Accelerated Insertion of Materials - Composites

A New Way to Design Composite Structures

C.R. Saff for the Innovative Design Workshop Hampton, VA March 2004

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## A New Way to Design Composite Structures

### Report Documentation Page

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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18
Acknowledgements

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Also:
Gail Hahn (PM), Charley Saff (DPM), & Karl Nelson (DPM) - Boeing Corp.

AIM-C Team - Boeing (St. Louis, Seattle, Canoga Park, Philadelphia), Northrop Grumman, Materials Sciences Corporation, Convergent Manufacturing Technologies, Cytec Fiberite, Inc, Massachusetts Institute of Technology, Stanford, American Optimal Decisions & NASA-Langley
What is AIM-C?

AIM-C is a methodology for accelerated insertion of materials into defense structures at reduced costs.

This methodology develops a design knowledge database that links what is known about a material system to what is needed in order to qualify its application to an application that meets certification requirements.

It allows rapid identification of which applications are too risky and which are not.

It uses verified analysis methods, existing test data, and lessons learned from previous experience to minimize the amount of data required to insert new materials into a system with confidence.
What Does AIM-C Do?

Replaces the Conventional, Sequential Building Block Approach to Insertion

Application
Requirements
3 Months

Target
Properties
3 Months

Supplier
Offerings
3-6 Months

Trade
Studies
2-6 Months

Fabrication
Studies
2-6 Months

Allowables
Development
6-18 Months

Full Scale
Fab & Test
12-24 Months

Time Reduction

Cost Reduction

Risk Reduction

With a Focused, IPT Approach to Insertion

Application
Requirements
3 Months

Supplier
Offerings
3 Months

Manufact.
3-6 Months

Risk Reduction
Fab & Test
2-6 Months

Full Scale
Fab & Test
12-24 Months

35% Reduction in Total Time to Certification

45% Reduction in Time to Risk Reduction

Key Features Article is the Key to Acceleration
It is the Focus of Development Activities
It Eliminates Rework
And It Focuses Certification Testing

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How Does AIM-C Accelerate Insertion?

- Focuses on Real Insertion Needs (Designer Knowledge Base)
- Identifies the Necessary IPT and provides IPT with Readiness Level Status
- Coordinates Use of
  - Existing Knowledge
  - Validated Analysis tools
  - Focused Testing
- Provides Access to the Latest Physics Based Material & Structural Analysis Methods
- Uses Integrated Engineering Processes & Simulations
- Uses Uncertainty Analysis and Management
  - Focuses on Early Feature Based Readiness Demonstration
  - Tracks of Variability and Error Propagation During Scale Up

Provides Orchestrated Knowledge Management to efficiently tie these elements to the Design Knowledge Base
How Do I Use AIM-C?

Web-Based System Delivery

AIM-C Contains Analytical Models From Constituents

To Processing

To Effects of Defects

To Structural Reqs.

To Provide Analysis Supported by Test To Technology Readiness Approval for Public Release; Distribution Unlimited

Process Guidance and Risk Reduction Status
What’s the Benefit of AIM-C?

Traditional Test Supported by Analysis Approach

AIM Provides an Analysis Approach Supported by Experience, Test and Demonstration

Time to Insertion Readiness Reduced by 55%

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The Approach

Integrated Modeling/Simulation And Data Analysis Tools

Modular Architecture
Uncertainty Analysis

Optimized Building Block Approach

Technology Readiness Levels

Prodicibility Issues
- Simulations
- Heuristics
- Lessons Learned

METHODOLOGY

Overview of Methodology

Design Knowledge Base

Committal

Problem Statement

Define Application Requirements

Conformance Assessment

Knowledge Generation

Plan to Meet Requirements

Design Knowledge Base

Master Design Knowledge Base

Document Readiness

Allowables Development

Full Scale Fab & Test

Risk Reduction Fab & Test

Key Features Fab & Test

Target Properties

Manufact. Features

Supplier Offerings

Design Features

Trade Studies

Application Requirements

Approvals

Application Requirements

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The AIM-C Process Uses the IPT to Commit Data to the DKB

All functions contribute – All receive data from the DKB

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# AIM Allows the IPT to Track and Plan Progress Toward Successful Insertion

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Technology Readiness Levels Differ in Focus

Technology Developers See TRLs Focused on That Development

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Application Developers See TRLs Focused on Insertion Into Their Products

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One Team

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AIM Developed TRLs Focused on Insertion but Linked Technology and Application Developers Into One Team

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At Each Step Each Discipline Follows A Defined Process for Knowledge Committal

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AIM-C Links Requirements from the System to the Technology / Material

Technologies Are Most Easily Evaluated At the Element or Part Level

Structural Certification Requirements Are Addressed Here: FARs, JSSG, etc

This Process Allows us to Focus Our Efforts on those Technologies and Components of Greatest Payoff to the System for the Customer and to Document the Process By Which We Came to This Selection
## Conformance Planning

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**AIM-C Helps the IPT Plan Its Maturation Process**

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Knowledge Gathering

Technology Readiness Levels

Detail or “x” Readiness Levels

Exit Criteria

Worksheet

Use of Prior Knowledge
Recommended Analyses
Recommended Tests
Recommended Combination of Prior Knowledge / Analysis / Test

The Same Linkage Used To Flow Down Requirements Is Used to Roll Up Knowledge And Track Progress as Designer Knowledge is Gathered.

