Accelerated Insertion of Materials - Composites

Presented to
AHS International Structures Specialists
by
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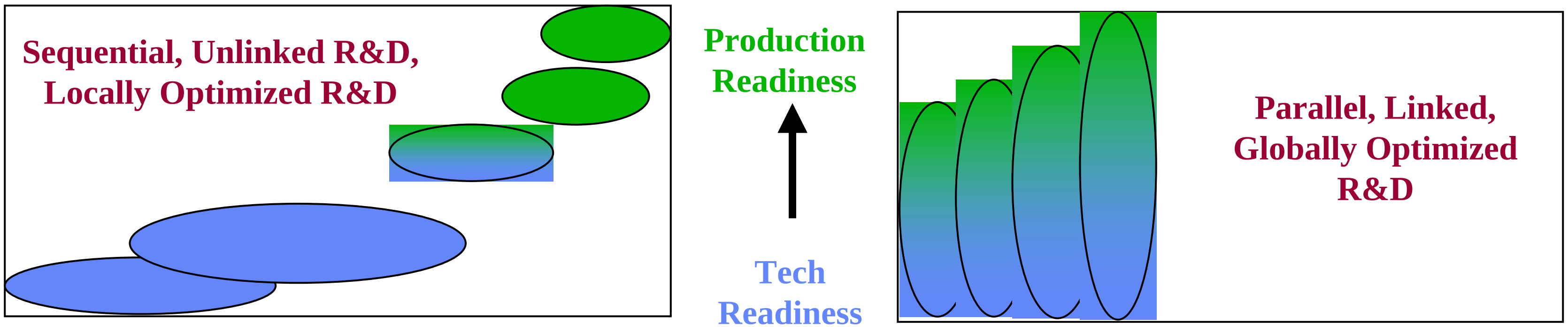
Jointly accomplished by BOEING and the U.S Government under the guidance of NAST

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

Dr. Steven G. Wax, November 16, 1999
Gail Hahn, (314) 233-1848, gail.l.hahn@boeing.com

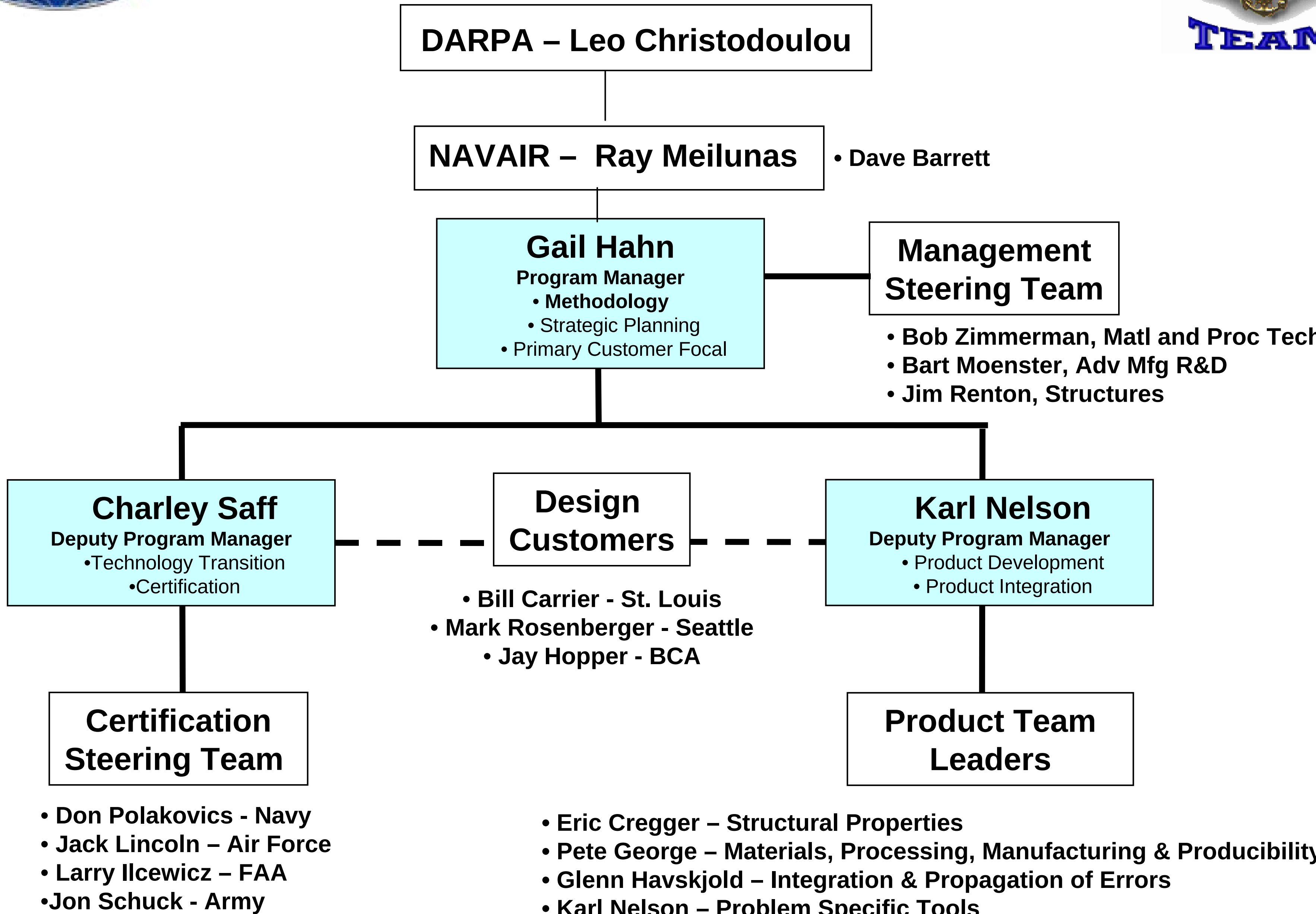


- **Development of Properties, Processing Done Without Quantifiable Link to Designer Needs**
  - **Processing Reality Requires Rework of Properties, Still No Link to Designer**
  - **Production Readiness Steps Reworks Technology Readiness**
    - » **Designer Knowledge Base NOT Ready Until Final Stages**

- **Development of Properties, Processing Explicitly (Through Models/Experiments) Linked to Designer**
  - **Development of Designer Knowledge Base Begins at Outset of R&D Based on Designer Needs**
  - **Time/Effort Refines Knowledge Base**
    - » **Driven by Properties, Performance, Accuracy Really Needed**

