
AIM-C Will Validate the Process

Methodology That Links an Accelerated Process to the Knowledge Requirements

Embedded

Software That Links the Methodology to Knowledge, Analysis Tools, and Test Recommendations

Validated By

Demonstrations Focused on Recreating Existing Data, Precluding Persistent Problems, and Independent Peer Assessment
AIM-C Software Architecture

- Web Browser Interface
- Help Subsystem
- Methodology Models
- Business Logic Engine
- Project Database

- Data Knowledge
- Heuristic Knowledge
- Computational Knowledge

- Library -- Validated Models
  - Fiber properties
  - Resin properties
  - Prepreg properties
  - Lamina properties
  - Processing properties
  - Strength Properties -- Closed Form
  - Strength Properties -- Open Form
  - Strength properties -- Residual stress state from processing
  - Durability properties
  - Producibility properties

- Library -- Validated Design Templates

- Manuals
The Oculus Integration System

**CO™: A Plug & Play Modeling Environment**

- **Integrates Data and Software Applications on-the-fly**
  - Drag & Drop, Plug & Play
  - Simple to create, modify, manage, maintain

- **Enables Real-time data sharing between applications**
  - Secure
  - Controlled
  - Intra/Internet

- **Platform Independent**
  - Distributed
  - Neutral to Platforms and Applications

- **Increases Value of Previous Investments**
  - Software
  - Hardware
  - Networks
AIM-C System Vision

- Application
- Certification
- Assembly
- Design
- Producibility
- Durability
- Schedule
- Test Data
- Inputs
- Heuristics
- DKB
- M-Vision
- Interface
- Heuristics
- TRL
- Worksheets
- Materials
- Supportability
- Cost
- Legal/Rights
- Strength
- Design Values & Maturity

RDCS
- Materials Module
- Process Module
- Structures Module
- Module Linkage System - CO
- Produc. Module
- Durability Module
The User Is Able to Run the Module At
*Three Different Levels*

1. Through the System Software
2. Through the Integration Software
3. For trouble-shooting, and validation, the individual modules can be ran directly from a driver program.
How Will the System Be Used?

Web-Driven
- Accessed via Internet
- Used via Internet
- Application file local
- DOME enabled
- Modules available anywhere
- Configuration controlled by user
- Application file contains configuration info

Web-Based
- Downloaded from Internet
- Used locally to create application file
- Application file local
- Modules & S/W available few locations
- Configuration controlled by application file
- DOME enables remote access to modules

Stand Alone
- Accessed locally
- Used locally to create application file
- Application file local
- Modules & S/W available locally
- Configuration controlled by application file

May be only way for classified programs to use AIM-C

Most flexible

Most controlled
Methodology Ground Rules

a. Integrate the building block approach to insertion.
b. Involve each discipline in maturation.
c. Focus tests on needs identified by considering existing knowledge and analyses.
d. Target long lead concerns, unknowns, and areas predicted to be sensitive to changes in materials, processing, or environmental parameters.
AIM Uses Knowledge, Analysis, and Test to Accelerate Insertion

Conventional Building Block Approach to Certification

<table>
<thead>
<tr>
<th>Application Requirements</th>
<th>Target Properties</th>
<th>Supplier Offerings</th>
<th>Trade Studies</th>
<th>Fabrication Studies</th>
<th>Allowables Development</th>
<th>Full Scale Fab &amp; Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Months</td>
<td>3 Months</td>
<td>3-6 Months</td>
<td>2-6 Months</td>
<td>2-6 Months</td>
<td>6-18 Months</td>
<td>12-24 Months</td>
</tr>
</tbody>
</table>

Time Reduction

Cost Reduction

Risk Reduction

The AIM Focused Approach to Certification

<table>
<thead>
<tr>
<th>Application Requirements</th>
<th>Trade Studies</th>
<th>Design Features</th>
<th>Allowables Development</th>
<th>Full Scale Fab &amp; Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Months</td>
<td>3 Months</td>
<td>2-6 Months</td>
<td>4-9 Months</td>
<td>12-24 Months</td>
</tr>
</tbody>
</table>

