Accelerated Insertion of Materials - Composites

Presented to Mil-Hdbk-17
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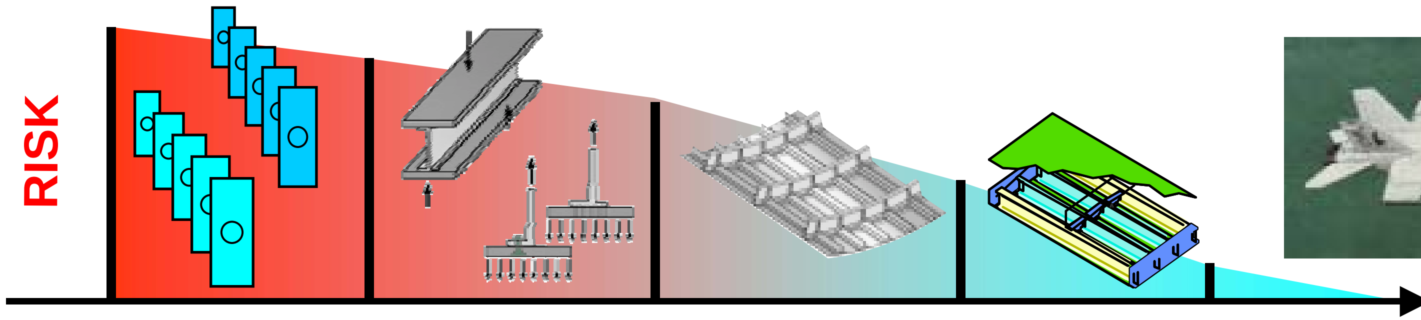
16 October 2001

Jointly accomplished by BOEING and the U.S Government under the guidance of NAST

This program was developed under the guidance of Dr. Steve Wax and Dr. Leo Christodoulou of DARPA. It is under the technical direction of Dr. Ray Meilunas of NAVAIR.

Accelerated Insertion of Materials

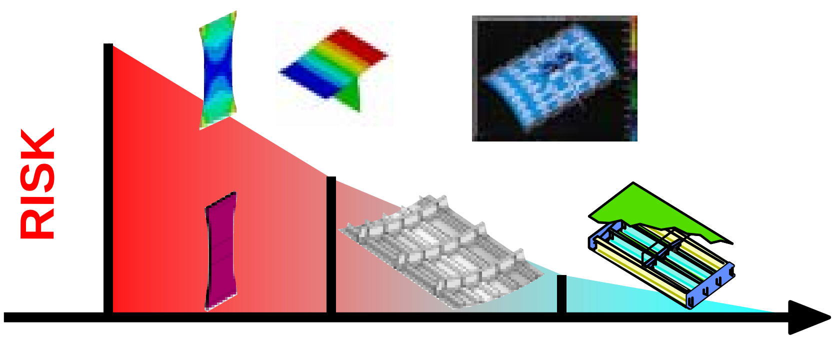
Traditional Building Block Approach Improves Confidence by Extensive Testing Supported by Analysis:
Too Often Misses Material Insertion Windows



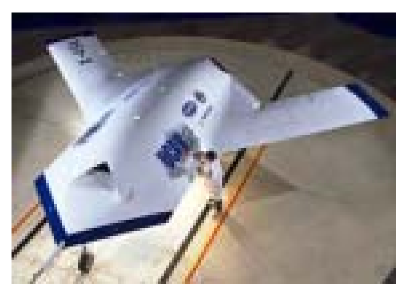
Time to Insertion Readiness

What AIM Enables

AIM Methodology Improves Confidence More Rapidly & Effectively by Analysis Supported By Test / Demonstration -
***Focusing* on the Designer Knowledge Base Needs**



Time to Insertion Readiness



Benefits
50% Time Reduction
33% Cost Reduction

Methodology is the Foundation of the AIM-C Comprehensive Analysis Tool

RDCS/DOME Framework

Structure Models
(Science Based)

Material & Process Models
(Science Based)

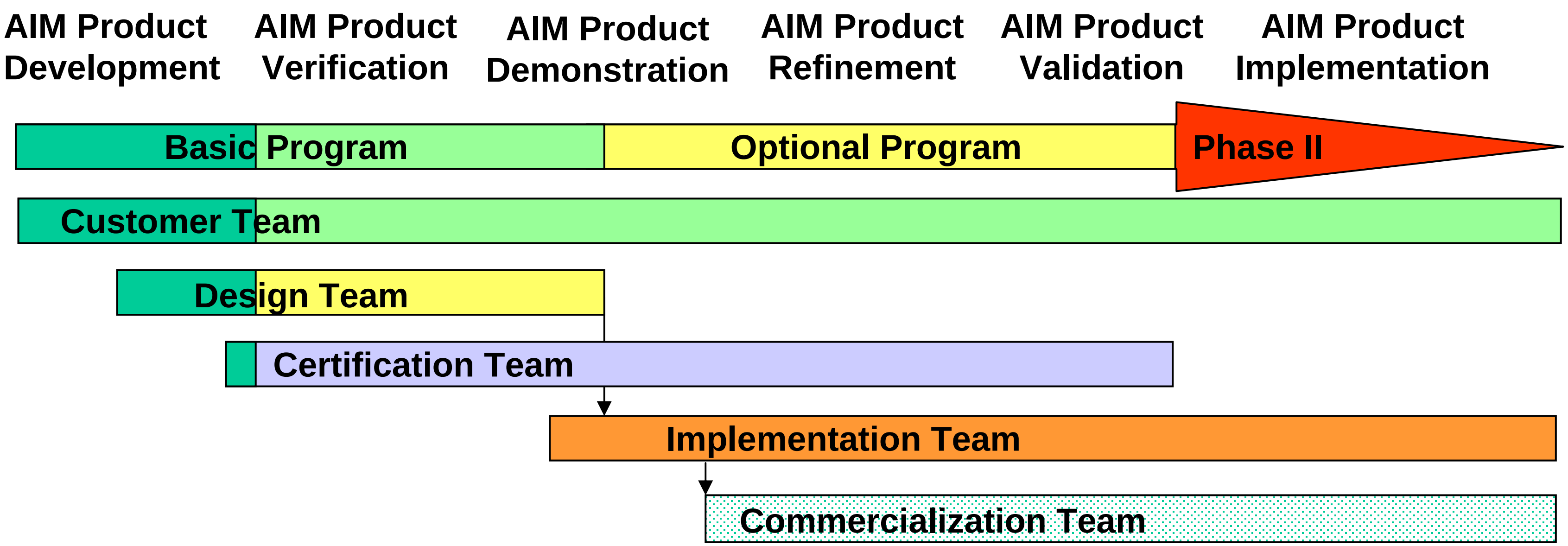
Producibility Models
(Science Based)