A New Paradigm in Materials Development is Required to Significantly Reduce the Timeframe of Insertion

AIM-C Program Organization



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

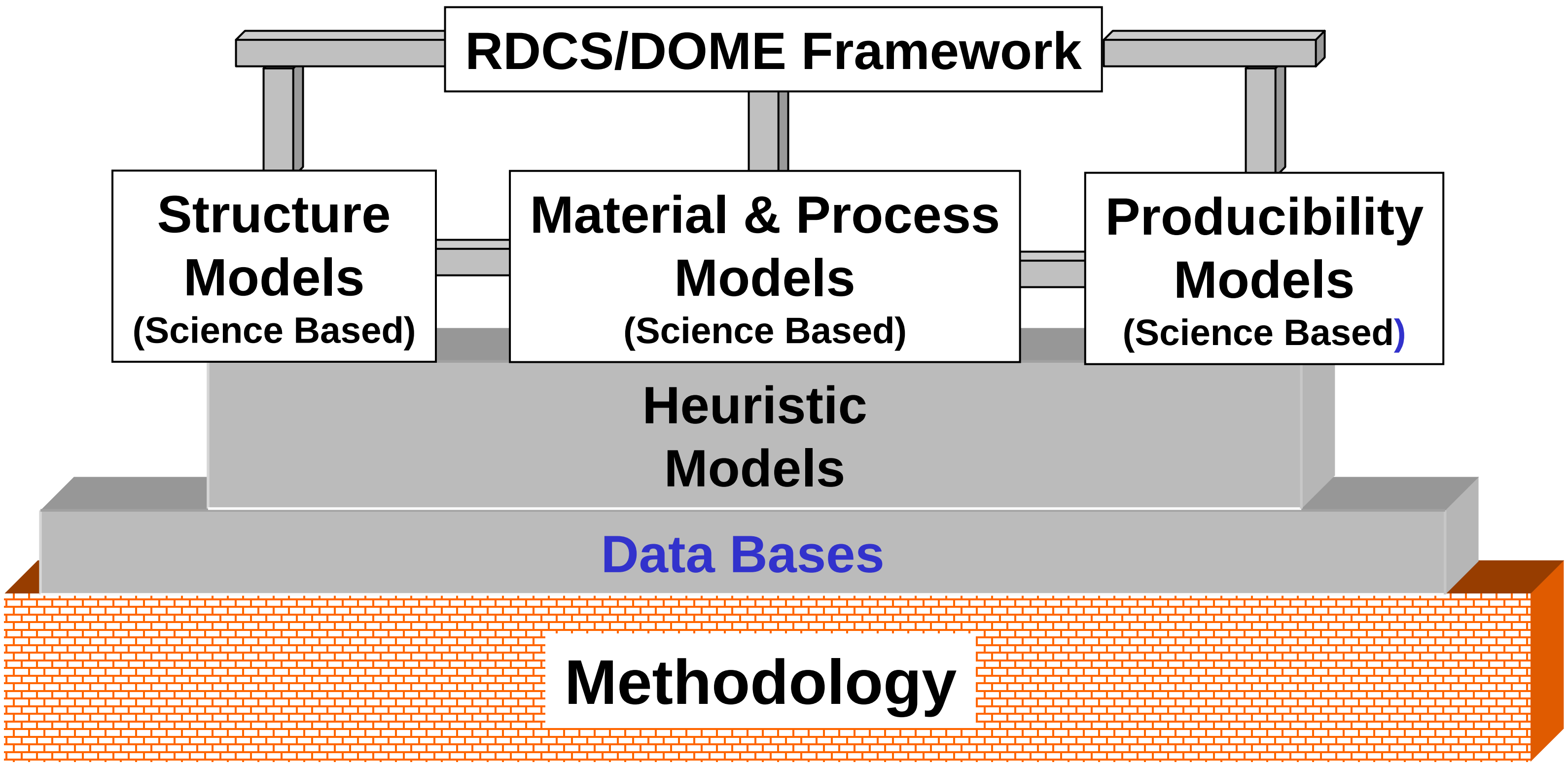
Risk in Each Area is Dependent Upon Application's Criticality and Material's Likelihood of Failure