Supplier Offerings

Design Features

Manufact. Features

Risk Reduction

Cost Reduction

35% Reduction in Total Time to Certification
45% Reduction in Time to Risk Reduction

3-6 Months

3-6 Months

2-6 Months

2-6 Months

2-6 Months

2-6 Months
**Methodology – Tool Sets**

**Tool Sets:**
- **Technology Readiness Level (TRL)**
- Definitions/Chart/Worksheet
- *(x) Readiness Level (xRL)*
- Definitions/Charts/Worksheets
- **Technical Requirements Definitions**
- Physics/Science Based Models
- Math/Statistics Models & Functions
- Heuristic Models
- Relational Data Bases for Information Storage/Retrieval
- Usage Scenarios
- Other

**Technology Readiness Levels**

- For Aerospace Applications
  - Fiber
  - Resin
  - Prepreg
  - Fabrication
  - Assembly
  - Quality
  - Other

- Fiber
- Resin
- Prepreg
- Fabrication
- Processing
- Productivity
- Lamina
- Laminate
- Durability
- Elements

- **Detailed Technical Properties/Characteristics**
- **Primary Test/Analysis Methods**
- Secondary Test/Analysis Methods
- Sequencing Requirements
- Data Requirements
- Quality Requirements
### Technology Readiness Levels

<table>
<thead>
<tr>
<th>TRL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Application Risk</strong></td>
<td>Very High</td>
<td>High</td>
<td>High - Med</td>
<td>Med - High</td>
<td>Medium</td>
<td>Med - Low</td>
<td>Low</td>
<td>Low - Very Low</td>
</tr>
<tr>
<td><strong>Application Maturity</strong></td>
<td>Concept Exploration</td>
<td>Concept Definition</td>
<td>Proof of Concept</td>
<td>Preliminary Design</td>
<td>Design Maturation</td>
<td>Component Testing</td>
<td>Ground Test</td>
<td>Flight Test</td>
</tr>
<tr>
<td><strong>Certification</strong></td>
<td>Certification Requirements Documented</td>
<td>Certification Plan Documented</td>
<td>Certification Plan Approved</td>
<td>Preliminary Design Allowables</td>
<td>Subcomponent Testing</td>
<td>Full Scale Component Testing</td>
<td>Full Scale Airframe Tests</td>
<td>Flight Test</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>Concept Exploration/ Potential Benefits Predicted</td>
<td>Concept Definition/ Applications Revised by Lamina Data (Coupons)</td>
<td>Applications Revised by Laminate Data (Coupons)/ Design Closure</td>
<td>Applications Revised by Assy Detail Test Data (Elements)/ Preliminary Design</td>
<td>Applications Revised by Subcomponent Test Data/ Design Maturation</td>
<td>Applications Revised by Component Test Data/ Ground Test Plan</td>
<td>Applications Revised by Airframe Ground Tests/ Flight Test Plan</td>
<td>Production Plan</td>
</tr>
<tr>
<td><strong>Assembly</strong></td>
<td>Assembly Concept</td>
<td>Assembly Plan Definition</td>
<td>Key Assembly Detail Definitions</td>
<td>Key Assembly Details Tested</td>
<td>Subcomponents Assembled</td>
<td>Components Assembled</td>
<td>Airframe Assembled</td>
<td>Flight Vehicles Assembled</td>
</tr>
<tr>
<td><strong>Structures Maturity</strong></td>
<td>Preliminary Properties/Characteristics</td>
<td>Initial Properties Verified by Test</td>
<td>Design Properties Developed</td>
<td>Preliminary Design Allowables</td>
<td>B-Basis Design Allowables</td>
<td>A-Basis Design Allowables</td>
<td>EMD Material Supplied</td>
<td>LRIP Material Supplied</td>
</tr>
<tr>
<td><strong>Materials Maturity</strong></td>
<td>Lab-Prototype Materials</td>
<td>Pilot Production Materials</td>
<td>Pre-Production Materials</td>
<td>Production Materials/ Material Specs</td>
<td>EMD Material Supplied</td>
<td>LRIP Material Supplied</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fabrication Maturity</strong></td>
<td>Unfeatured-Panel Fabrication</td>
<td>Feature Based Generic Small/Subscale Parts Fabricated</td>
<td>Property-Fab Relationships Tested/ Target Application Pilot Production of Generic Full Size Parts</td>
<td>Process Specs/ Effects of Fab Variations Tested/ Elements Fab'd/ Production Representative Parts Fab'd</td>
<td>Subcomponents Fab'd</td>
<td>Full Scale Components Fabricated</td>
<td>EMD Fabrication</td>
<td>Low Rate Initial Production (LRIP)</td>
</tr>
<tr>
<td><strong>Cost Benefits Maturity</strong></td>
<td>Cost Benefit Elements ID’d &amp; Projected</td>
<td>ROM Cost Benefit Analysis</td>
<td>Cost Benefit Analysis Reflect Size Lessons Learned</td>
<td>Cost Benefit Analysis Reflect Element and Production Representative Part Lessons Learned</td>
<td>Cost Benefit Analysis Reflect Subcomponent Fab &amp; Assembly Lessons Learned</td>
<td>Cost Benefit Analysis Reflect Component Fab &amp; Assembly Lessons Learned</td>
<td>Cost Benefit Analysis Reflect EMD Lessons Learned</td>
<td>Cost Benefit Analysis Reflect LRIP Lessons Learned</td>
</tr>
<tr>
<td><strong>Supportability</strong></td>
<td>Repair Items/ Areas Identified</td>
<td>Repair Materials &amp; Processes Identified</td>
<td>Repair Materials &amp; Processes Documented</td>
<td>Fab Repairs Identified</td>
<td>Fab Repair Trials/ Subcomponent Repairs</td>
<td>Component Repairs</td>
<td>Production Repairs Identified</td>
<td>Flight Qualified Repairs Documented</td>
</tr>
<tr>
<td><strong>Intellectual Rights</strong></td>
<td>Concept Documentation</td>
<td>Patent Disclosure Filed</td>
<td>Proprietary Rights Agreements</td>
<td>Data Sharing Rights</td>
<td>Vendor Agreements</td>
<td>Material and Fabrication Contracts</td>
<td>Production Rate Contracts</td>
<td>Vendor Requal Agreements</td>
</tr>
</tbody>
</table>
Methodology – What & When

