Composite Safety & Certification Initiatives
Progress and Plans for Bonded Structure

Presented at 9/18/02 FAA Workshop (Chicago, IL)

- Overview
  - Applications of bonding
  - Technical thrust areas and timelines
- Benchmark bonded structures
  - Plans, deliverables and technical scope
- Past progress
  - Research
  - Action groups
- Technical issues
  - Material and process control
  - Manufacturing and design integration
  - Product development and substantiation
- Discussions

Larry Ilcewicz
CS&TA, Composites
State-of-the-Art in Structural Joining and Attachments

Small airplanes
- Extensive bonding in propeller-driven airplanes (sandwich skin panels and major joints to close wing torque box, attach main spars & fuselage skin splices)
- Business jets use bonded sandwich in fuselage (major fuselage splices include bolted redundancy)

Rotorcraft
- Combination of bolted and bonded structures in airframe and dynamic parts (major splices are bolted, many bonded attachments)

Transport aircraft
- Bonded attachments (e.g., stringers) are common, but major joints remain bolted
- Bonded fiberglass/aluminum (GLARE) laminate fuselage panels are planned for the A380 (major fuselage panel splices remain bolted)

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All CS&CI Technical Thrust Areas will be Active for Bonded Structure Efforts

Advancements depend on close integration between areas

Material Standardization and Shared Databases

Structural Substantiation
- Advances in analysis & test building blocks
- Environmental effects
- Manufacturing integration

FAA and NASA R&D is currently active in most of these areas

Damage Tolerance and Maintenance Practices
- Critical defects
- Bonded repair issues
- Fatigue & damage considerations
- Quantitative NDE
- Equivalent levels of safety

Bonded Joint Processing Issues

Advanced Material Forms and Processes

Significant progress, which has relevance to all aircraft products, has been gained to date

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### FAA Composite Team Members

<table>
<thead>
<tr>
<th>Represented Group</th>
<th>Team Member Name</th>
<th>FAA Organization Number &amp; Routing</th>
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Composite Team has placed an emphasis on a need to address bonded structure issues (metal & composite)

**Names in italics are present at the 9/16 to 9/18/02 FAA Workshop**

But we also have some spies present who shall remain nameless
Major Milestones for Bonded Structure
Policy, Guidance & Training in 2004 + 2007


- AGATE Shared Databases
- Initial static strength substantiation
- International M&P specs, database standards and initial environmental effects
- Stiffness, dimensional stability and flutter
- Final process control, design, manufacturing, structural integrity and repair issues for bonded structures

- National Plan* for aircraft products
- Rotorcraft ARAC for fatigue and damage tolerance
- Initial process control, design, manufacturing, structural integrity and repair issues for bonded structures
- Final environmental effects and material limits
- Final damage tolerance substantiation & maintenance
- Updates for new material forms & processes

* International participation in many of the tasks since 2001
Benchmark Bonded Structures

*Primary Deliverables*

- Development of a FAA Technical Center Document on “best engineering practices” for bonded structure
- Bonded Structure Workshop in 2004 to review the draft FAA Technical Center Document
  - To be coordinated with joint meetings of Mil-17 & CACRC (May or early June)
- FAA policy covering the different engineering aspects of bonded structure
Benchmark Bonded Structures

Technical Scope

- Commercial general aviation, rotorcraft and transport aircraft (coordinated with military groups)
- Secondary bonding in structural applications
  - Composite to composite
  - Metal to metal
  - Composite to metal
- Functional areas to be covered
  - Control of raw materials & process (raw material manufacturing)
  - Bonding process controls
  - Manufacturing
  - Design
  - Product development and structural substantiation
Approach Used for Initial Bonded Structures Efforts

1) Start with input from certification, production and service experiences, plus research performed to date

» Initial research and industry review (*light yellow boxes*), used to generalize industry experiences and identify longer-term research needs

2a) Focussed research to draft “best engineering practices”

2b) Workshop & industry review to release detailed documentation on “best engineering practices”

3) Rules, policy and/or guidance as necessary

4) Training for industry and government workforce

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Progress and Plans to Benchmark Bonded Structure Technology

