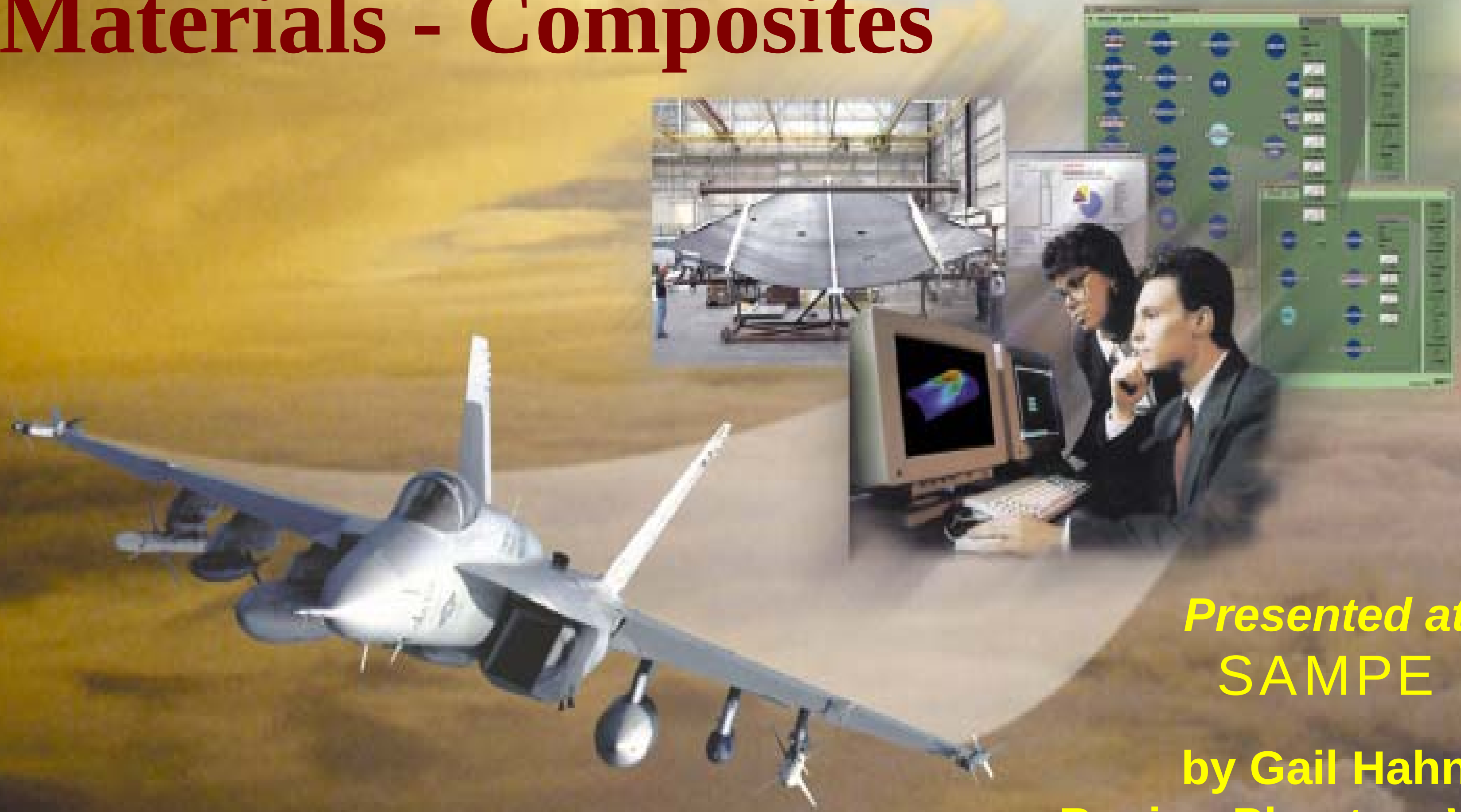
# Accelerated Insertion of Materials - Composites



***Presented at***

SAMPE

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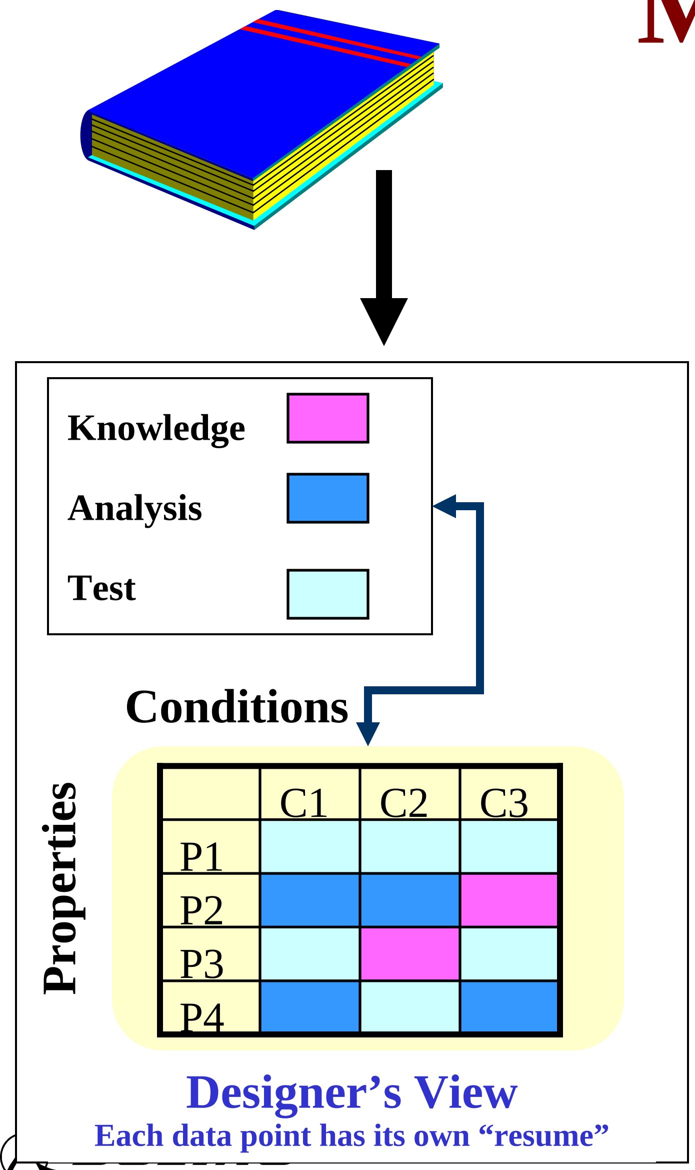
**AIM-C Team - Boeing (St. Louis, Seattle, Canoga Park, Philadelphia), Northrop Grumman, Materials Sciences Corporation, Convergent Manufacturing Technologies, Cytec Fiberite, Inc, Massachusetts Institute of Technology, Stanford & NASA (Langley)**

