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**COMPOSITES AFFORDABILITY INITIATIVE (Preprint)  
CANCOM 2007, Winnipeg, Manitoba, 15 Aug 07**

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UNITED STATES AIR FORCE**

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<b>14. ABSTRACT</b> In the mid 1990's, the United States Air Force Research Laboratory (AFRL) recognized that despite the potential of advanced composites to drastically reduce aircraft structural weights compared to conventional metal structures, the aircraft industry was reluctant to implement them in new aircraft. As a result, AFRL launched the Composites Affordability Initiative (CAI) to address these concerns. CAI found that the key to affordability in composites was to reduce assembly costs through the integration of parts and by bonding parts, structural assembly costs could be drastically reduced. As a result, CAI's objective was to establish the confidence to fly large integrated and bonded structures. A partnership between AFRL, the Office of Naval Research, Bell Helicopter, Boeing, Lockheed Martin, and Northrop Grumman was established to develop technologies to meet this objective. This initiative required a multidisciplinary approach: maturation of materials and processes, an understanding of the structural behavior of bonded joints, quality assurance and nondestructive evaluation to ensure bonded joints remain bonded throughout an aircraft's service life, and the buy off of U.S. Department of Defense (DoD) aircraft certification authorities. An assessment will be provided of the technical achievements, technology transition successes and failures, and the program structure and teaming arrangements.					
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# COMPOSITES AFFORDABILITY INITIATIVE

**CANCOM 2007**  
**Winnipeg, Manitoba**  
**15 Aug 07**



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# OUTLINE



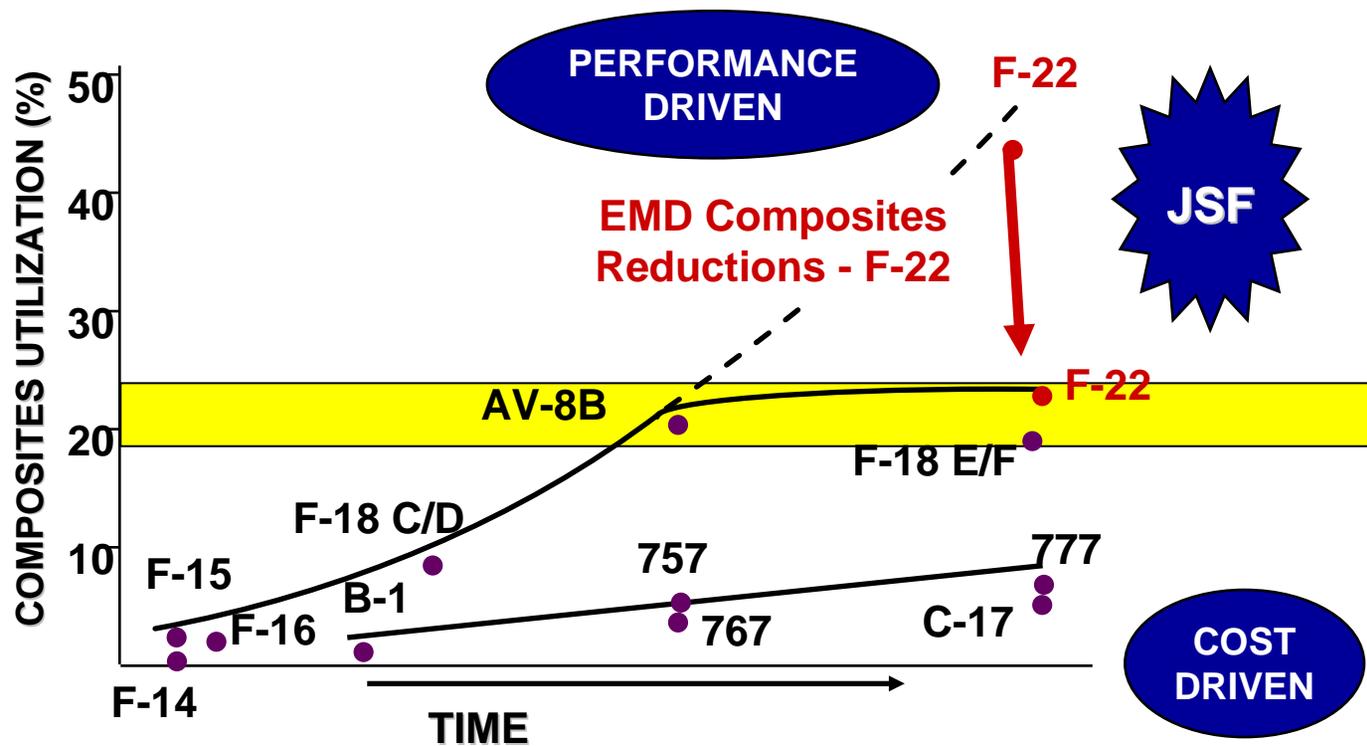
- **Introduction/motivation**
- **Objective and program structure**
- **Technical achievements**
  - **Integrated structures**
  - **Bonded structures**
- **Technology transition**
- **Summary**