Technology Readiness Level

10. Disposal
9. Production
8. Flight Test
7. Ground Test
6. Component Test
5. Design Maturation (Subcomponents)
4. Preliminary Design (Stable Mat’l & Process + Elements)
3. Proof of Concept Prototype
2. Concept Definition
1. Concept Exploration

Activity Steps Moving to Certification

System

(x)

Readiness Level

9. Industry Std
8. Production

7. Qualified Mat’l/Process
6. Pre-Production
5. Pilot Production
4. Lab/Prototype Production
3. Beaker/Bench Product
2. Theoretical/Beaker Product
1. Concept Exploration

Activity Steps Moving to Qualification

Technologist Activity Description

Final Capabilities
Expanded Capabilities
Preliminary Capabilities
Preliminary Investigations, Research, Development

Preliminary Capabilities

Activity Steps Moving to Certification
Understanding Uncertainty – The Benefit of Linked Simulation Tools and Methodology

<table>
<thead>
<tr>
<th>Probabilistic Tools</th>
<th>Statistical Tools</th>
<th>Risk Analysis Tools</th>
</tr>
</thead>
</table>

### Coupon Failure Modeling Errors and Uncertainties

#### Producibility Uncertainty

- **Inherent variations** associated with physical system or the environment (Aleatory uncertainty)
  - Also known as variability, stochastic uncertainty
  - E.G. manufacturing variations, leading environments