# 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**

# AIM-C Alignment Tool

**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**

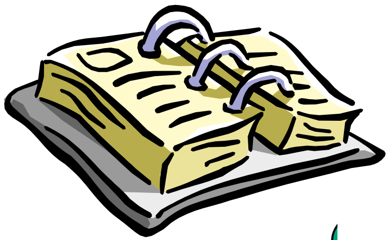
AIM-C Will Accomplish This Three Ways

**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**

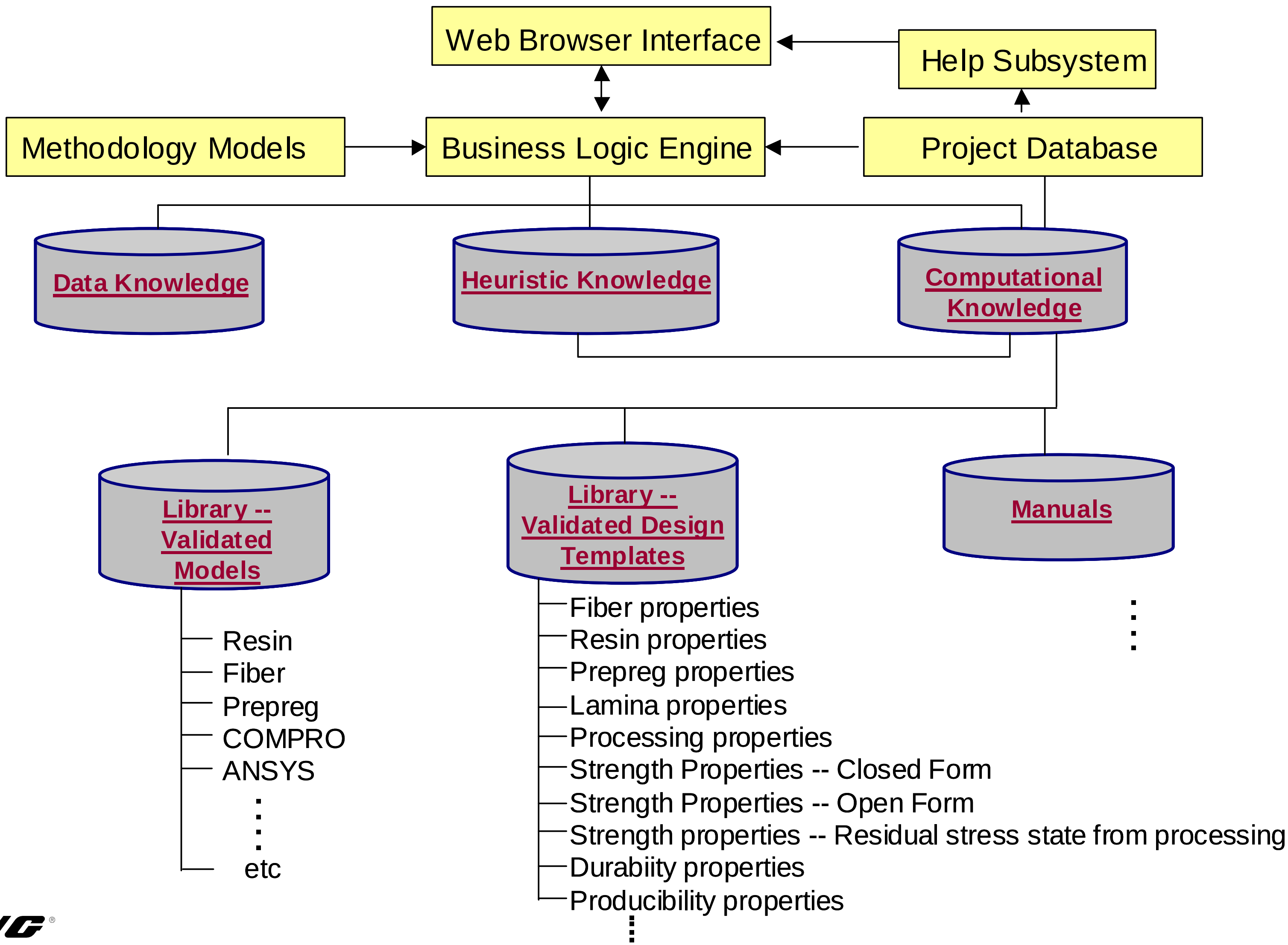
**Embedded In**


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

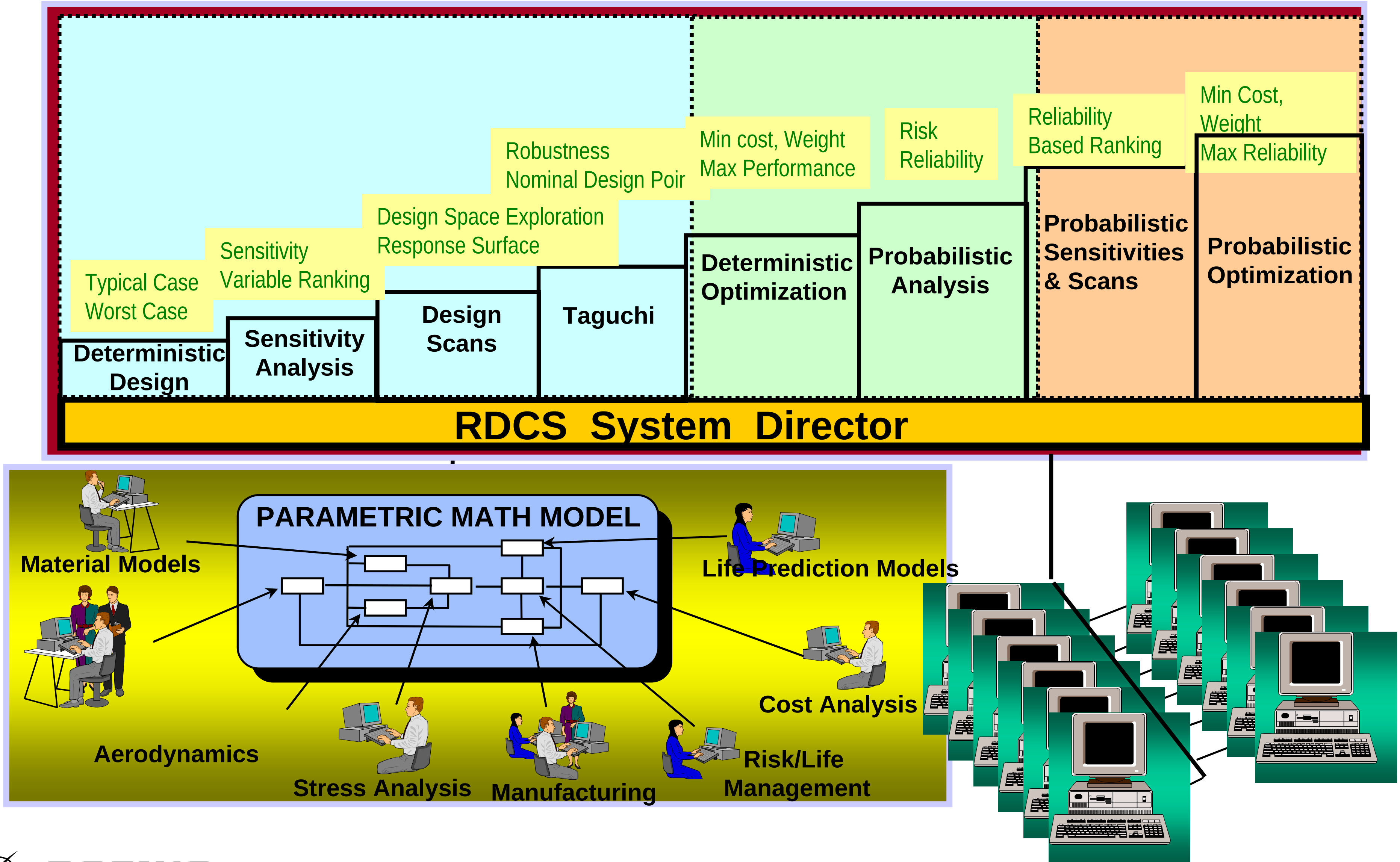
**Validated By**

**Demonstrations**
**Focused on Recreating Existing Data, Precluding Persistent Problems, and Independent Peer Assessment**