Oct. 2004  Draft FAA policy for Certification of Bonded Structure
Jul. 2004  Update FAA TC Bonded Structures Document
May 2004  Conduct FAA/NASA/industry workshop to review draft document following joint Mil-17/CACRC mtg.
Mar. 2004  First draft of Bonded Structures Document
Nov. 2003  Select team, establish AACE grant, develop detailed outline and start to draft the benchmark document
Oct., 2003  Meet with transport, rotorcraft and military groups to develop detailed plans and ID experts to support work
Sep., 2003  Introduce plans & collect inputs at M&P control workshop
July, 2003  Meet with GA companies on their involvement
May, 2003  Developed strategy and resource requests for near term work
2000 to 2003  FAA research per the “Don Oplinger Plan”

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Progress for Bonded Structures

FAA and NASA Research

- Surface prep studies on removable plies and abrasion
  - Clarify terminology for peel plies and release fabrics
  - In-process control testing
- Advances in test methods for adhesive joint shear and peel
- Characterization of environmental effects, fatigue and creep for a wide range of adhesives used by industry
  - Consideration of temperature guidelines used for material selection
- Evaluation of structural analysis methods for strength and damage tolerance
  - Development & test validation of methods suitable for design
  - Evaluation of realistic structural detail (e.g., thick and variable bondlines, joggles) and load cases (e.g., shear flow)
Progress for Bonded Structures

Action Groups for Detailed Documentation

- Some guidance for bonded structures, which comes from military and commercial aircraft experiences, are documented in a TTCP report
  - Composite and metal bonding
  - Starting point for current effort
- Mil-17 Debond & Delamination Task Group since 2000
  - T.K. O’Brien, K. Kedward and Hyonny Kim are Co-chairman
Preface

This publication is the result of three years of deliberations by Action Group 13 chartered by The Technical Cooperation Program to provide guidance on the important subject of certification of bonded structures. Bonded structures are being used to reduce mass and cost in new aircraft, particularly in unmanned applications. They are also a major factor in the safe and economic life extension of aging fleets of military aircraft. This document is intended to fill a void by addressing the essential elements that aircraft designers and owners must address in the certification of bonded structures.

The document is truly a team effort by a group of engineers dedicated to ensure successful applications in the future of this valuable technology. The chairman of the team is grateful for the contributions of the following individuals and for their dedication to making this document useful:

Australia
Dr. Alan Baker Aeronautical and Maritime Research Laboratory
Dr. Francis Rose Aeronautical and Maritime Research Laboratory
Mr. Maxwell Davis Royal Australian Air Force

Canada
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United Kingdom
Dr. Peter Poole Defence Research Agency

United States
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Mr. Eric Robeson U. S. Army Aviation & Troop Command
Mr. Edward Rosenzweig Naval Air Warfare Center Aircraft Division
Mr. Joseph Soderquist Federal Aviation Administration

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John W. Lincoln, Chairman
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Technical Issues

Material and Process Control *

- Adhesive qualification
  - Type (film and paste) and filler materials
  - Test methods for requirements
  - Adhesive preparation

- Raw material (adhesive and substrate) M&P controls
  - Receiving inspection & equivalency testing/acceptance criteria
  - Supplier/user relationships
  - Distribution, handling and storage

- Bonding process qualification and control
  - Substrate and adhesive selection/compatibility
  - Surface preparation (cleaning, abrading, removable plies)
  - Test methods (static, durability and damage tolerance)
  - Process steps
  - Cure cycle variables

* Applies to production and repair
Technical Issues

Manufacturing and Design Integration *

- Manufacturing scaling
  - Tooling and equipment
  - Environmental and cleanliness controls
  - Cured part dimensional tolerance and warpage control
  - Large scale surface preparation and adhesive application
  - Implementation of bonding process steps (sequence, timing)

- Cure process variables
  - Bondline thickness control
  - Local part variations in temperature, pressure and vacuum

- In-process controls and tests

- Structural design considerations
  - Part lay-up and mating surface details
  - Relationships with manufacturing scaling issues
  - Redundant design features

* Applies to production and repair

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Building Block Approach to Product Development & Structural Substantiation

- Protect large non-recurring costs for certification and production
- Risk mitigation for design-specific detail and complex internal loads
- Establish material & process control
- Design/manufacturing integration
- Manufacturing process scaling
- Analysis validation
- Study variability, environmental effects, damage and repair as important parts of product development and structural substantiation

Schematic from a structures perspective
**Bonded Primary Structure**

Product Development and Structural Substantiation

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**Material & Process Control**

- Adhesive qualification
- Bonding process qualification
- Raw material (adhesive and substrate) M&P controls
- Suitable tests for durability, strength and damage tolerance

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**Internal Load Paths and Redundancy??**

**Manufacturing Induced Process Traits??**

**Base Material and Process Characterization??**

**Structure**

**Elements and Subcomponents**

**Coupons**

**Structural Scaling**
Bonded Primary Structure

Product Development and Structural Substantiation

Manufacturing and Design Integration
- Manufacturing scaling
- Cure process variables
- In-process controls and tests
- Structural design considerations

Material & Process Control
- Adhesive qualification
- Bonding process qualification
- Raw material (adhesive and substrate) M&P controls
- Suitable tests for durability, strength and damage tolerance

Internal Load Paths and Redundancy??