- **Uncertainty due to lack of knowledge** (Epistemic uncertainty)
  - Inadequate physics models
  - Information from expert opinions

- **Known Errors** (acknowledged)
  - Mistakes (unacknowledged)

- **Uncertainty due to lack of knowledge**
  - Human errors e.g. error from machine arithmetic, mesh size errors, convergence errors, error propagation algorithm

- **Errors/bugs in code.**

- **Errors in calibration of the tool-part interaction.**

### Prepreg Module Uncertainty Considerations

- **Temperature Boundary Conditions**
  - Variation in temperature throughout an autoclave; variation in bagging thickness across part
  - Modeling of heat transfer coefficient of autoclave includes pressure effect but not shielding of part.
  - Assumptions made about tool-part resistance.
  - Convergence of mesh must be checked. Time-steps and temperature steps must be small enough.

- **Tool Part Interaction**
  - Part to part and point to point variations in tool limit and application of release agent
  - Tool-part interaction is very complex, and very local effects may at times be significant.
  - Current model of tool-part interaction is too simple for large parts on high CTE tools.

- **Layup**
  - Variation in lay-up during hand or machine lay-up.
  - Layers are smeared within an element and it is assumed that the smeared response is representative

- **Residual Stresses**
  - Many parameters can affect residual stress:
    - Local fiber volume fraction, ...
  - Micro-stresses are considered to be independent of meso-stresses; there are few independent measurements of residual stress
  - The formulation is believed to be most accurate when the cure cycle temperature is higher than the Tg. Otherwise the residual stress calculated can be an overestimate.

- **Errors in defining layup, or alternatively errors in the manufactured part compared to the model.**

- **Errors in material property definition, errors in coding, errors in integrating process and structural models.**
AIM-C Reduces Time and Cost of Insertion through Orchestration of Knowledge, Analysis, and Test

Reduction in rework cycles driven by reduced uncertainty (increased confidence)

Uncertainty reduction from risk mitigation activity

Slope gives average cost of rework cycle

Cost Of Rework Cycles $B

Number Of Corrective Actions

Known-Unknowns

Unknown-Unknowns

Close to Experience

Years

Uncertainty

0 0.5 1.0 1.5

0 50 100 150 200 250 300

0 0.5 1.0
Hat Stiffener Run-out
Analysis Validation Tests

Variables and interactions exercised include processing effects and defects.

- Static Strength
- Durability
- Damage Tolerance
- DCB and ENF
- \( J_1 \) and \( \epsilon_{\text{eqv}} \)
- Laminates/Joints
The AIM-C System Provides a Methodology for Insertion Via Knowledge, Analysis, and Test

The Next Four AIM-C Presentations Will:

• Demonstrate an Analytical Approach to Establish the Processing Window
  – “Exploration of Composites Processing Window and Producibility by Analysis” – Pete George

• Describe a Software Tool That Links Process Induced Residual Stress to Structural Performance
  – “Integration of Process Modeling and Stress Analysis Methods for Composite Materials” – Anthony Caiazzo

• Show How Durability Will be Assessed Using Analysis/Test
  – Methodology for Composite Durability Assessment – A. Kuraishi

• Give Examples of Using Analytical Tools in Composite Design
  – Robust Design of Composite Structure – Eric Cregger
Back up
AIM Methodology: Criteria for Success

1. Architecture
   - Open/controlled (secure/open)
   - Platform independent (Intranet vs. Internet)

2. Capabilities – at least 4 capabilities/modules
   - Properties – time dependent properties
   - Durability/Lifing
   - Processing/Manufacturing/Producibility
   - Cost
AIM Methodology: Criteria for Success

3. Features/Outputs
   - Demonstrate that the methodology reproduces the DKB
   - Demonstrate that “a rogue” process spec will result in a flag by the system
   - Demonstrate that a rogue “geometry” results in an “un-producible” flag
   - Demonstrate the ability of the system to direct experiment – to direct an experiment to determine a “benchmarking” parameter, or a basic physical quantity. (validation/calibration)
Means to Impart Methodology

a. User interface screens/prompts
b. Linked text files
c. Software documentation
d. Training
e. Methodology/process definition and change procedures document
Material Insertion Methodology