Heuristic Models

Data Bases

Methodology

Technology Transition Plan



DESIGN TEAM'S NEEDS
Requirements are Multi-Disciplined

Structural

- Strength and Stiffness
- Weight
- Service Environment
  - Temperature
  - Moisture
  - Acoustic
  - Chemical
- Fatigue and Corrosion Resistant
- Loads & Allowables
- Certification

Manufacturing

- Recurring Cost, Cycle Time, and Quality
- Use Common Mfg. Equipment and Tooling
- Process Control
- Inspectable
- Machinable
- Automatable
- Impact on Assembly

Supportability

- O&S Cost and Readiness
- Damage Tolerance
- Inspectable on Aircraft
- Repairable
- Maintainable
  - Accessibility
  - Depaint/Repaint
  - Reseal
  - Corrosion Removal
- Logistical Impact

Material & Processes

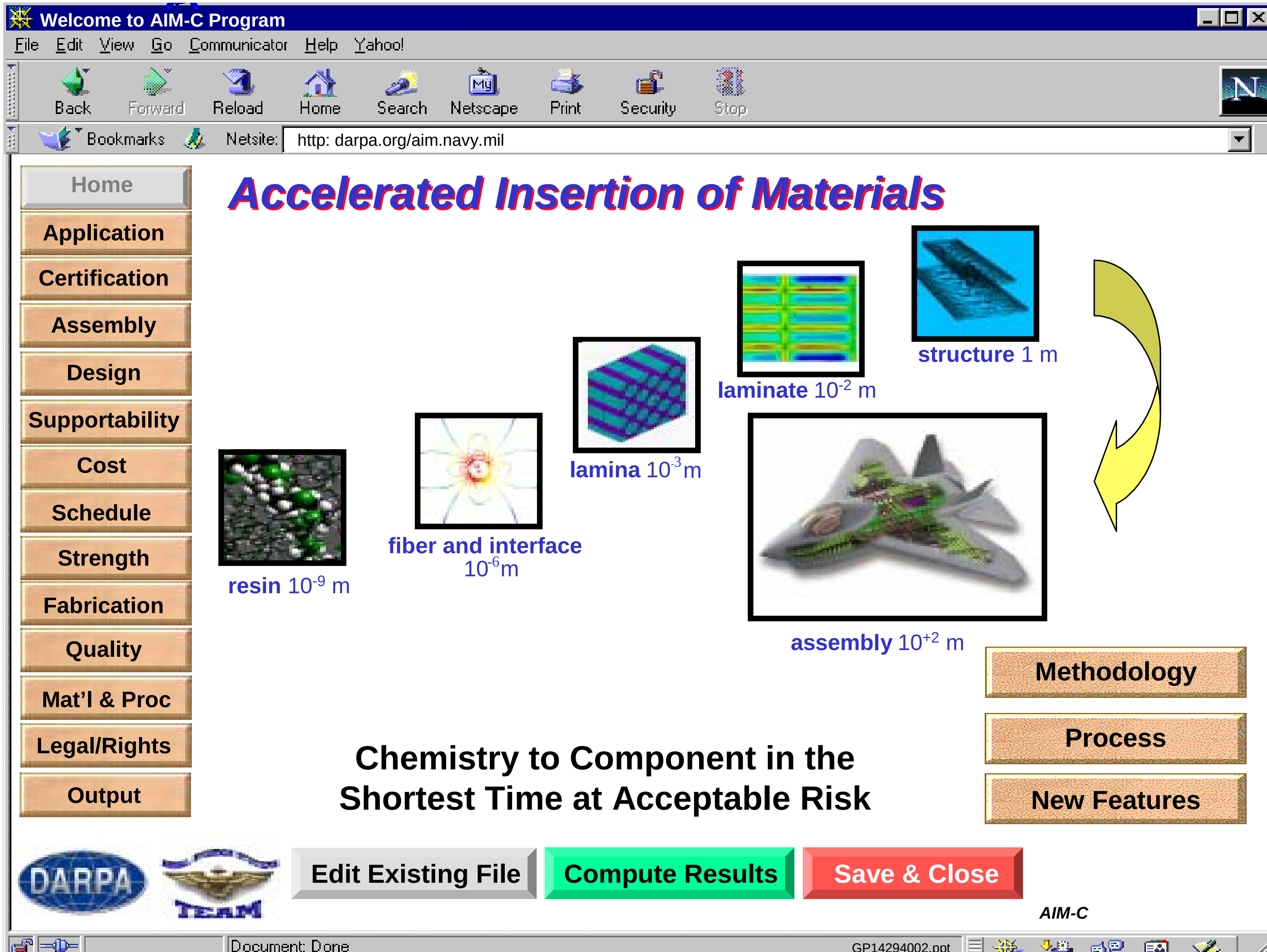
- Development Cost
- Feasible Processing Temperature and Pressure
- Process Limitations
- Safety/Environmental Impact
- Useful Product Forms
- Raw Material Cost
- Availability
- Consistency