# AIM-C Software Architecture

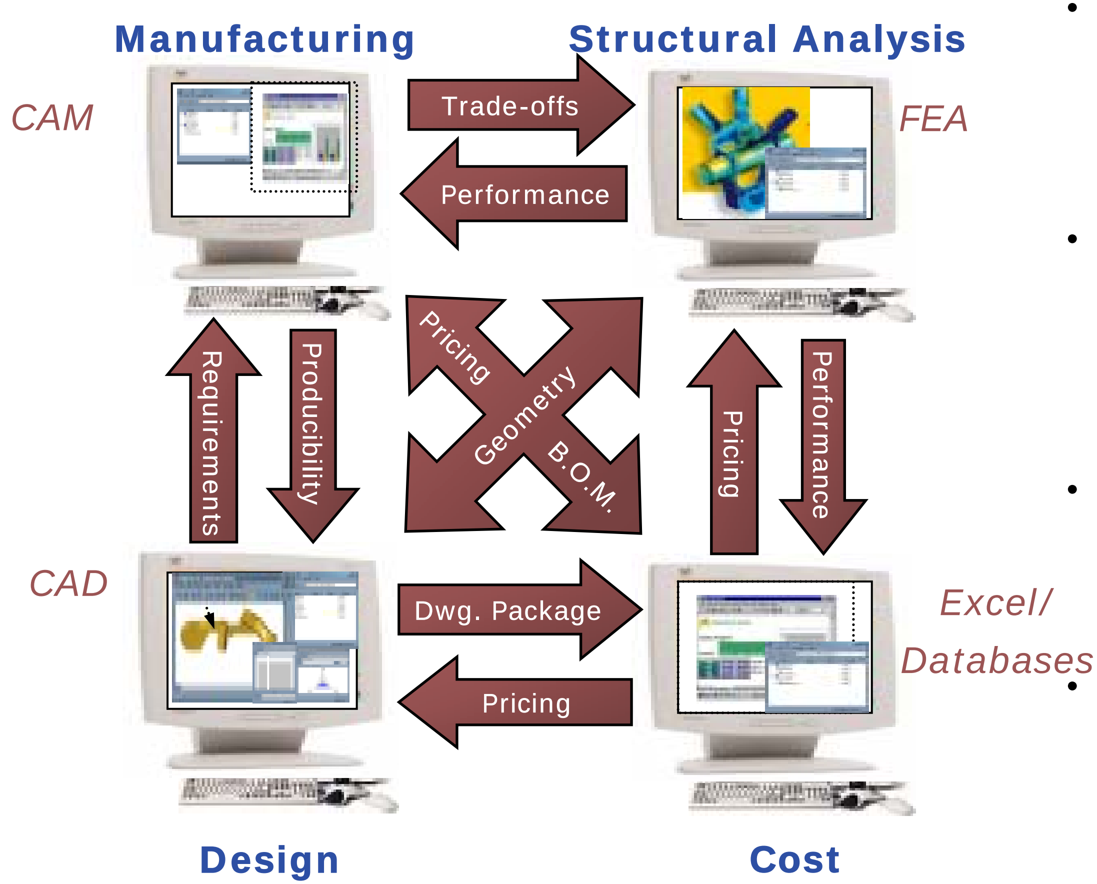


# Robust Design Computational System



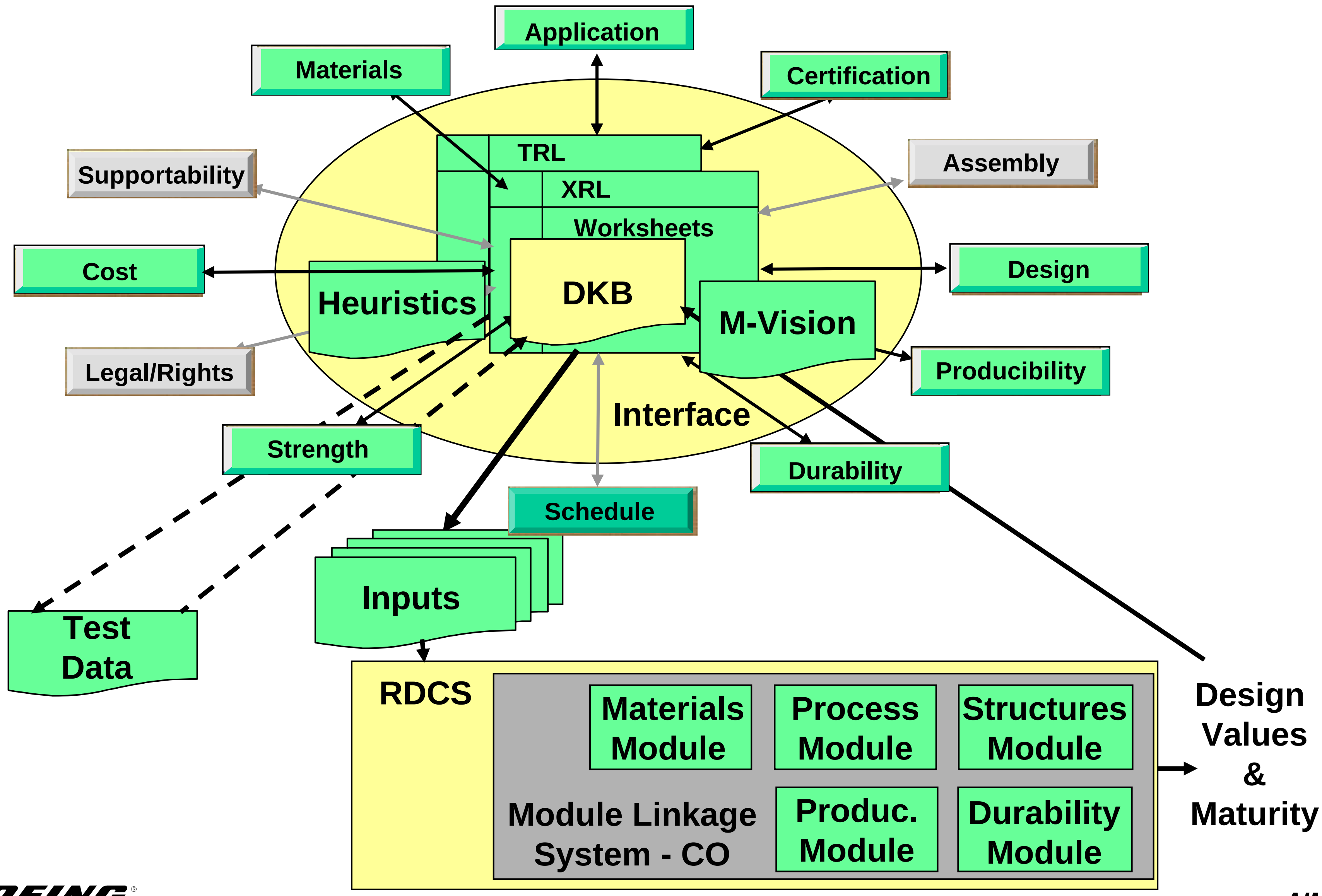
# The Oculus Integration System

## CO™: A Plug & Play Modeling Environment

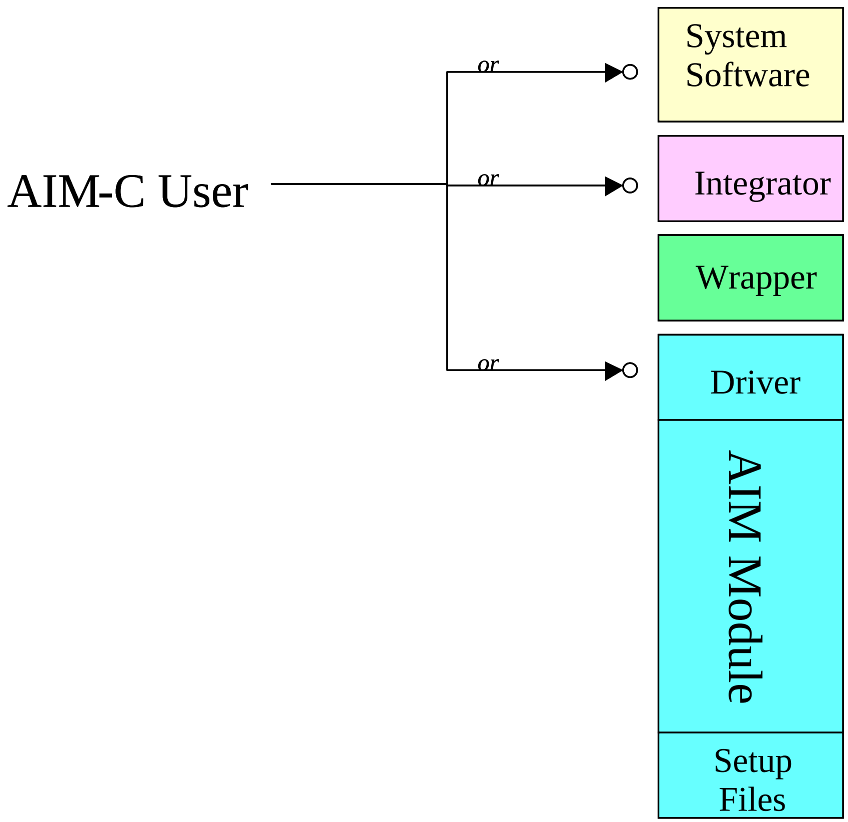



- **Integrates Data and Software Applications on-the-fly**
  - Drag & Drop, Plug & Play
  - Simple to create, modify, manage, maintain
- **Enables Real-time data sharing between applications**
  - Secure
  - Controlled
  - Intra/Internet
- **Platform Independent**
  - Distributed