**Methodology Covers:**
- What Needs to be Done?
- When is it Done?
- How is it Done?
- Why is it Done?

**Methodology Has to Accommodate:**
- Designer Perspective + Others
- Product Certification Requirements
- Material Qualification Requirements
- Multiple Tool Sets
- Testing
- Traceability
- Integration

**Tool Sets:**
- Technology Readiness Level (TRL) Definitions/Chart/Worksheet
- (x) Readiness Level (xRL) Definitions/Chart/Worksheet
- Technical Requirements Definitions
- Definitions/Worksheets/Templates
- Physics/Science Based Models
- Math/Statistics Models & Functions
- Heuristic Models
- Relational Data Bases for Information Storage/Retrieval
- Usage Scenarios
- Other

**What, When, Why**

**How**
AIM-C Methodology Impact on Traditional Qualification

<table>
<thead>
<tr>
<th>Structures Maturity</th>
<th>Non Structural Applications</th>
<th>Secondary Structural Applications</th>
<th>Primary Structural Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIM-C Application</td>
<td>AIM-C CAT Run to Identify Critical Factors for Analysis, Test, Demonstration To Fill Screening Database Requirements</td>
<td>Screening Database Exists Broad Range of Data Limited Replications</td>
<td>Preliminary Design Database Exists Full Distribution on Few Key Properties</td>
</tr>
<tr>
<td></td>
<td>Preliminary CAT Run to Define Preliminary Design Database Requirements</td>
<td></td>
<td>Allowables Database Exists Full Distribution on Key Properties</td>
</tr>
<tr>
<td></td>
<td>Preliminary CAT Run to Define Design Database Requirements For a Desired Confidence Level</td>
<td></td>
<td>Production Readiness Established and System Validated with Confidence Metrics</td>
</tr>
<tr>
<td></td>
<td>AIM-C Run to Define Remaining Design Database Requirements</td>
<td></td>
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<table>
<thead>
<tr>
<th>TRL</th>
<th>Confidence Lvl</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<th>6</th>
<th>7</th>
<th>8+</th>
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<tr>
<td></td>
<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>40%</td>
<td>50%</td>
<td>60%</td>
<td>70%</td>
<td>80%+</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Criteria-Based Assessment</th>
<th>Quantitative Assessment via Distance From Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rework Cycles &amp; Failure Modes</td>
<td>Distance</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Design Point</td>
</tr>
<tr>
<td>Axes are the “drivers” for this application</td>
<td>Distance</td>
</tr>
<tr>
<td>Distance from experience (“similar” hardware, building block tests, and/or anchor points for models) measured using “anchored” models</td>
<td></td>
</tr>
</tbody>
</table>
Re-creation of DKB and AIM Dem/Val

- Decision to use AS4/977-3
- Re-create a DKB for IM7/977-3
- Re-create a DKB for AS4/977-3
- Provide a DKB for Hat Stiffened Panel (HSP)
- Demonstration and Validation of the AIM-C System
Phase 1 Schedule

April 04 – Final Documentation and Software Deliverable
• Feb 04 – Final Briefing – All Teams – Phase 1 Technical Effort Concludes – Full System Validation and Compelling Demonstration Validated
Jan 04 – AIM-C CAT Training
• Nov 03 – Blind Validation Complete
• Aug 03 – Demonstration/Validation – AIM-C CAT applied to hat stiffener insertion technology
Jun 03 – DARPA’s presentation for Phase 2
• May 03 – AIM-C CAT Demonstration to DARPA; Separate Quarterly Review
• Feb 03 – Full AIM Team Quarterly Review; Validation of AIM-C CAT Alpha- Modules and System; Alpha Version of Modules
• Nov 02 – Methodology linked to CAT Tools
• Aug 02 – Alpha- Version of Interface Software
• May 02 – Five CAT demonstrations; certification team participates