Miscellaneous

- Observables
- EMI/Lightning Strike
- Supplier Base
- Applications History
- Certification Status
  - USN
  - USAF
  - ARMY
  - FAA

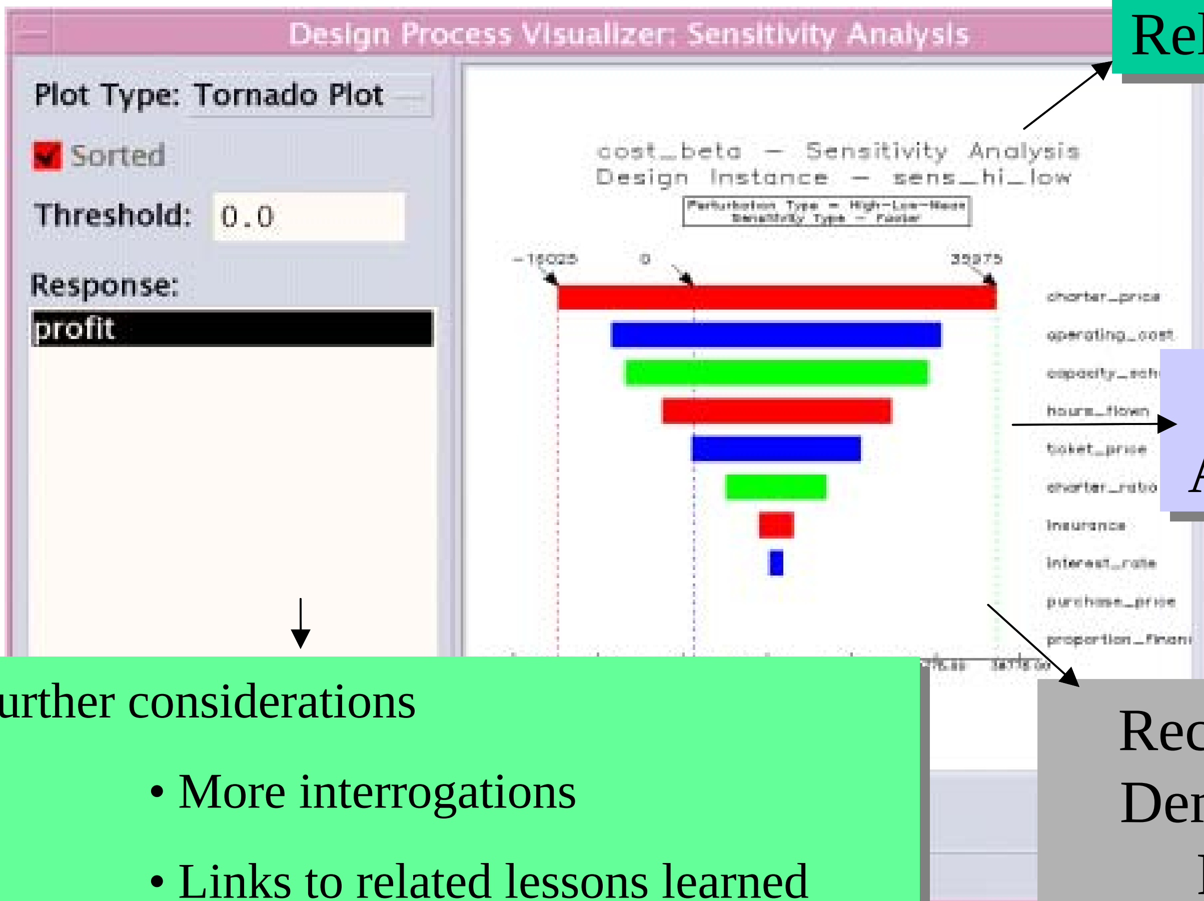
Risk in Each Area is Dependent Upon Application's Criticality and Material's Likelihood of Failure