  - Neutral to Platforms and Applications
- **Increases Value of Previous Investments**
  - Software
  - Hardware
  - Networks

# AIM-C System Vision



# 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

***Most flexible***

## 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

***Most controlled***

## 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***

# 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

- 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
  - Critical Details Fab & Test — 2-6 Months
  - Subcomponent Fab & Test — 2-6 Months
  - Component Fab & Test — 2-6 Months
- Full Scale Fab & Test — 12-24 Months

Time Reduction

Cost Reduction

Risk Reduction

## The AIM Focused Approach to Certification

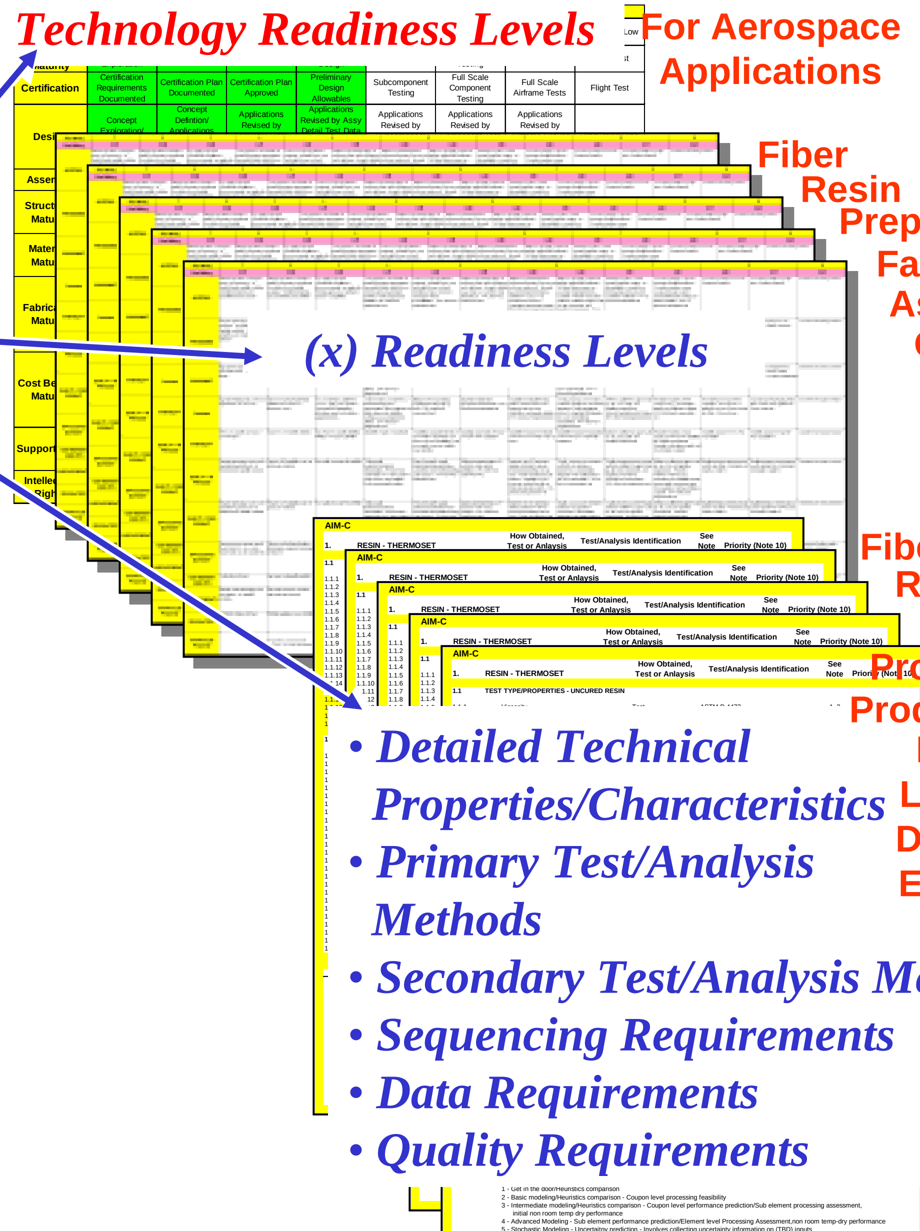
- Application Requirements — 3 Months
- Trade Studies — 3 Months
- Supplier Offerings — 3-6 Months
- Target Properties — 2-6 Months
- Design Features — 2-6 Months
- Manufact. Features — 3-6 Months
- Key Features Fab & Test — 2-6 Months
- Allowables Development — 4-9 Months
- Risk Reduction Fab & Test — 4-9 Months
- Full Scale Fab & Test — 12-24 Months