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

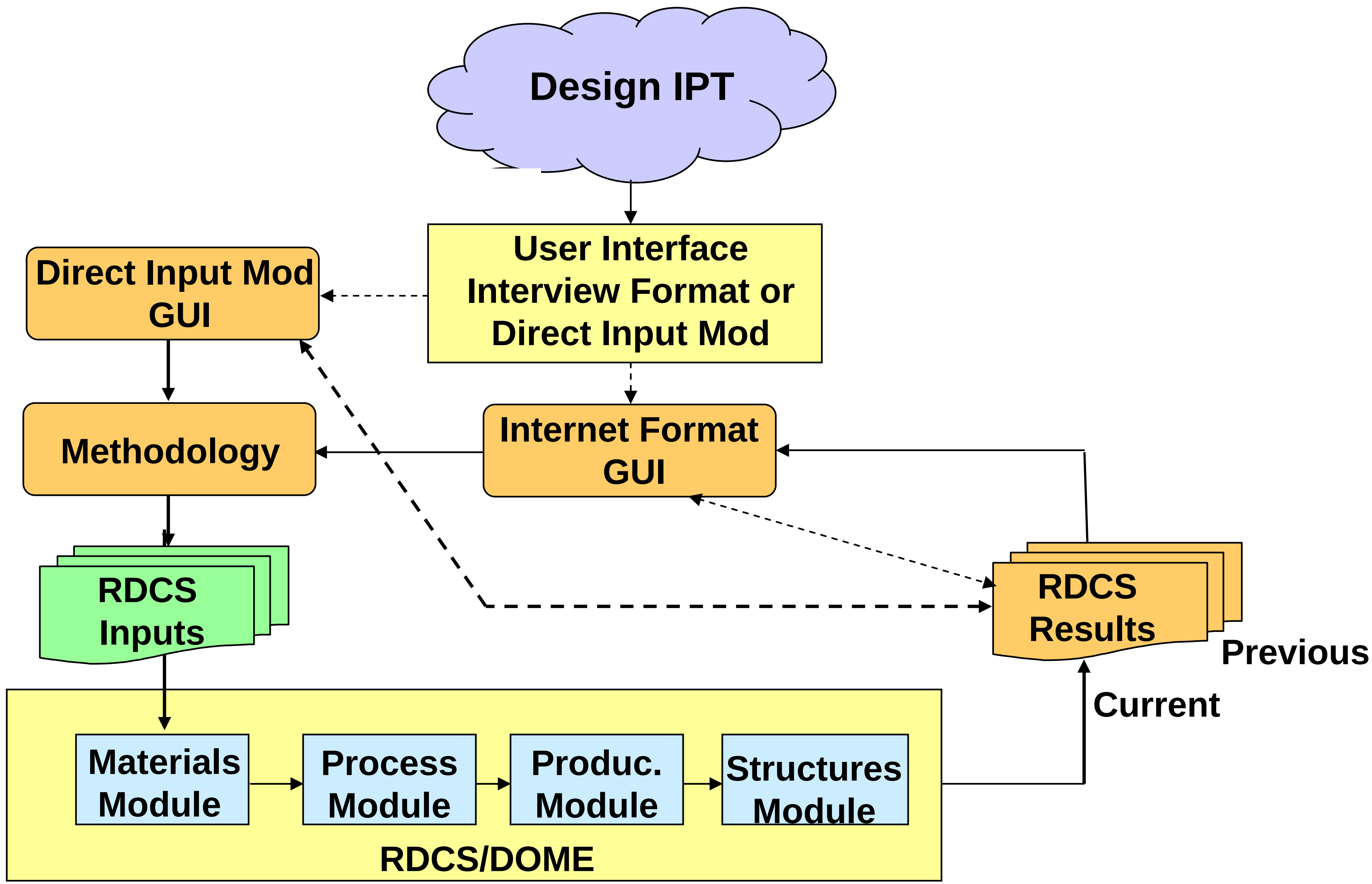
TRL	1	2	3	4	5	6	7	8	9	10
Application Maturity	Concept Exploration	Concept Definition	Proof of Concept	Preliminary Design	Design Maturation	Component Testing	Ground Test	Flight Test	Production	Recycle or Dispose
Application Risk	Very High	High	High - Med	Med - High	Medium	Med - Low	Low	Low - Very Low	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	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									
Structures Maturity	Potential Benefits Predicted									
Fabrication Maturity	Target Applications Identified									
Quality										
Materials Maturity	Key Target Properties Defined from Chemistries									
Intellectual Rights	Concept Documented	Filed	Agreements			Contracts	Contracts	Agreements	Agreements	Agreements

	Development	Demonstration	Integration	Implementation
Owner & Supplier				
Business				
Design, Fab, & Test				
Support, Repair, & Disposal				

AIM-C Comprehensive Analysis Tool Must Rest Solidly on the Methodology



Our Current Vision of the AIM Product



Welcome to AIM-C Program

File Edit View Go Communicator Help Yahoo!

Back Forward Reload Home Search Netscape Print Security Stop

Bookmarks Netsite: http: darpa.org/aim.navy.mil

Home

Application

Certification

Assembly

Design

Supportability

Cost

Schedule

Strength

Fabrication

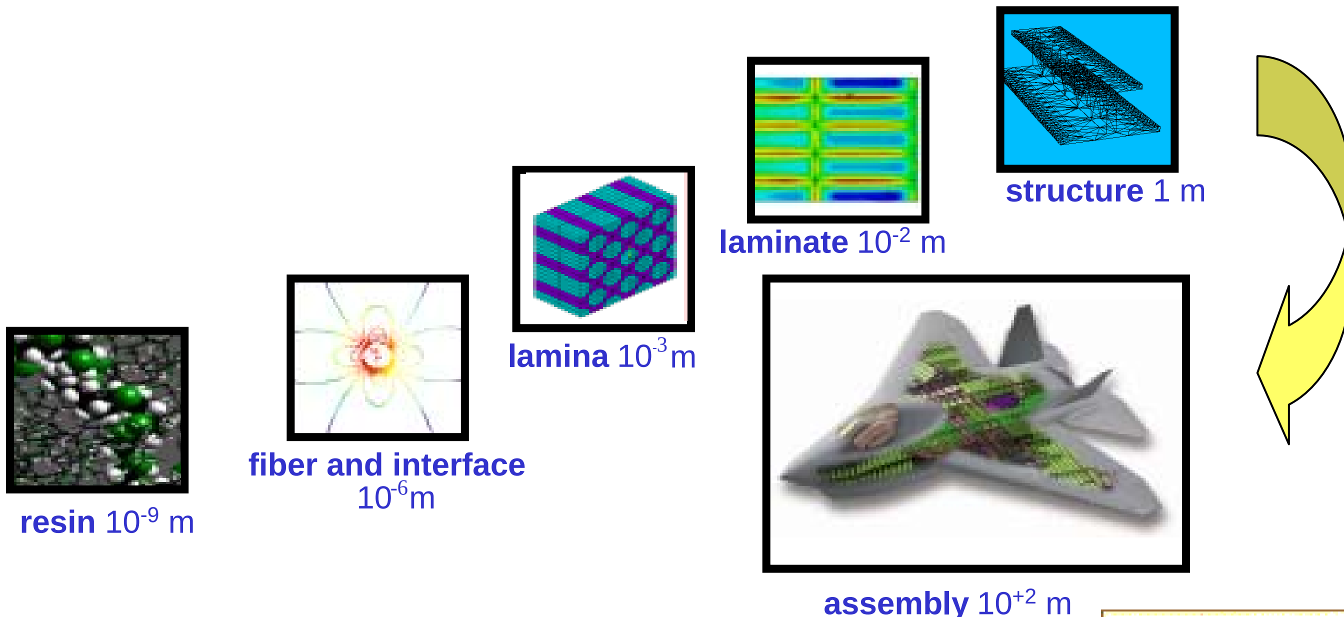
Quality

Mat'l & Proc

Legal/Rights

Output

Accelerated Insertion of Materials



Methodology

Process

New Features

Chemistry to Component in the Shortest Time at Acceptable Risk

DARPA

TEAM

Edit Existing File

Compute Results

Save & Close

AIM-C

BOEING

Document: Done

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Boeing AIM - C Goals

AIM-Composites Will Take Us From Test Supported by Analysis to Analysis Supported by Test