Conceptual Vision of the AIM-C CAT User Interface



Example of an Output Screen for the AIM-C CAT

Drivers of Cost, Schedule, Technical Outcomes



Related Tests

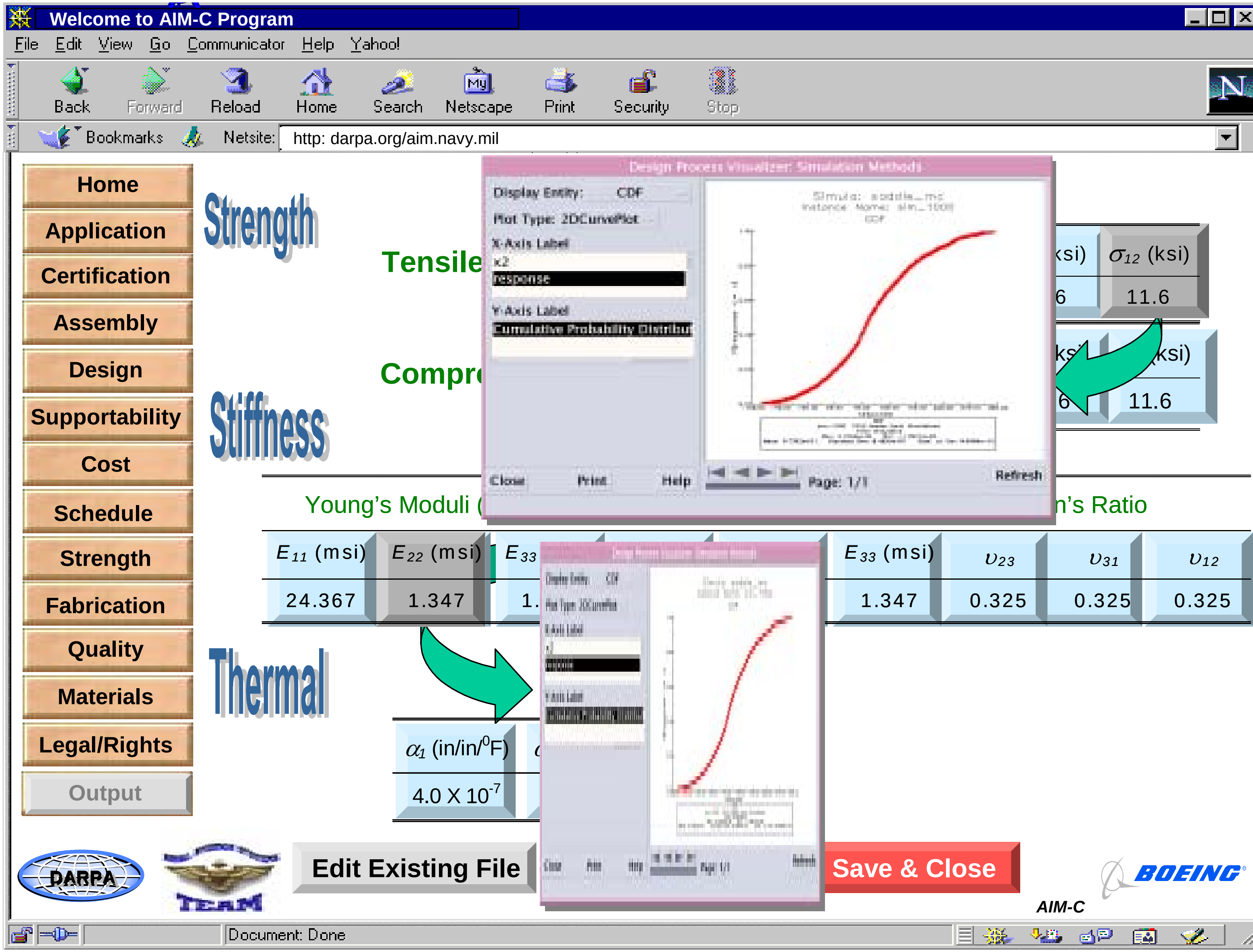
Recommended Analysis Methods

Recommended Demonstration Features

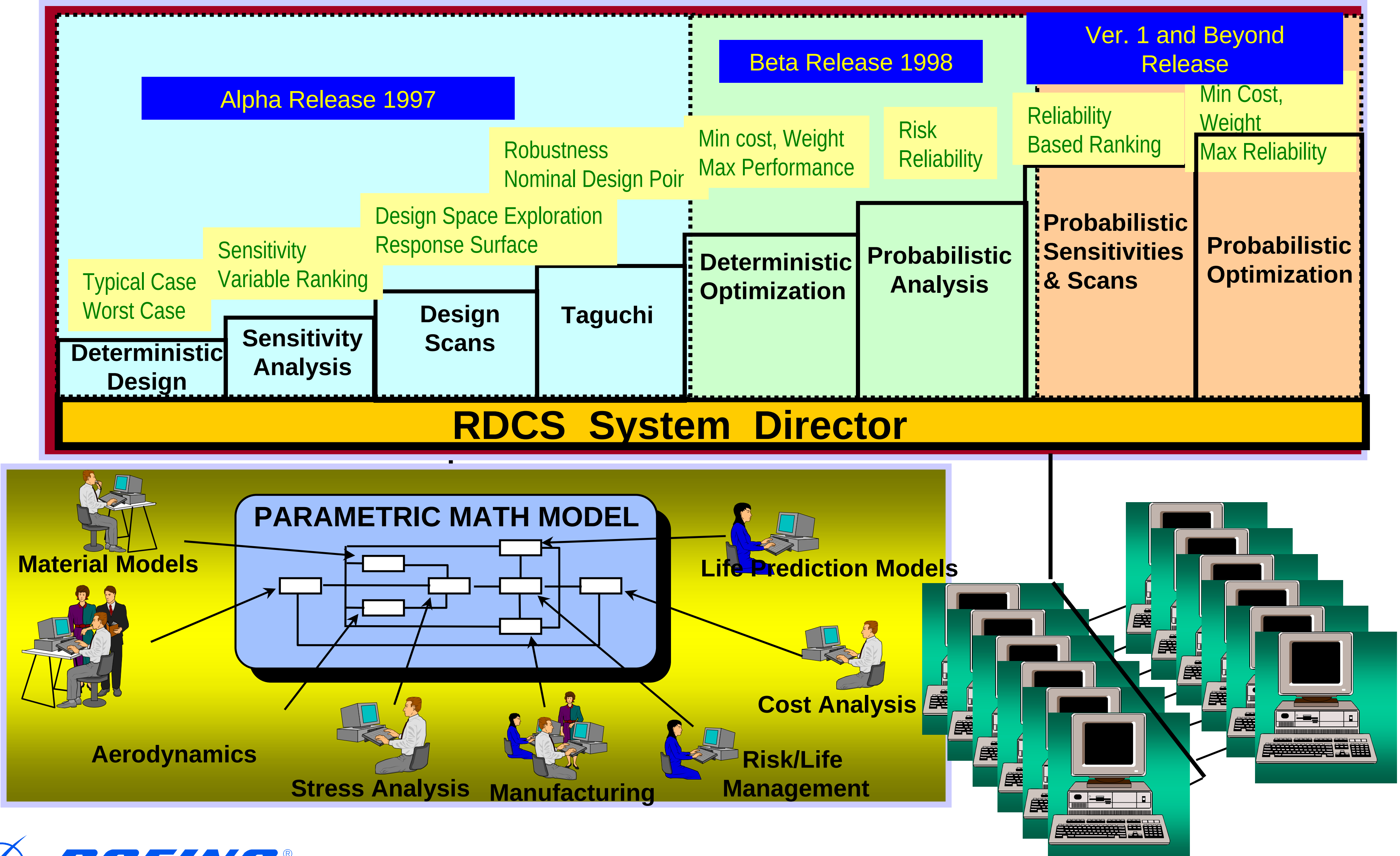
Further considerations

- More interrogations
- Links to related lessons learned
- Links to more information