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

# 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




- Detailed Technical Properties/Characteristics
- Primary Test/Analysis Methods
- Secondary Test/Analysis Methods
- Sequencing Requirements
- Data Requirements
- Quality Requirements

# Technology Readiness Levels

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

# 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

(Levels 10–7: System)

*Activity Steps Moving to Certification*

**(x) Readiness Level**

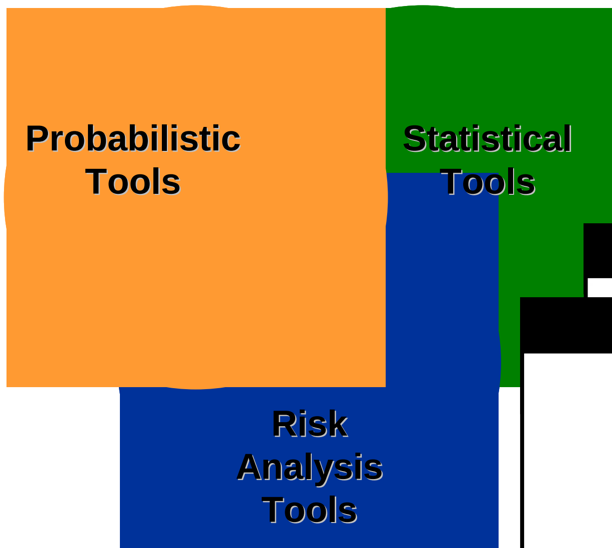
9. Industry Std
8. Production
7. Qualified Mat'l/Process — Final Capabilities
6. Pre-Production — Expanded Capabilities
5. Pilot Production — Preliminary Capabilities
4. Lab/Prototype Production
3. Beaker/Bench Product
2. Theoretical/Beaker Product
1. Concept Exploration

(Levels 4–1: Preliminary Investigations, Research, Development)

*Technologist Activity Description*

*Activity Steps Moving to Qualification*

# Understanding Uncertainty – The Benefit of Linked Simulation Tools and Methodology




## Coupon Failure Modeling Errors and Uncertainties

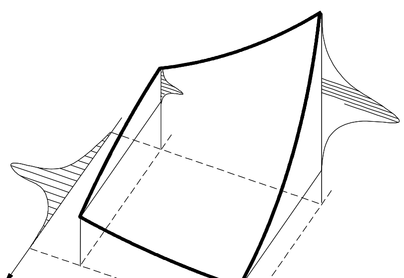
## Producibility Uncertainty

## Prepreg Module Uncertainty Considerations

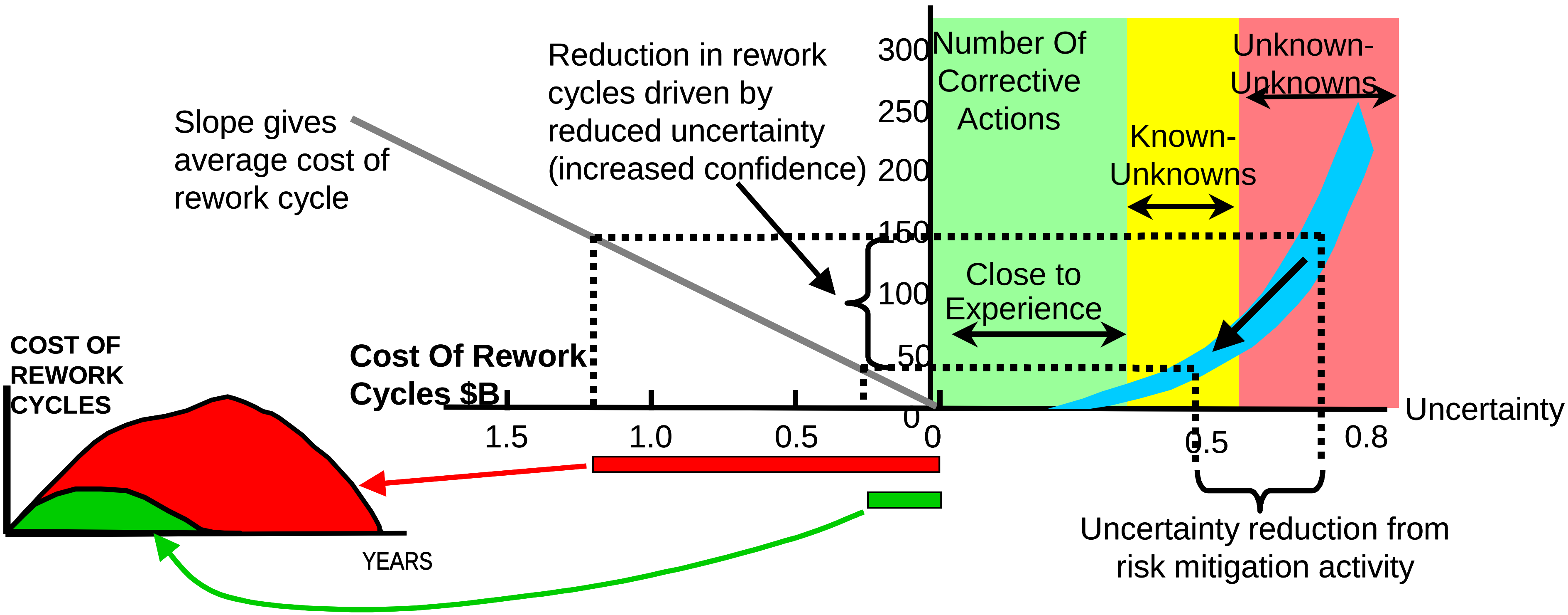
## Resin Module Uncertainty Considerations