Designer Knowledge Base Driven

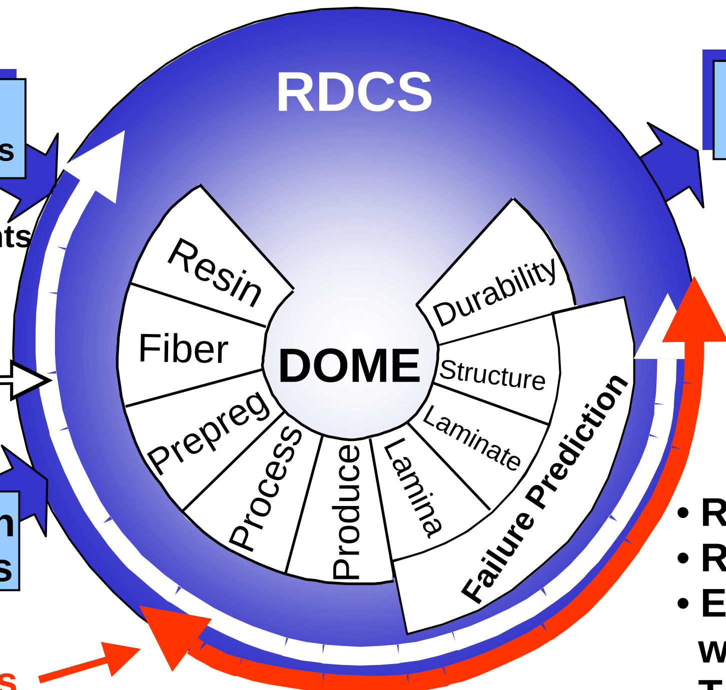
Designer Constraints = Designer Requirements

- Configuration
- Environmental Requirements
- Dimensional Tolerances
- Certification Requirements

Reduced Time

Application/Fabrication Concept Requirements

Reduced Costs



Designer Needs/Information

- Viable Design Options
- Element Level Properties for Structural Analysis
- Quality Capability
- Producibility Capability
- Variability Impact

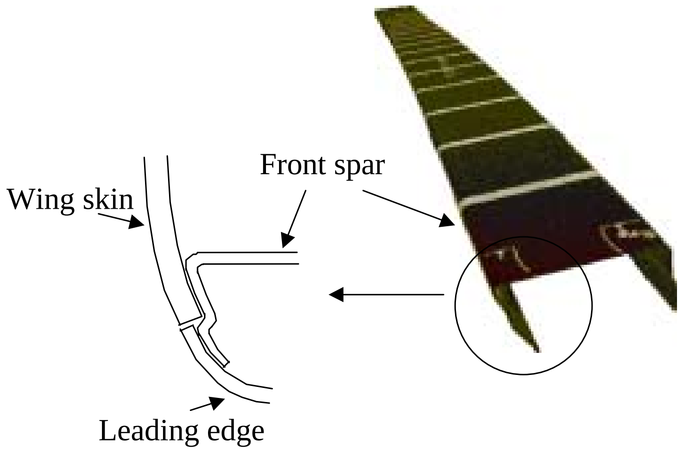
Payoffs

- Reduced Insertion Time
- Reduced Insertion Costs
- Expandable Methodology with Time and New Technologies

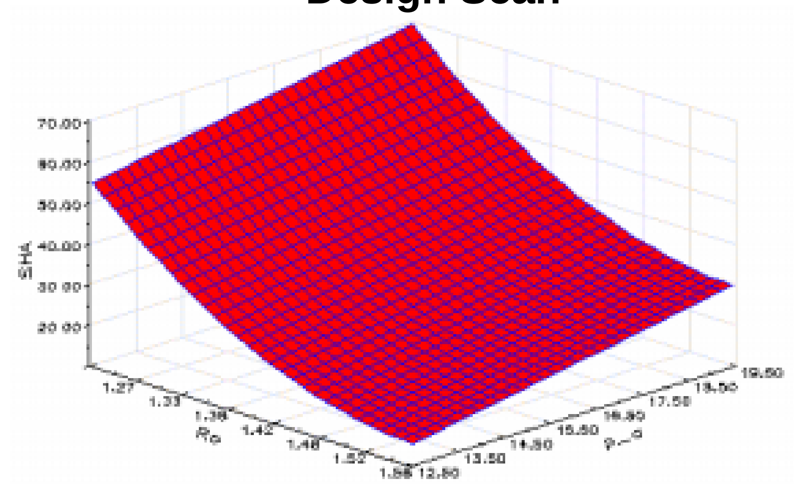
RDCS- Robust Design Computational Systems (Rocketdyne)
DOME- Distributed Object Oriented Modeling Environment (MIT)

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



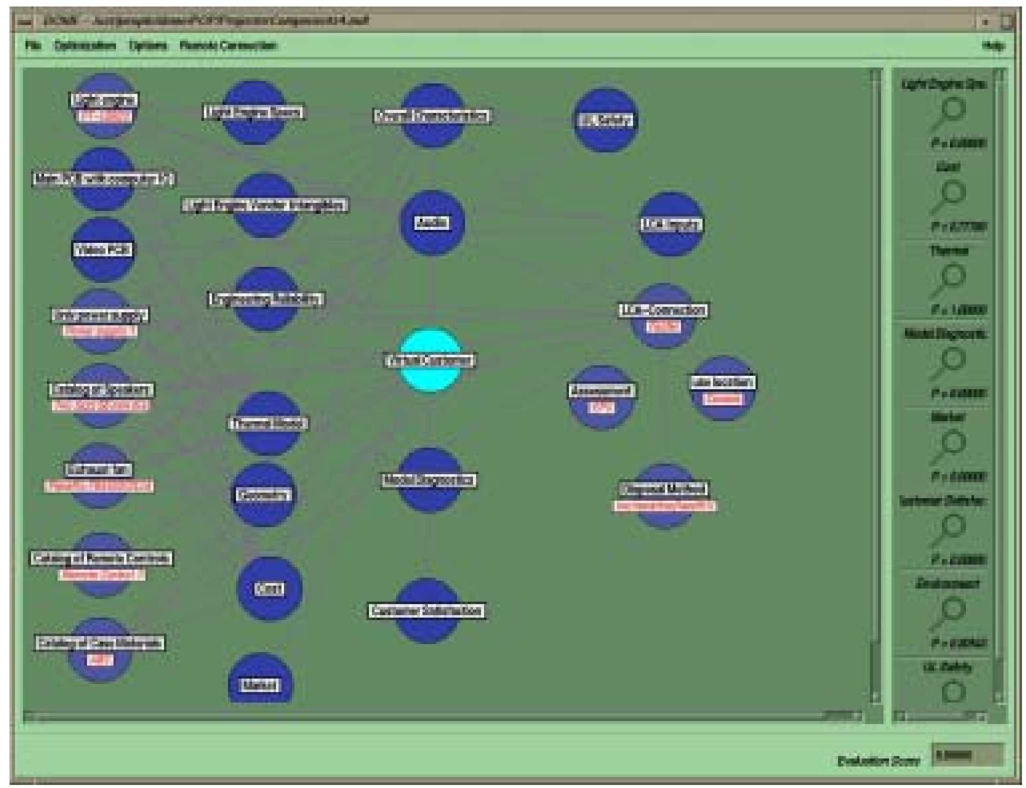
Conventional Approach	Integrated with RDCS
• 32-Runs for Simple DOE	• 127-runs for Sensitivity Analysis and Design Scan
• 4-Months Calendar Time to Set-Up and Solve	• 1-2 Weeks Calendar Time to Set-Up and Solve
• Computer (time) intense	• User Isolated from Intense Interaction with Multiple Codes
• 216-Hrs Actual Labor to Complete	• 28-Hrs. Actual Labor to Complete
• Labor-Intense Data Reduction	• Automated Data Reduction and Graphics