Example of an Output Screen for the AIM-C CAT

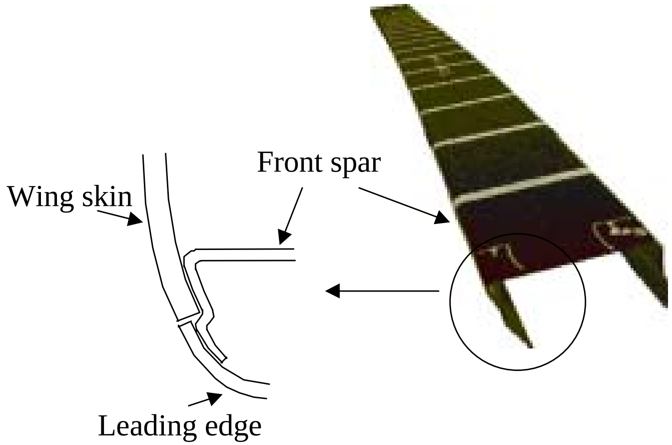


RDCS Tool
An Instance of Modern Design Framework

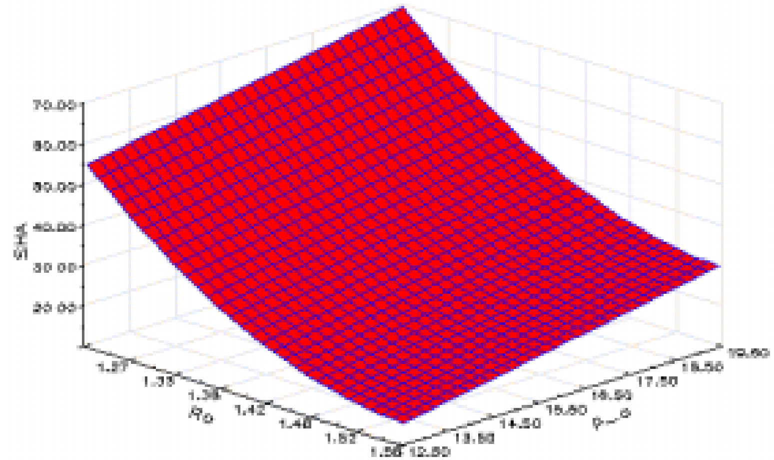


AIM-C CAT Benefits: COMPRO Integration with Robust Design Computational System (RDCS)

767-400 Raked Wingtip Front Spar DOE Sensitivity Analysis



RDCS Sensitivity Analysis Plus Design Scan



Conventional Approach

- **32-Runs for Simple DOE**
- **4-Months Calendar Time to Set-Up and Solve**
- **Computer (time) intense**
- **216-Hrs Actual Labor to Complete**
- **Labor-Intense Data Reduction**

Integrated with RDCS

- **127-runs for Sensitivity Analysis and Design Scan**
- **1-2 Weeks Calendar Time to Set-Up and Solve**
- **User Isolated from Intense Interaction with Multiple Codes**
- **28-Hrs. Actual Labor to Complete**
- **Automated Data Reduction and Graphics**

Kathryn L. Nesmith,
Roland Cochran and Denise Wong

May 21-24, 2001

Naval Air Systems Command
Air Vehicle Department
National Conference
Jacksonville, FL

"Building Block" Test Program

Material/Process and Design Development

Material Selection
- Metals
- Composites

Manufacturing Process
- Process Development
- NDT Standards

Material Properties
- Repair
- Physical/ Chemical/ Processing
- Environmental Effects
- Mechanical Properties
- Statistical Knockdown
- Fatigue Scatter
- Effects of Defects

Elements/ Subcomponents
- Design Details
- Damage Tolerance
- Repair
- Validation of Analysis Methodology
- Fatigue
- Static
- Acoustic

Components
- Configuration Details
- Damage Tolerance
- Static
- Fatigue
- Repair
- Validation of Analysis Methodology

Reproduction Verification

Full Scale Laboratory

Certification Tests
- Static
- Fatigue
- Drop
- Dynamics

EMD Aircraft
- Flight Test
- Ground Test

Small Portion of ONR Protocol N00014-97-C-0417

Key

● - Must evaluate amount of testing requested to address this issue. No testing required may be an acceptable answer. Testing amount dependent upon contractual requirement, application, complexity and level of acceptable risk

Q – Typically required for quality control testing of each batch of material fabricated

☐ - - Test not required. Identified change is not anticipated to affect this property or a related property will identify this material as not being equivalent.

	New Fiber, New Resin, New Airframe	New Fiber, New Resin	New Resin, Baseline Fiber	New Fiber, Baseline Resin	New Process, Baseline Fiber & Resin	New Prepreg Supplier, Baseline F & R (mixes)	New Prepreg Supplier, Baseline F & R (buys)	New Fiber line, Baseline Fiber	New PAN line, Baseline Fiber	Mod to Qual. Fiber Line, Baseline Fiber
Fiber Characterization	●	●	Q	●	Q	Q	Q	●	●	●
Resin Characterization	●	●	●	Q	Q	●	Q	Q	Q	Q
Interface Characterization	●	●	Q	●	Q	Q	Q	●	●	●
Chemical	●	●	●	Q	●	●	Q	Q	Q	Q
Physical	●	●	●	●	●	●	●	●	●	●
Nominal Cure Process	●	●	●		●					
Nominal NDE Process	●	●	●							
Mechanical (Lamina)	●	●	●	●	●	●	●	●	●	●
Structural Properties (Static)										
Unnotched Tension	●	●	●	●	●	●	●	●	●	
Unnotched Compression	●	●	●	●	●	●	●	●	●	●
Pin Bearing	●	●	●	●	●	●	●			
Flexure (w/ & w/o holes)	●	●	●							
Others	●	●	●	●	●	●	●	●	●	●