# WHY CAI

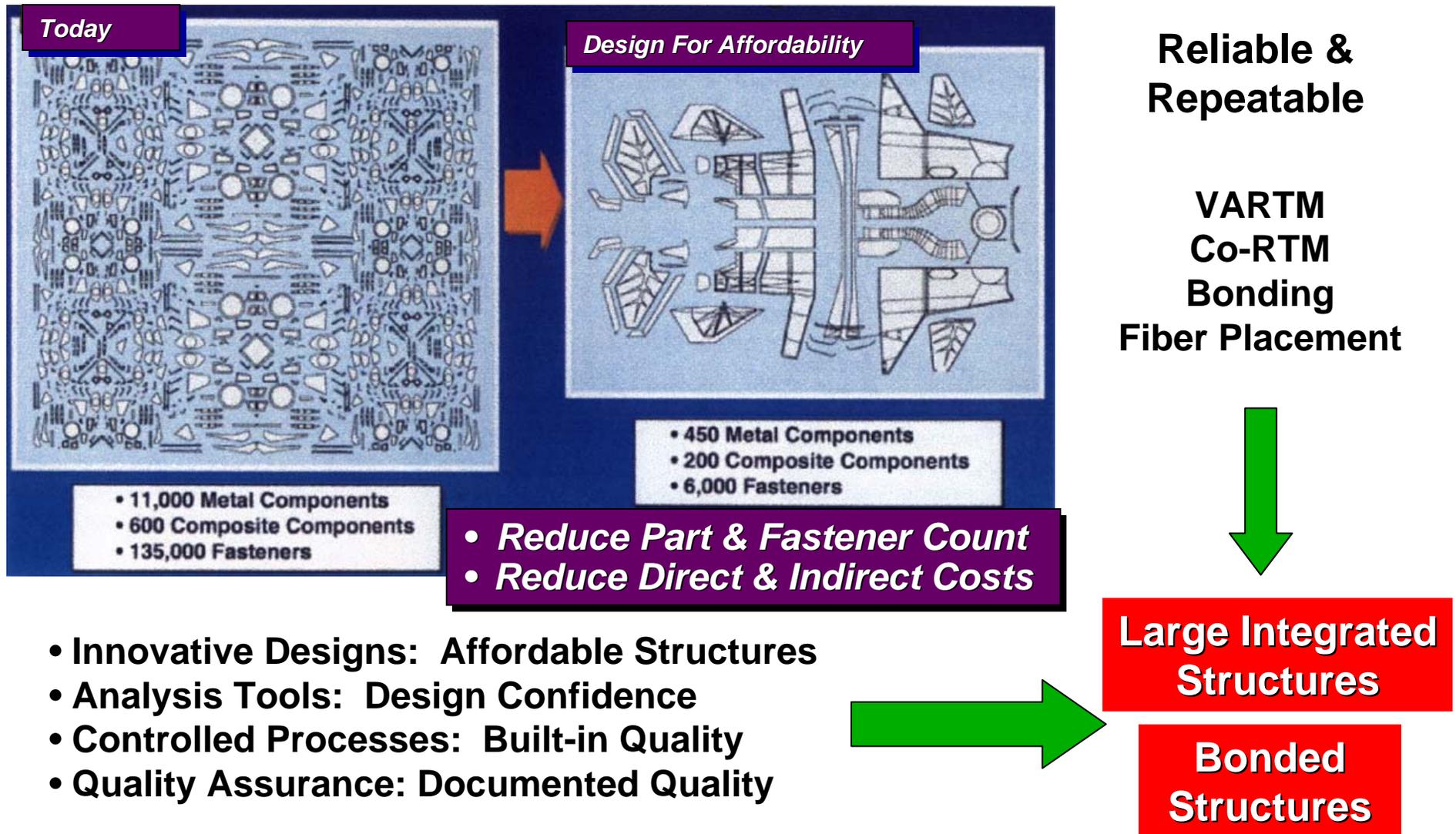


## Unacceptable cost & risk for new structures & applications





# RISK REDUCTION FOR AFFORDABLE STRUCTURES





# BUSINESS MODEL



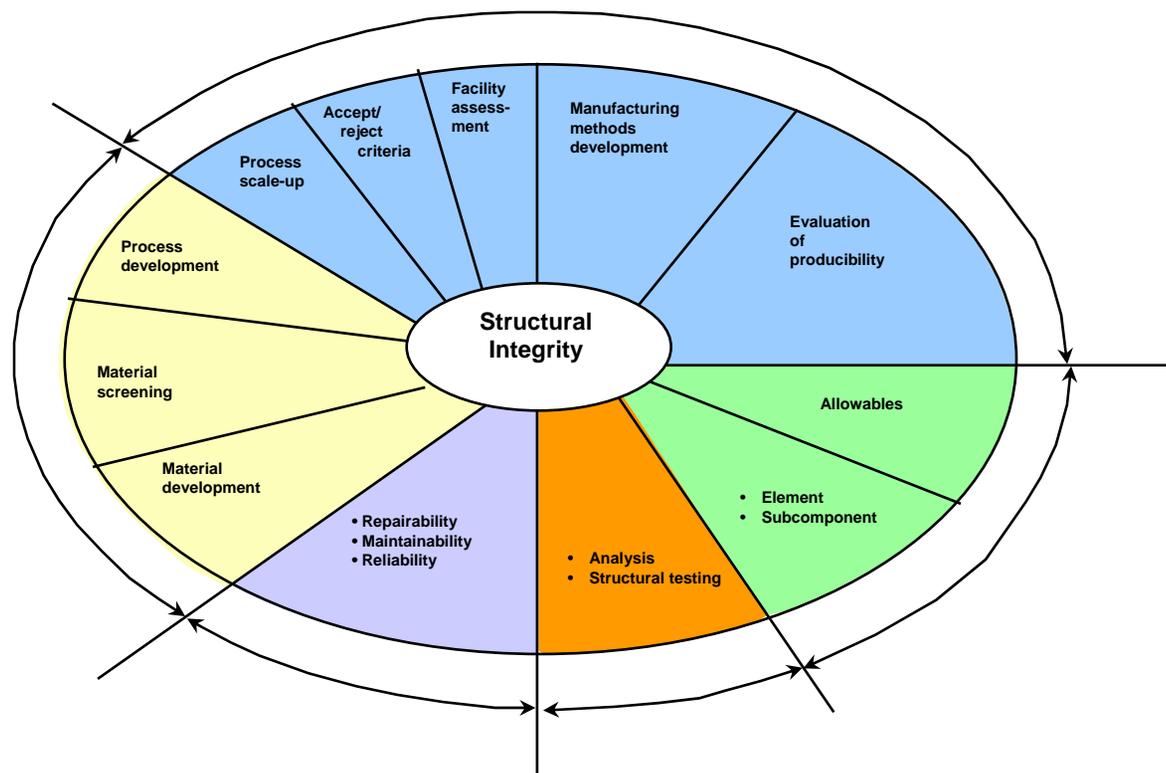
- **Funding**
  - USAF-US Navy funded program
  - 50-50 cost share with airframe industry
    - Bell, Boeing, Lockheed Martin, Northrop Grumman
- **Technology sharing**
  - Pre-competitive technology
  - Government - industry integrated product teams
  - Shared data rights among industry partners
- **Technology transition**
  - Customer involved at all levels of CAI
    - Government and industry
  - Cost share gives industry added incentive to transition



# KEY TECHNOLOGIES TO ADDRESS STRUCTURAL INTEGRITY



- Structurally sound bonded joints
- VARTM & Co-VARTM for integrated structures
- Validated analysis methods
- Bondline validation testing
- Quantifiable in-process QA / NDE
- Material & process specifications
- Certification plans
- Guidelines
- Database to support and validate technologies