Module Integration

DOME: Distributed Object-Oriented Modeling Environment

- Modules Link Via Internet
- Visual Interface
- Connections Represented via Lines Between Modules
- Resolves Firewall & Proprietary Code Issues
- Utilize Existing Software

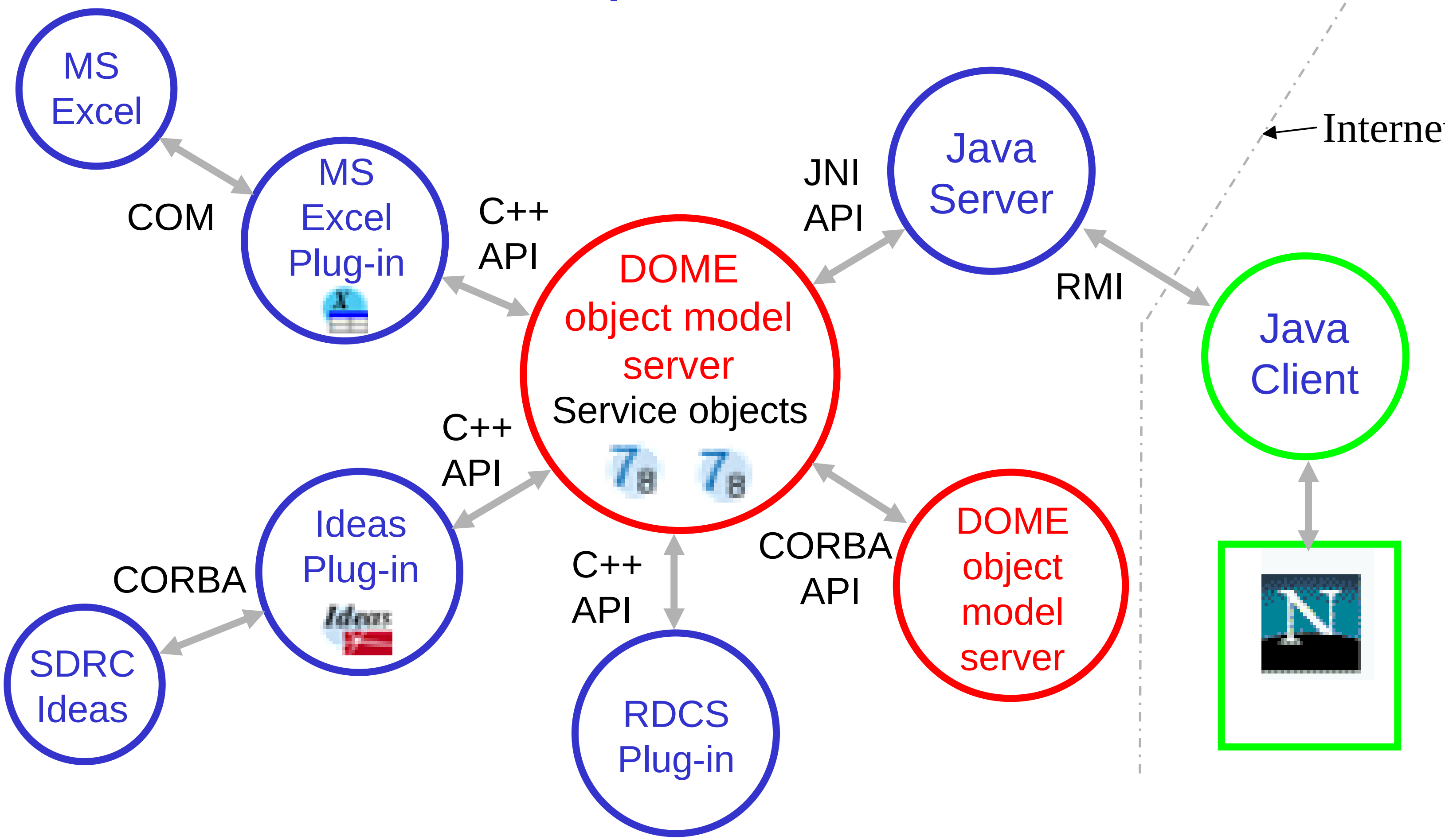
(Some minor modifications expected)