Manufacturing Induced Process Traits??

Base Material and Process Characterization??

Structure

Elements and Subcomponents

Coupons

Structural Scaling
Bonded Primary Structure

Product Development and Structural Substantiation

Strength and Damage Tolerance
- Building block test selection
- Analysis validation
- Full-scale test conditions

Manufacturing and Design Integration
- Manufacturing scaling
- Cure process variables
- In-process controls and tests
- Structural design considerations

Material & Process Control
- Adhesive qualification
- Bonding process qualification
- Raw material (adhesive and substrate) M&P controls
- Suitable tests for durability, strength and damage tolerance

Internal Load Paths and Redundancy??

Structure

Elements and Subcomponents

Coupons

Base Material and Process Characterization??

Manufacturing Induced Process Traits??

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Bonded Primary Structure

Product Development and Structural Substantiation

Long-Term, Environmental Durability
- Building block test selection
- Critical environment and acceleration factors
- Considerations of full-scale structural detail

Manufacturing and Design Integration
- Manufacturing scaling
- Cure process variables
- In-process controls and tests
- Structural design considerations

Material & Process Control
- Adhesive qualification
- Bonding process qualification
- Raw material (adhesive and substrate) M&P controls
- Suitable tests for durability, strength and damage tolerance

Internal Load Paths and Redundancy??
Structure
Elements and Subcomponents
Coupons
Base Material and Process Characterization??
Manufacturing Induced Process Traits??

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Inputs from Discussion

**Material and Process Control**

- **Adhesive qualification**
  - What tests need to be considered? Chemical, physical & mechanical
  - Candidate Experts: Peter Vanvoast (Boeing)

- **Raw material (adhesive & substrate) M&P controls**
  - What tests need to be considered? Chemical, physical & mechanical
  - Monitors and environmental controls for storage and working lives
  - Candidate Experts:

- **Bonding process qualification and control**
  - Links with adhesive qualification and raw material M&P controls (system approach, including application criticality)
  - What tests need to be considered? Static, environmental durability
  - Historical databases for successful applications (physical basis, e.g., what has worked)
  - NDI aspects
  - Candidate Experts: Kay B. (Boeing)

* Applies to production and repair

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Inputs from Discussion

Manufacturing and Design Integration

- Manufacturing scaling
  - Bondline thickness control
  - Nature of defects and their location (e.g., paste adhesive experiences) related to structural geometry
  - Training for critical details

- Cure process variables
  - Preload in real parts mating prior to cure (as developed in paste adhesive joints)

- In-process controls and tests
  - Wedge tests (utility of witness coupons)
  - Control of chemical tanks, shop cleanliness
  - Utility of proof loading
  - Records of problems
  - NDI aspects (including surface prep monitoring)

* Applies to production and repair
Inputs from Discussion

Manufacturing and Design Integration *

• Structural design considerations
  – Classification of joints for criticality
  – Critical defect locations and types must relate to real manufacturing considerations, as well as “high stress points”
  – Bolts versus bonding redundancy

• Product development
  – Considerations for sandwich structure
  – Inverted building block approach
  – Candidate Experts: Paul Brey (CDC)

• Structural substantiation
  – Failure prediction (static and damage tolerance, failure modes)
  – Allowables (what basic materials and joint data is needed for analysis procedures)
  – Impact damage affects (static/propagation)

* Applies to production and repair
Summary

• Composite safety & certification initiatives (CS&CI) are progressing with international help
  – Work for bonded structure integrates all technical thrust areas and both near- & longer-term research

• Best engineering practices and initial FAA policy for bonded structure will be documented in 2003 and 2004
  – TTCP document provides a starting point
  – Workshop in May or early June, 2004
  – Policy in late 2004

• Thank-you for your input on technical issues

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