**Establish the confidence to fly large integrated and bonded structures**



# CAI TECHNOLOGY ACHIEVEMENTS



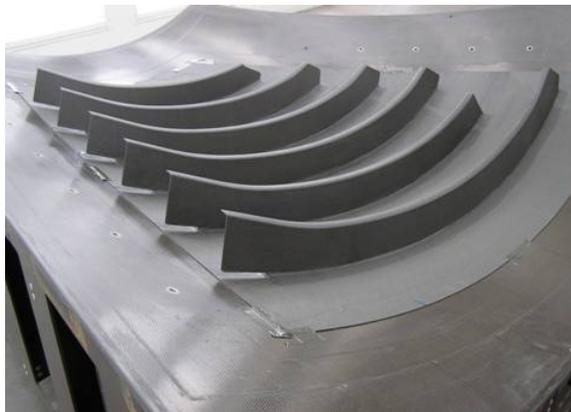
- **Vacuum Assisted Resin Transfer Molding (VARTM)**
  - Non autoclave process for making large yacht hulls was transitioned to the aerospace industry (ex. SCRIMP)
  - Uses a lower than atmospheric pressure (typically full vacuum) to pull a liquid resin into a fiber bed.
  - Advantages
    - Autoclave is not needed
      - Reduced capital equipment costs
      - Expands supplier base for part fabrication
    - Typical VARTM resins cure at a low enough temperature to enable the use of inexpensive tooling such as medium density fiberboard



# CAI TECHNOLOGY ACHIEVEMENTS



- CAI has significantly reduced the risk on VARTM
  - Part sizes over 50 ft<sup>2</sup>
  - Aerospace quality fiber volumes
  - High consistency (per ply thickness)
  - EX1510, SI-ZG-5A, and VRM-34 resins



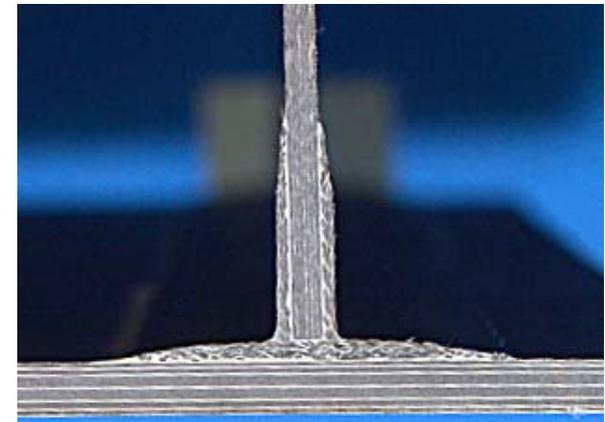
**AEROSPACE QUALITY COMPOSITES  
WITHOUT AN AUTOCLAVE**



# CAI TECHNOLOGY ACHIEVEMENTS



- **“Pi” Joint**
  - Provides structural redundancy
    - Acts as two independent bondlines
    - Stronger than a double lap shear joint
  - Takes advantage of the excellent shear properties of EA 9394 adhesive, the pi joint of the material
    - EA 9394 performs better in shear than in tension loaded bonds
  - Paves the way for much reduced assembly times
    - Determinate assembly feature
    - Minimizes outtime issues when compared to faying surface bonds
    - Eliminates need for verifilm to correct tolerances

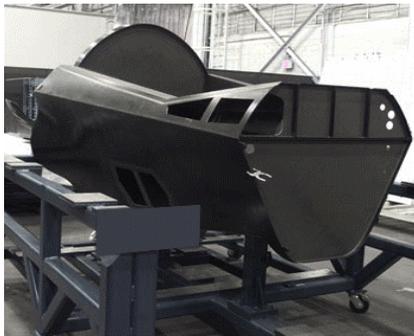
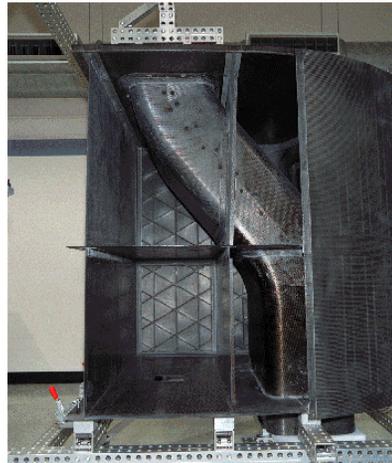