David Wallace
MIT Mechanical Engineering CADlab

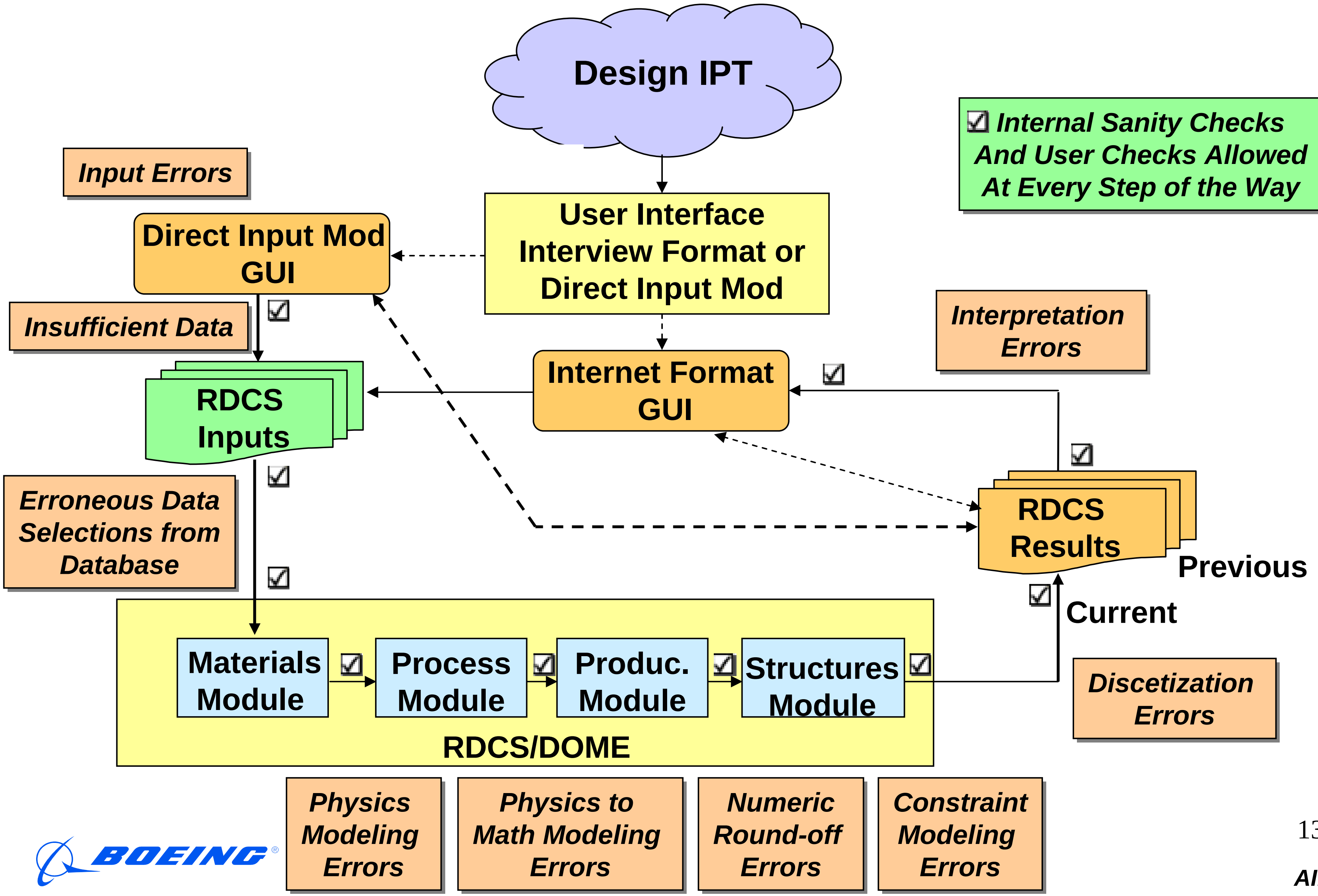
Distributed Object Oriented Modeling Environment

DOME Architecture: Conceptual Overview

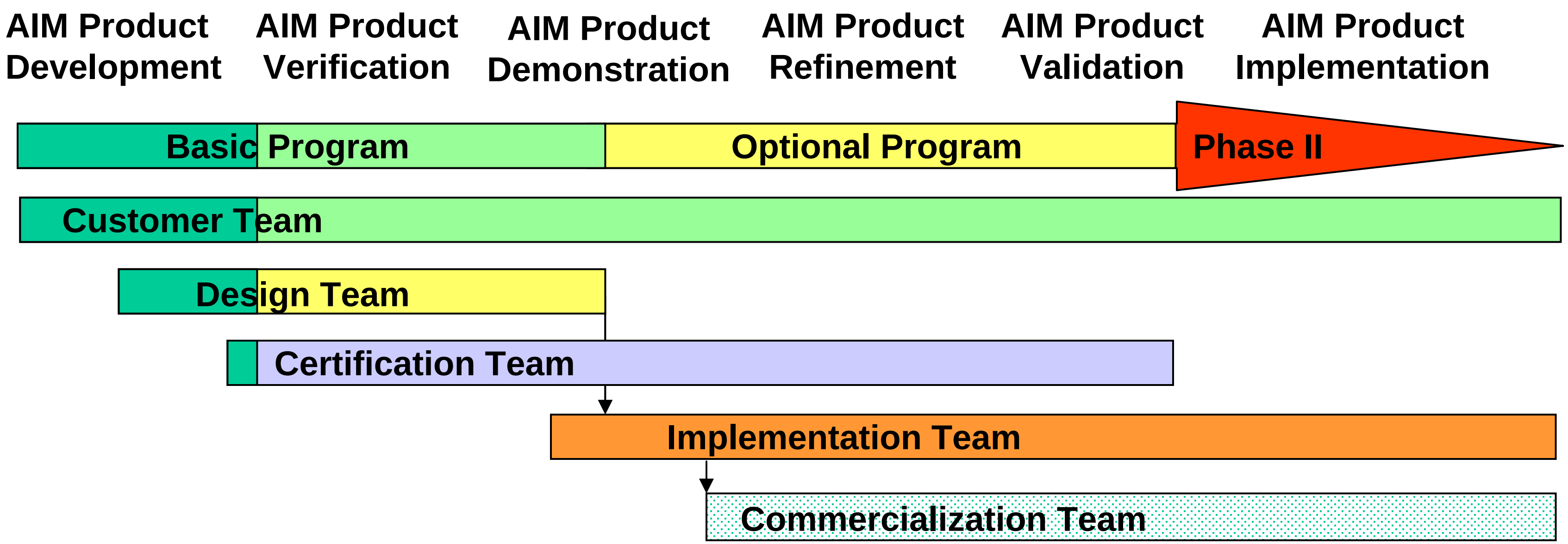


Addresses heterogeneity, interoperability, accessibility, complexity, scalability, flexibility, & proprietary knowledge

Error Sources and Mitigation in The AIM-C Product



Technology Transition Plan



Customer Team – To Insure that the Product Meets the Needs of the Funding Agents

Design Team – To Insure Acceptance Among Users in Industry

Certification Team – To Insure Acceptance Among the Certification Agents for Structures

Implementation Team – To Insure Acceptance Among the User Community

Commercialization Team – To Insure Commercial Support of Users

The Boeing Design Team

Navy Fighters
Bill Carrier
F/A-18 Forward Fuselage
(Prev. ALAFS CRAD Mgr.)
Air Force Fighters
Mark Rosenberger
JSF Airframe IPT Lead
Commercial Aircraft
Jay Hopper
NAPD Structures Chief
(Prev. 777 Design Team &
747 Chief Structures Engineer)
Uninhabited Aircraft
Charley Saff
UCAV Structures Integration