## Modeling of the Process

| | Inherent variations associated with physical system or the environment (Aleatory uncertainty)<br>Also known as variability, stochastic uncertainty<br>E.G. manufacturing variations, loading environments | Uncertainty due to lack of knowledge (Epistemic uncertainty)<br>inadequate physics models information from expert opinions. | Known Errors (acknowledged)<br>e.g. round-off errors from machine arithmetic, mesh size errors, convergence errors, error propagation algorithm | Mistakes (unacknowledged errors)<br>human errors e.g error in input/output, blunder in manufacturing |
|---|---|---|---|---|
| **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. | Errors in setup files, and other initialization procedures. Errors/bugs in code. |
| **Tool Part Interaction** | Part to part and point to point variations in tool finish 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. | Errors in calibrating the tool-part interaction |
| **Layup** | Variation in lay-up during hand or machine lay-up. | The layers are smeared within an element and it is assumed that the smeared response is representative | | Error in defining layup, or alternatively errors in the manufactured part compared to model |
| **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 material property definition, errors in coding, errors in integrating process and structural models. |

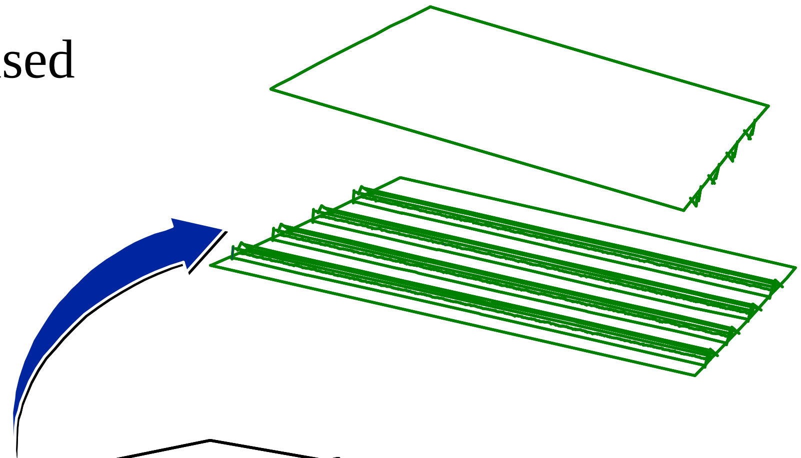


# AIM-C Reduces Time and Cost of Insertion through Orchestration of Knowledge, Analysis, and Test

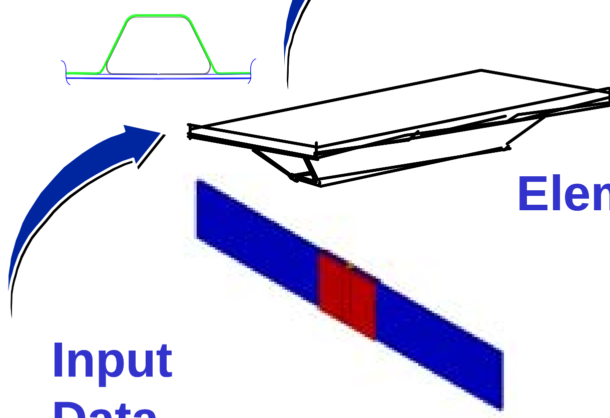


# Hat Stiffener Run-out Analysis Validation Tests

Variables and interactions exercised include processing effects and defects.

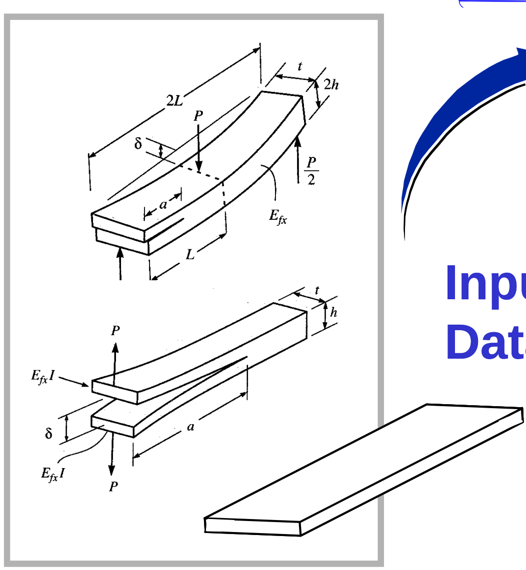


**Analysis Validation Tests**



**Elements**

- Static Strength
- Durability
- Damage Tolerance



**Input Data**

- DCB and ENF
- $J_1$ and $\varepsilon_{eqv}$ 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