AIM-C Methodology Addresses All Elements of the Maturation Process Simultaneously

TRL	1	2	3	4	5	6	7	8	9	10
Application Maturity	Concept Exploration	Concept Definition	Proof of Concept	Preliminary Design	Design Maturation	Component Testing	Ground Test	Flight Test	Production	Recycle or Dispose
Application Risk	Very High	High	High - Med	Med - High	Medium	Med - Low	Low	Low - Very Low	Very Low	Negligible - Recycle or Disposal
Certification		Certification Plan Documented	Certification Plan Approved	Preliminary Design Allowables	Design Allowables / Subcomponents	Full Scale Component Testing	Full Scale Airframe Tests	Flight Test	Production Approval	Disposal Plan Approval
Assembly	Assembly Concept	Assembly Plan Definition	Assembly Definition	Assembly Details Tested	Subcomponents Assembled	Components Assembled	Airframe Assembled	Flight Vehicles Assembled	Production	Disassembly for Disposal
Design	Concept Exploration	Concept Definition	Design Closure	Preliminary Design	Design Maturation	Ground Test Plan	Flight Test Plan	Production Plan	Production Support	Disposal Support
Supportability		Repair [illegible]	Repair Processes Documented	Fabrication Process Repairs Identified	Fabrication Repair Process Trials Subcomponents	Repair of Component Test Articles	Production Repairs Identified	Flight Qualified Repairs Documented	Repair / Replace Decisions	Support for Recycle or Disposal Decisions
Cost/Benefit Maturity	Cost Benefit Projected	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Structures Maturity	Potential Benefits Predicted	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fabrication Maturity	Target Applications Identified	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Quality		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Materials Maturity	Key Target Properties Defined from Chemistries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Intellectual Rights	Concept Documented	[illegible] Filed	Agreements	[illegible]	[illegible]	Contracts	Contracts	Agreements	Agreements	Agreements

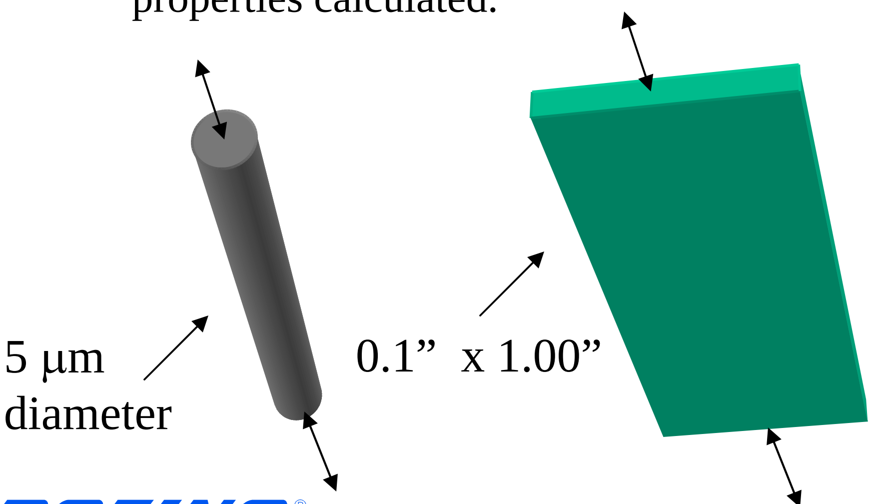
	Development	Feasibility	Practicality	Application
Customer				
Design				
Business				
Vendor				

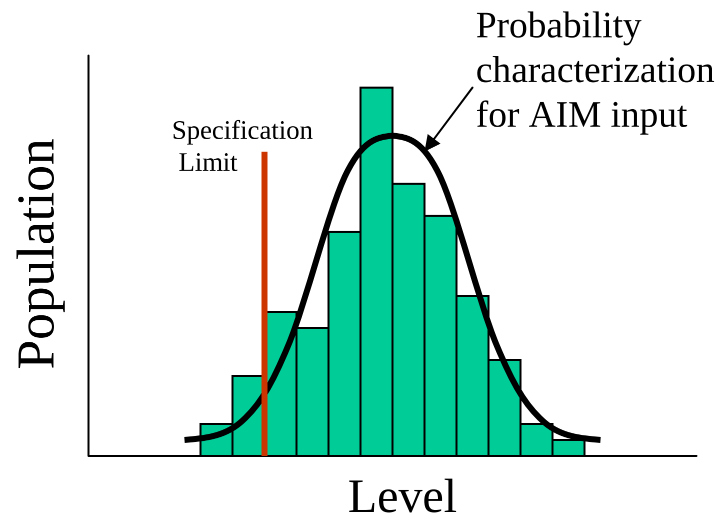
Uncertainty Management

•Input Material Properties

- Test methods – accuracy, repeatability
- Distribution – data correlation, population

Example:
Fiber properties
single fiber tests not practical
Laminate tests performed, fiber properties calculated.