This team insures that the product will be desired and used by Airframe IPTs

Program Level Conclusions from Design Team

AIM-C Needs to Address

- **Early scale up and maturation of materials & processes to address readiness for program development**
- **Repeatability**
- **Non-destructive quality measurement techniques and defect characterization as well as pristine allowables**
- **Repairs, both as manufactured and in service**
- **Life Cycle Costs, from start-up and capital requirements to disposal**

The Certification Team

Agency	Integration	Structures	Materials	Producibility
Boeing	Charley Saff	Eric Cregger	Pete George	John Griffith
Navy	Don Polakovics	Dave Barrett	Kathy Nesmith	Steve Claus
Air Force	Jack Lincoln	Dick Holzwarth	Tia Benson-Tolle	Bob Reifenberg
FAA	Richard Yarges	Larry Ilcewicz	David Swartz	Dave Ostrodka
Army	TBD	Jon Schuck	TBD	TBD
NASA	TBD	Jim Starnes	TBD	TBD

To Insure That the Methodology, Verification, and System Validation We Do Satisfies Certifying Agencies

Certification Team Feedback
Biggest Obstacles to Acceleration

Customer / Stakeholders	IPT	Design	Allowables
Regulatory agency understands and approves methods used to insert materials	Full time focus of development team	Design teams can make design decisions before design guidelines were established	Testing for allowables costs too much
Customers are ready for 1) price, 2) service level, 3) maintenance & Inspection reqs, and 4) repair requirements	Development maturity in one area that outstrips the general maturity can be detrimental to the overall process	Preliminary design values can be developed with very few tests in prototype. How do we move into this paradigm with reduced risk for operational vehicles?	Must establish the requirements for the material
Customer is part of IPT in good and bad times	If materials development lags product development, the product is at risk	Concept development is done without regard to materials - this imposes limitations on designs, concepts, and costs	Early specs did not address the variables which impacted the process downstream
When customer changes, the tolerance for risk, vision, and technical criteria change	Has the material been used on other products or is it currently in use on other products?	Multifunctional parts require different designs than we traditionally look at.	Must test durability, aging, and environmental effects
Identify stakeholders early	Is an industry database available?	Design criteria that are late in being developed or established can eliminate new materials from the design space.	Moisturization takes a long time
Need to resolve conflicting requirements	IPTs need to be much larger than is currently perceived. They must include more administrative disciplines.	When designers do not follow composite design guidelines, there will be problems manufacturing parts.	Must understand long term environmental exposure effects
Material decisions must be made with the head and not with the heart.	Must demonstrate the ability to manufacture parts as designed	Design capabilities for composite parts and tools are required.	The impact of proof testing on certification and risk reduction must be determined
Government programming - large scale demos instead of basic materials and structural data. These programs leave many unaddressed issues and uncertainties	Need an On-the-Floor support staff capable of identifying problems and resolving them.	Conceptual design tools impose load paths that make composites a tough sell.	Due to miscommunication, the entire materials qualification program was run with an incorrect postcure - autoclave cycles used in the lab were not validated.
	Material form not compatible with design requirements and manufacturing process (K-3 wing, tow vs slit tape, fabric types, large Ti castings)	Incorrect ply stacking design or lay-up sequence	Lower performance of the materials in design details
	Lack of interface between design, materials, and manufacturing	Product design requirements and objectives must be met	Coupon data doesn't translate into elements

Certification Team Feedback
Roadblocks to Success

Limitations of the Process	Prediction Accuracy	Validation	Intellectual Property Rights	Technology Transition	Commercialization
This is a moving target depending on the modules being used and the data input. I think this goes beyond just knowing the 'errors'. We've seen before instances in which engineers who did not understand the limits of the software came out with answers tha	How does one insure that the company that actually builds the part can achieve the required properties? Additional testing?	There is going to have to be a lot of 'proof testing' (validation of AIM-C results) to convince the overall M&P/Structures community	Intellectual property rights to protect databases, test methodologies, and process specifications	Getting past 'Not Invented Here" or industry familiarization.	Developers leave and the certifiers of the next generation process are the next generation
Missing an important behavioral characteristic (ex., crystallinity in thermoplastics, free edge effects in laminates)	Unavailability of useful accurate models for specific technical areas will limit the scope of AIM.	Populating models with 'actual' values and distributions of variations	Protecting company proprietary information; magnitude of variations, costs, etc.	Getting past the "It will never work" crowd	Commercialization buy-in. What is the product?
Complexity of designing aircraft. There are thousands of issues to be considered. How is AIM going to capture them and deal with them in a logical fashion.	Will the producibility module really be able to identify fabrication show stoppers? As this point it is more a lessons learned from the past collection area.	Diversity and the extent of the validation activities (more contour, highly loaded, higher fatigue requirements)	Proprietary limitations: Commercial marketing may limit access to non-Boeing data sources.	Certification of materials and structures has different rules depending on who is doing it, the ultimate use of the structure, history of certifying organization… Not sure the 'one size fits all" approach will work.	Training to make it work: expert vs casual users
Input data validation: To be universally accepted, data from a large array of sources will be required (I.e., a world standard, ala, MIL-HDBK-5). Who sets this up?	Ability to address long term exposure and fatigue data in a manner different from today. May have to rely on testing for this.	Validation data: gathering sufficient data to certify the multitude of constituent software tools resident in AIM. For instance data to certify strain invariant (if that will be the failure theory used).		Broad adoption by the user community when faced with the "not invented here" syndrome.	Selection of the appropriate time to commercialize. Too early (before the tool is really ready) could be fatal.
Overselling the program to user community on what CAT can and cannot predict, I.e., showstoppers.	Failure of multi-axially loaded composites still difficult to predict.	Can you really provide compelling evidence that you've validated the tool? Criticism could be that since you knew the answers, you developed a system that can regurgitate the answers.		Perception that this is just another big program with no practical value.	Commercialization plan. At the end of AIM, what? Where are the $ for maintenance, improvements, advertising, and sales, training
Limited funding limits the scope of the program to results in specific technologies. It eliminates those not fully developed (I.e., RTM, fiber placement) resulting in loss of interest by user community, I.e., will not be able to please everybody.		Providing enough confidence to the user community for computational analysis to replace experimental testing for specific applications.		Unfamiliarity of the certification community with computational approaches will result in fall back to building block approach to materials certification.	Where are the $ to support adoption by other industries, sites? Software, hardware, training, new personnel, revision practices, codes, standards
How far will AIM assist in better understanding composite / metal structure interactions?		Partial validation. Demo leaves loose ends in fatigue, environmental testing, and structural details.		"Not invented here" roadblock. Aim will be perceived as a Boeing only, or a Boeing subcompany process.	How do you partition AIM so that portions can be used before having to use the whole thing?
Can you include a prediction of risk versus benefit for different levels of materials development maturity?					Can AIM be structures so that portions can be spun off and used prior to validation of the whole system?