***What, When, Why***

***How***

## ***Tool Sets:***

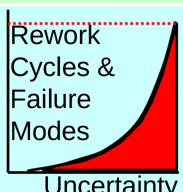
- ***Technology Readiness Level*** (TRL) Definitions/Chart/Worksheet
- ***(x) Readiness Level*** (xRL) Definitions/Chart/Worksheet
- ***Technical Requirements*** Definitions
- Definitions/Worksheets/Templates
- Physics/Science Based Models
- Math/Statistics Models & Functions
- Heuristic Models
- Relational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

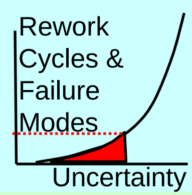
# AIM-C Methodology Impact on Traditional Qualification

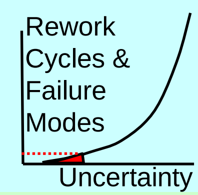
| Structures Maturity | | Non Structural Applications | | Secondary Structural Applications | | Primary Structural Applications | |
|---|---|---|---|---|---|---|---|
| **AIM-C Application** | AIM-C CAT Run to Identify Critical Factors for Analysis, Test, Demonstration To Fill Screening Database Requirements | Screening Database Exists Broad Range of Data Limited Replications | AIM-C CAT Run to Define Preliminary Design Database Requirements | Preliminary Design Database Exists Full Distribution on Few Key Properties | AIM-C CAT Run to Define Design Database Requirements For a Desired Confidence Level | Allowables Database Exists Full Distribution on Key Properties | AIM-C Run to Define Remaining Design Database Requirements | Production Readiness Established and System Validated with Confidence Metrics |

| TRL | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8+ |
|---|---|---|---|---|---|---|---|---|
| Confidence Lvl | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80%+ |

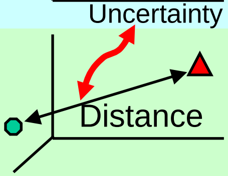
**Criteria-Based Assessment**



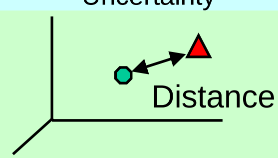




**Quantitative Assessment via Distance From Experience**

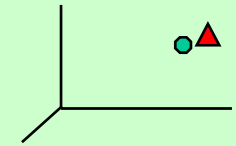



▲ Design Point
● Experience Data Point

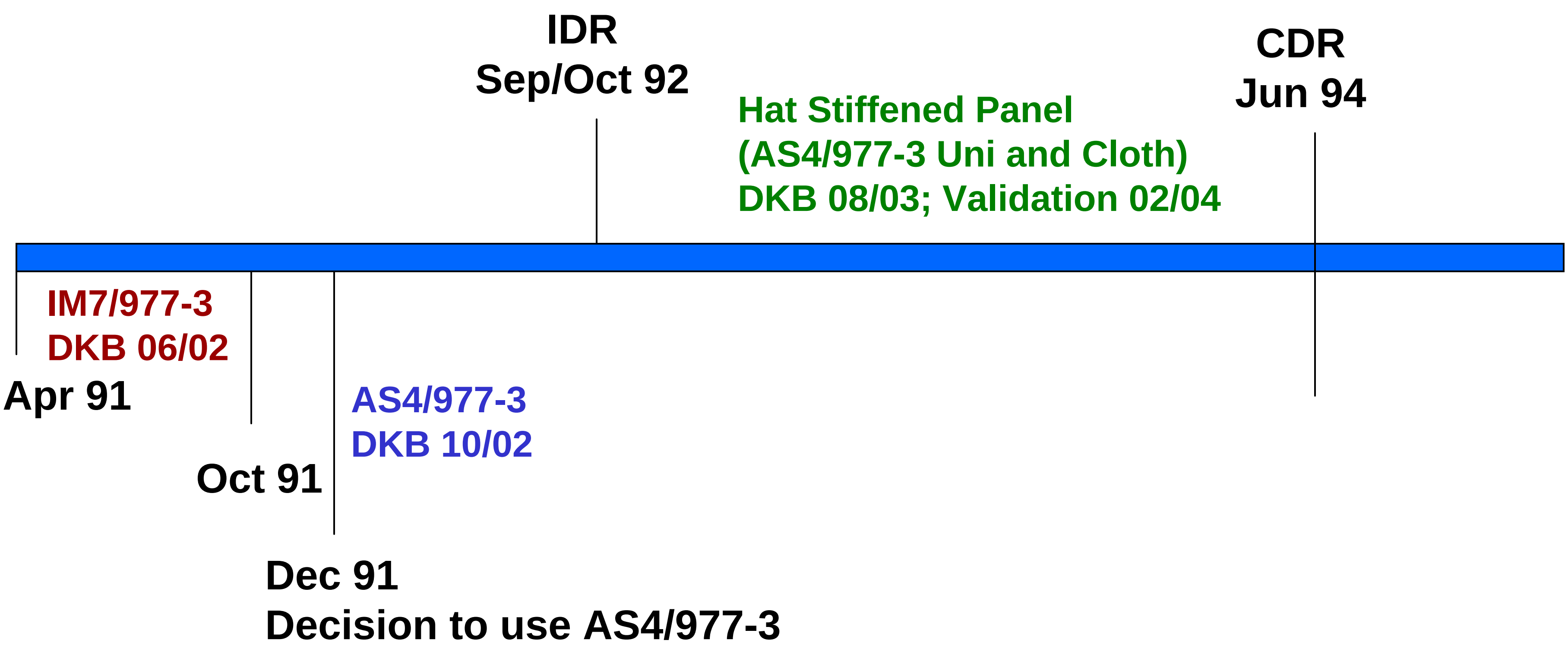
Axes are the "drivers" for this application




Distance from experience ("similar" hardware, building block tests, and/or anchor points for models) measured using "anchored" models



# Re-creation of DKB and AIM Dem/Val




(1) Re-create a DKB for IM7/977-3

(2) Re-create a DKB for AS4/977-3

(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