Example:
Actual data may not be ideal distribution shape, Distribution of material actually used may be truncated by specification acceptance criteria

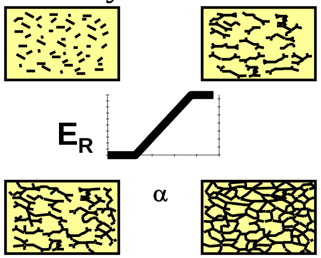
Uncertainty - Modeling of the Fiber

<table>
<tr>
<th></th>
<th>Inherent variations associated with physical system or the environment (Aleatory uncertainty)
Also known as variability, stochastic uncertainty
E.G. manufacturing variations, loading environments</th>
<th>Uncertainty due to lack of knowledge (Epistemic uncertainty)
inadequate physics models information from expert opinions.</th>
<th>Known Errors (acknowledged)
e.g. round-off errors from machine arithmetic, mesh size errors, convergence errors, error propagation algorithm</th>
<th>Mistakes (unacknowledged errors)
human errors e.g error in input/output, blunder in manufacturing</th>
</tr>
<tr>
<td>Coefficient of thermal expansion, $\alpha1$, $\alpha2$</td>
<td rowspan="4">Batch to batch variation in material, arising from variations in PAN precursor, and carbonization process</td>
<td rowspan="4">Models almost always assume no temperature or moisture effect.</td>
<td rowspan="4">Lack of direct measurement techniques; property is measured on a lamina/laminate basis.</td>
<td rowspan="4">Back-calculation values based on micromechanics. Complex experimental methods.</td>
</tr>
<tr>
<td>Modulus (E11, E22)</td>
</tr>
<tr>
<td>Strength (to failure)</td>
</tr>
<tr>
<td>Strain (to failure – linked to strength)</td>
</tr>
</table>

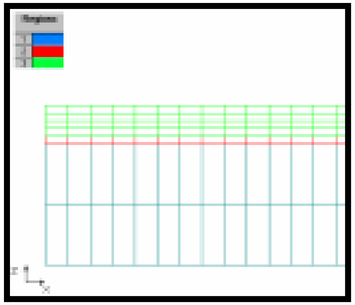
Uncertainties Introduced in Modeling

- Accuracy of physics
- Use of models outside of known limits
- Code Bug

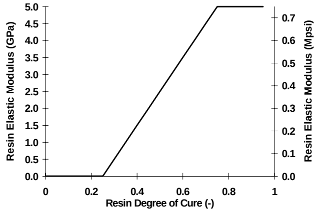
Example: Unknown mistake in calibrating DSC leads to wrong heat of reaction and incorrect temperature history



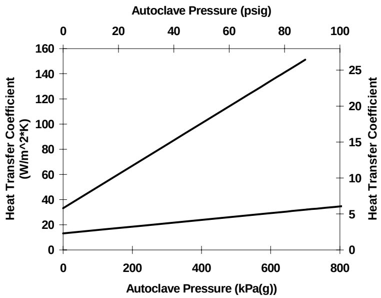
Example: The tool surface finish is not uniform for a tool or between tools.



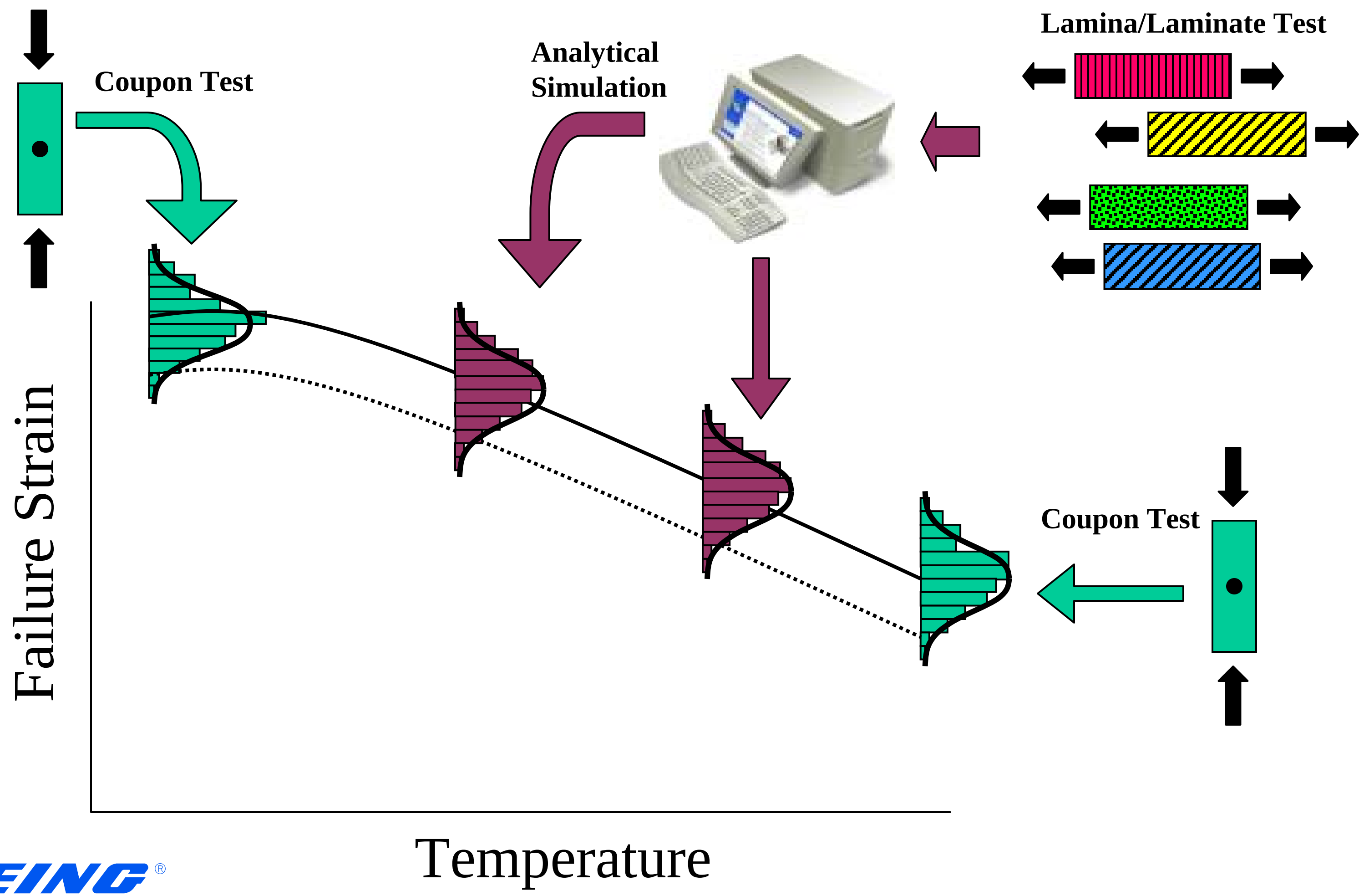
Example: Physics of cure-hardening linear elastic versus fully viscoelastic