The Certification Team Will Validate Our Methodology and Our Verification Approach

Step 1

Individual Module Validation

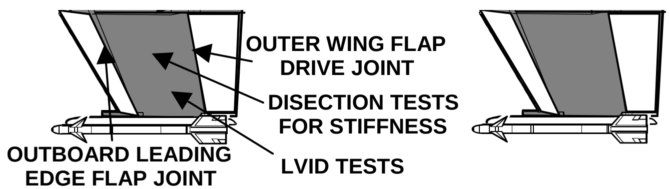
Existing Data

Step 2

Process Validation

Existing Subcomponent Test Results

Existing Component Test Results

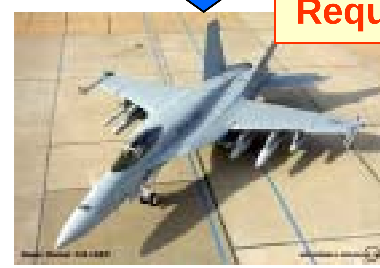


& Tests of Wing Skin Validate Projected Means and Scatter

Step 3

System Validation

Known Design Requirements



"Blind" Subcomponent Test Results

"Blind" Component Test Results

Validates Technical Results, Time Reductions, Cost Reductions

Commercialization Planning

- **Past Experience/AIM-C Plan**
  - **Boeing Parametric Composite Knowledge System (PACKS) with Unigraphics Solutions, Inc.**
  - **CAICAT with Galorath**
  - **DMAPS with Unigraphics Solutions, Inc.**
  - **Easy5 via Boeing's former Computer Services Group**
  - **RDCS via MSC Software, Inc.**

  - **Discussion held with MSC Software, Inc., Galorath and others**

Technology Transfer Goes Far Beyond Just Communication

It Requires Teams That Are Actively Involved In Making It Happen
We Are Assembling Those Teams

We Have Customer Team Engaged

We Have Boeing's Designers Involved

We'll Be Getting Certification Agencies Involved Over the Next Month

We'll Expand the Design Team to Insure User's Like It

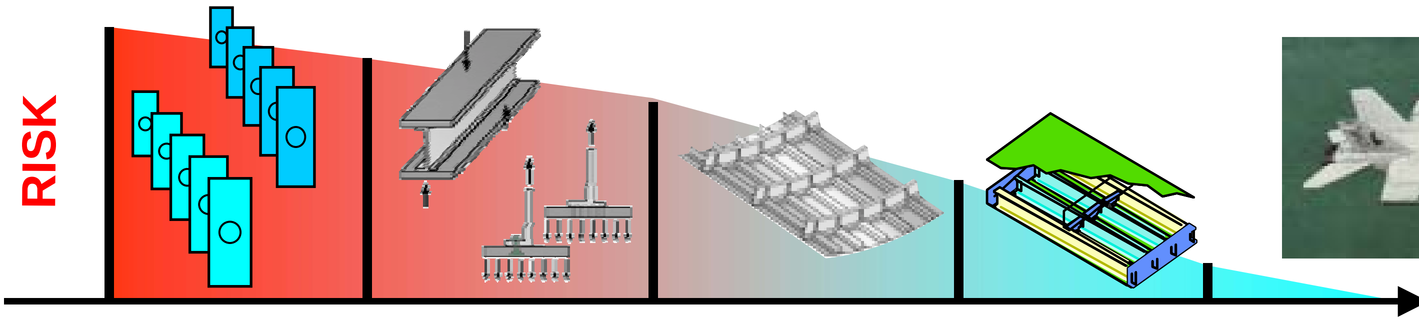
We'll Expand the Implementation Team to Insure That We Can Support It

The Path to the AIM Product Vision

Basic Product **May '02**	**Architecture Backbone in Place** **Limited Heuristic Link to Methodology** **Modules Very Limited Utility** **No AIM User Interface / Use RDCS?**
Optional Product **2004**	**Architecture with Moderate Robustness** **Firm Heuristic Link to Methodology** **Modules with Validated Functionality** **Internet User Interface for Input**
Phase II Product **2007**	**Architecture Robust** **Firm Heuristic Link to Methodology** **Modules with Complete Functionality** **Internet User Interface for Real Time Input / Output Manipulation Capability**

Accelerated Insertion of Materials

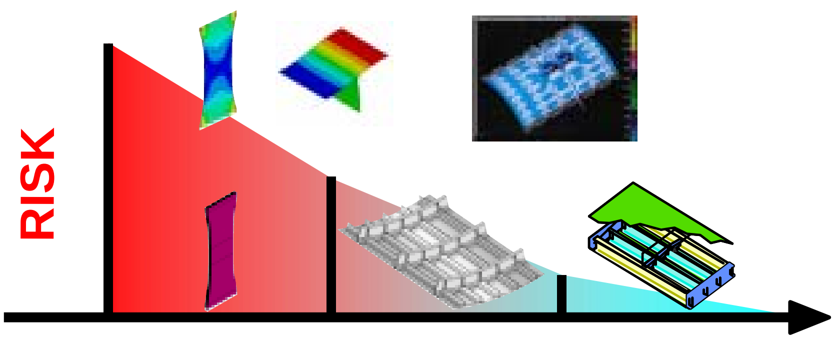
Traditional Building Block Approach Improves Confidence by Extensive Testing Supported by Analysis:
Too Often Misses Material Insertion Windows



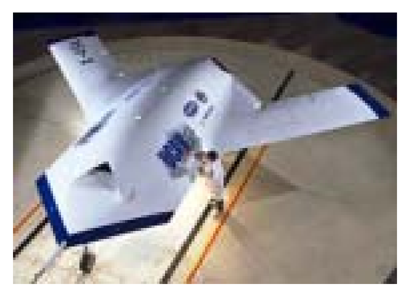
Time to Insertion Readiness

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

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