# CAI TECHNOLOGY ACHIEVEMENTS



## BONDED STRUCTURES DEMONSTRATIONS





# CAI TECHNOLOGY ACHIEVEMENTS



- **CAI has significantly reduced the risk on bonded structures (pi joints)**
  - **Easier and much faster to assemble structures than with faying surface bonds**
    - **Eliminates verifilm checks, adhesive out time issues**
  - **Robust (effects of defects), predictable performance**
  - **Room temperature paste bond is stronger than composite base material**
  - **Demonstrated a ballistically survivable, mostly composite wingbox**
  - **Demonstrated manufacturing of several realistic structures with bonding**
  - **Enables a significant reduction in the number of fasteners from the outer mold line**
  - **ASC/EN, NAVAIR, FAA concurrence on certification methods for large integrated/bonded structures**



# CAI TECHNOLOGY ACHIEVEMENTS



- **Tools**
  - **Conventional analysis methods for bonded joints were limited in capabilities and accuracy**
    - **A4EI only applicable to adhesive failures in shear-loaded joints, does not account for peel stresses or for potential adherend failures**
    - **Only alternative to these limitations has been to develop detailed finite element models of a joint**
      - **Time consuming**
      - **Requires great skill and care**
      - **Small errors in modeling can lead to substantial errors in joint performance prediction**
  - **No NDE technique to assess the strength of a bonded joint**
    - **Detect “kissing” bonds**
  - **Weight based cost models can’t accurately/credibly estimate the cost of composite structures manufactured w/ emerging technologies**



# CAI TECHNOLOGY ACHIEVEMENTS



- **Advanced Tools**
  - Demonstrated ability to measure the strength of bonded joints via non-destructive inspection
    - 2 SBIRs ongoing to build a system
  - Validated improved structural analysis tools for bonded joints
    - Static and DaDT
  - Validated an advanced bottoms-up cost analysis tool for improved accuracy on new processes
- **Database**
  - Gathered a comprehensive database with pedigree attached
  - Standing up AMMTIAC as the permanent host



# CAI TECHNOLOGY ACHIEVEMENTS



## TECHNOLOGY GUIDELINE MANUALS

### Design and Manufacturing

- Pi Preform Design
- Pi Preform Allowables
- Back-to-Back L
- Aluminum-Composite Bonding
- Pi Preform Cobonded Structure Process
- Pi Preform Cocured Structure Process
- VARTM Process
- Stitching
- Pi Joint Design and Manufacturing (\*)
- Secondary Bonded Structure Process (\*)
- Damage Level and Types (\*)
- K-Spar and T-Joint (\*)

### Analytical Methods

- Durability and Damage Tolerance (DaDT)
- StressCheck Analysis and Modeling Guide
- Strain Invariant Failure Theory (SIFT) (\*)

### Quality Assurance

- Bonded Joint Evaluation
- Bonding QA Process Control
- Angle Beam Ultrasonic Spectroscopy (ABUS)
- Composite Detailed UT Evaluation
- Laser UT
- Laser Bond Inspection Local Proof Test
- Surface Preparation Procedures
- Surface Wetting Tension
- Surface Texture Measurement
- Solvent Wipe FTIR Surface Measurement
- Wing Witness Proof Test
- Field Inspection Guidelines