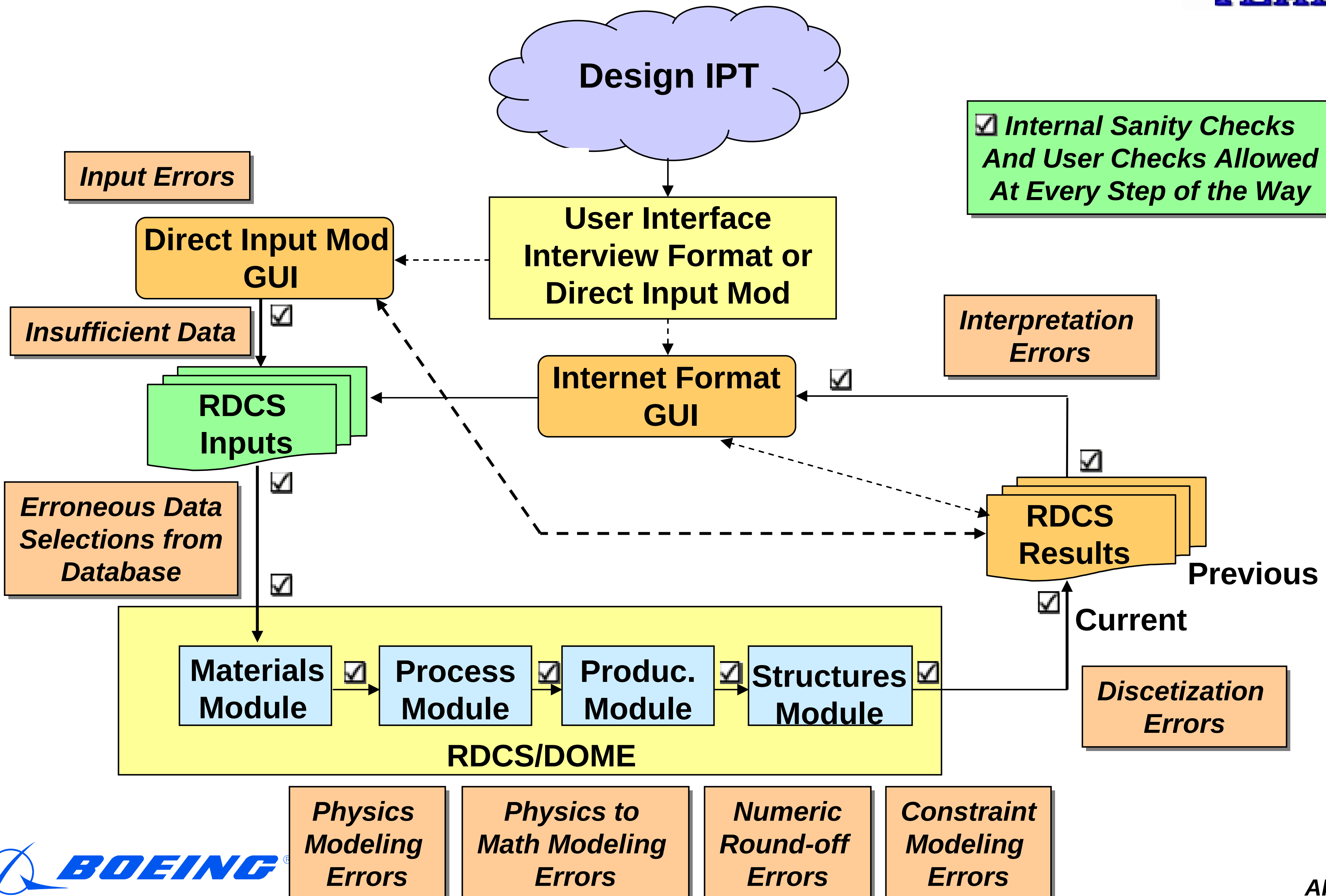
Example: Autoclave heat transfer equation is used outside of known limits



Obtaining Design Values from Mixed Test and Analysis Data



Error Sources and Mitigation in The AIM-C Product



The Development Path of the AIM-C CAT

Basic Product	**Architecture Backbone in Place** **Limited Heuristic Link to Methodology** **Modules Very Limited Utility** **No AIM User Interface / Use existing DOME and RDCS interfaces**
Optional Product	**Architecture with Moderate Robustness** **Firm Heuristic Link to Methodology** **Modules with Validated Functionality** **Internet User Interface for Input**
Phase II Product	**Architecture Robust** **Firm Heuristic Link to Methodology** **Modules with Complete Functionality** **Internet User Interface for Real Time Input / Output Manipulation Capability**

Industry Benefits from AIM

- Cost, schedule, performance with confidence factor
- Focus based on needs
- Knowledge management – orchestrated models, simulations, experiments to maximize useful information
- Built on building block methodology while facilitating discipline integration
- Internet access
- Path from criteria based to probabilistic based approaches
- Platform support for changes – bill of materials, pedigree, re-certification
- Design process application
- The best of emergent modeling and explicit modeling
- Applications to other problem sets

Improve productivity, facilitate radically new approaches to material insertion