Integrated Product Team Chooses How To Meet Each Exit Criteria

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Conformance Assessment
Data from Knowledge, Analysis, and Test
– Design Values with Uncertainty

• Existing Data with replicates => can estimate design values (quantities and confidence bands)

• RDCS allows simulation of physical data with sources of randomness including batch effects (aleatory or random uncertainty) => can simulate design values.

• Combined data: design values with uncertainty bands

Property estimate = quantile with confidence band. This is the “aleatory”/measured content

Bayesian uncertainty band on analysis based properties

Aleatory and Bayesian are kept separate
### AIM Allows the IPT to Track Progress

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<td>System Requirements Review</td>
<td>Material and Process Readiness</td>
<td>Key Features Design and Fabrication</td>
<td>Key Features Test / Conformance</td>
<td>Preliminary Design</td>
<td>Critical Design / Ground Test Readiness</td>
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**Diagram:**
- **Design Knowledge Base**
- **Problem Statement**
- **Conformance Assessment**
- **Conformance Planning**
- **Knowledge Generation**

**Legend:**
- Green: Technology Insertion Readiness
- Yellow: System Requirements Review
- Red: Material and Process Readiness
- Orange: Key Features Design and Fabrication
- Blue: Key Features Test / Conformance
- White: Preliminary Design
- Pink: Critical Design / Ground Test Readiness
- Brown: Flight Test Readiness
- Blue: Production Readiness
- Green: Operational Readiness
- Yellow: Technology Insertion Readiness

**Remark:**
- AIM Allows the IPT to Track Progress
- Approval for Public Release; Distribution Unlimited
AIM Has Assembled a Web-Based System to Help the IPT Apply the Process

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How Do Materials Engineers Use AIM-C?

AIM-C Helps Monitor Conformance to Requirements

AS4/977-3 - Transverse Modulus Development

Time (min)

Modulus (Psi)

355°F Experimental
355°F Replicate Exp
355°F Model
330°F Experimental
330°F Model
315°F Experimental
315°F Model
275°F Experimental
275°F Replicate Exp
275°F Model

355°F
330°F
315°F
270°F

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How Does Manufacturing Use AIM-C?

AIM-C Helps Identify Analysis Tools to Guide Fabrication

Evaluation of Results
Adjust Mesh for Compensations
Evaluate Results
Compensation Dimensions
As Designed Shape
Compensated Mandrel Shape

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How Do Structures Engineers Use AIM-C?

Fed Back to FEM For Verify Satisfaction Of Requirements

From Full FEM to Segments

Details to Effects of Defects

Elements to Details

AIM-C Helps Plan the Maturation Process

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How Does AIM-C Assess Strength?

Detailed 3D FEA of complex structures combined with simple strain-based failure criterion (SIFT)

Design parameters
- Ply orientations
- Material
- Complex geometry

3-D Finite element analysis

Failure Criteria
- 3 Strain invariants

Prediction
- Prediction of failure

Global
Local
Micro-mechanic

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How Does AIM-C Assess Durability?

This Module Predicts the Effects of Four Competing Failure Modes – Time, Temperature, Environment and Chemical Degradation

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The AIM-C System Uses These Tools to Produce a DKB That Meets Certification Requirements

- Materials
- Application
- Certification
- Design
- Assembly
- Supportability
- Cost
- Legal/Rights
- Strength
- Durability
- Schedule
- Previous Knowledge (Heuristics, Lessons Learned)

**RDCS**
- Materials Module
- Process Module
- Structures Module
- Produc. Module
- Durability Module

Recommended Tests

Analytical Results

Approval for Public Release; Distribution Unlimited
Robust Design Computational System

Wide Variety of Error Propagation and Uncertainty Analysis Tools

A Domain Independent Comprehensive Tool Set to Analyze the Design Space

PARAMETRIC MATH MODEL

RDCS System Director

Module Integration

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AIM-C Three Step Validation Approach

**Step 1**
Individual Module and System Validation

**Step 2**
Demonstrations and System Validation of Improvements

**Step 3**
Blind Validation

Existing Data

System Demonstration and Tests of Compelling Demo Validate Projected Means and Scatter

NGC IPT Uses AIM-C

Validates Technical Results, Time Reductions, Cost Reductions

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AIM-C Significant Accomplishments

Physics Based 3D SIFT & Fracture Failure Theories

Design, ANOVA, Design Explorer, & Probabilistic Optimization RDCS Links

SIFT/Accelerated Testing

Materials & Processing

Durability

Processing data passed to Structural Analyses

AIM-C Methodology Links Readiness Levels

DTL - Technology Readiness Level

3D Re-creation

Processing data passed to Structural Analyses

AIM-C Methodology Links Readiness Levels

1. Concept Exploration (x)

2. Theoretical/Beaker Product

3. Beaker/Bench Product

4. Lab/Prototype Production

5. Pilot Production

6. Pre-Production

7. Qualified Mat'l/Process

8. Production

9. Industry Std

xRL - Activity Steps Moving to Certification

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

Technology Readiness Level

TRL - Activity Steps Moving to Qualification

9. Disposal

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
Where is AIM Being Used?

- Materials Selection for X-45
- Composite Flap for F/A-18 E/F
- Transparencies for 7E7

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