### Repair Methods

- Bonded Wing Repair Concepts
- 3-D Pi Preform Bonded Joint Repair Concepts

(\*) In Review



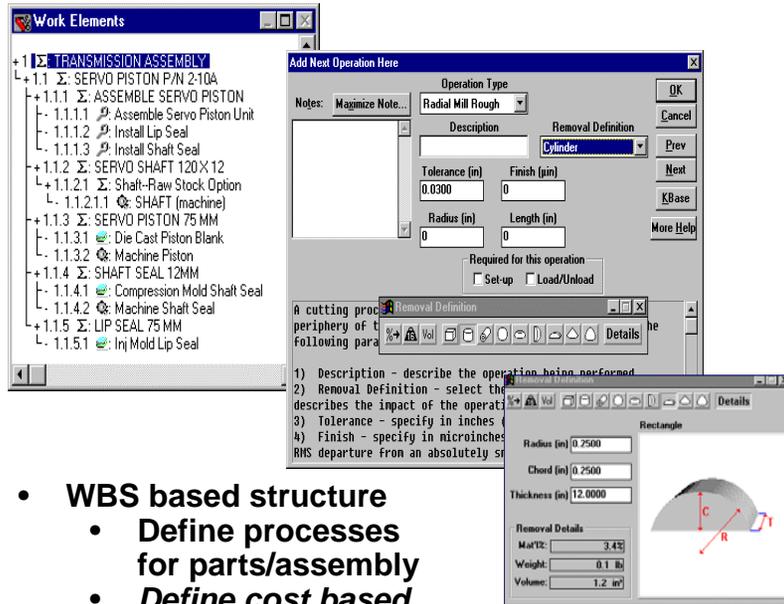
# CAI TECHNICAL SUMMARY



- **Significant technical successes**
- **Large number of demo articles and huge database of test results**
- **Surprisingly small number of technical failures**
  - **E-beam, CoVARTM**
- **Documented procedures on how to employ these technologies**
- **CAI has significantly reduced the risk on large integrated and bonded structures**
- **Does industry have the confidence to implement large integrated and bonded structures?**



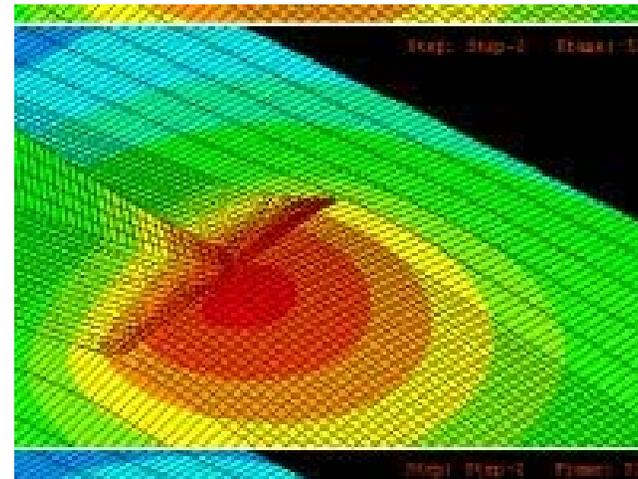
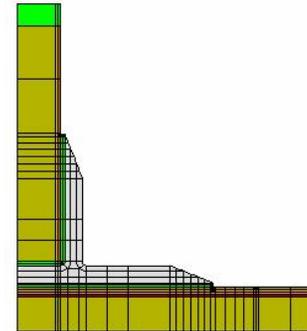
# CAI TECHNOLOGY TRANSITION PERVASIVE TOOLS



- **WBS based structure**
  - Define processes for parts/assembly
  - Define cost based on simple engineering data

Advanced cost analysis tools commercialized  
Cost estimates validated with actual production data to prove accuracy of tools

In use to cost numerous DoD weapon systems and commercial aircraft



Advanced structural analysis tools commercialized  
In use to design numerous DoD weapon systems and commercial aircraft  
Reduced design times, improved design accuracy



# CAI TECHNOLOGY TRANSITION C-17



- **VARTM, Stitched landing gear doors**
- **One piece main landing gear doors adopted by C-17**
- **Eliminates numerous field repair issues**
- **\$6M life cycle cost savings (before AF decision to limit production to 180 aircraft)**



# CAI TECHNOLOGY TRANSITION



- **No other hardware transitions at this time**
  - **Parallel path development needs MAJOR cost or performance improvements to replace the baseline**
  - **Program issues (schedule, cancellation, lack of transition funding, etc.) are impossible for a technology development program to overcome**
- **Being strongly considered by several companies for new military and commercial applications**



# CONCLUSIONS



- **CAI has made tremendous technical strides to advance the state of the art in design and manufacture of aircraft structure**
- **DoD certification community concurs that bonded structure is technically feasible**
- **CAI has established the confidence to fly large integrated and bonded structures**
- **In 10 to 20 years, CAI methods will be commonplace for building aircraft structure**