Composite Safety & Certification Initiatives
Progress and Plans for Bonded Structure

Larry Ilcewicz, FAA
Workshop Dedications
for Contributions to Bonded Structures Initiatives

Mr. Don Oplinger
December 2, 1928
June 12, 2000

Dr. Jack Lincoln
March 22, 1928
February 10, 2002

Dr. Jim Starnes
March 2, 1939
October 27, 2003
Composite Safety & Certification Initiatives
Progress and Plans for Bonded Structure
*Presented at 6/16/04 FAA Bonded Structures Workshop*

- **Overview of CS&CI**
  - Technical thrust areas, approach and milestones

- **Progress with bonded structures**
  - Applications of bonding to aircraft structures
  - 2004 bonded structures initiative
  - Workshop objectives & speaker instructions
  - Synopsis of progress to date

- **Critical bonding issues**
  - Certification and continued airworthiness
  - Material & process qualification and control
  - Design development and structural substantiation
  - Manufacturing implementation and experience
  - Repair implementation and experience

- **Support during & after the workshop**
Ongoing Composite Safety & Certification Initiatives*

Objectives

1) Work with industry, other government agencies, and academia to ensure safe and efficient deployment of composite technologies being pursued for use in aircraft

2) Update policies, advisory circulars, training, and detailed background used to support standardized composite engineering practices

* Efforts started in 1999 to address issues associated with increasing composite applications
Current CS&CI Technical Thrust
Areas Pursued by FAA and NASA

Advancements depend on close integration between areas

Material Standardization and Shared Databases

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

Damage Tolerance and Maintenance Practices
- Critical defects (impact & mfg.)
- Bonded structure & repair issues
- Fatigue & damage considerations
- Life assessment (tests & analyses)
- Quantitative NDE/Service POD
- Equivalent levels of safety

Bonded Joint Processing Issues

Advanced Material Forms and Processes

Flammability & Crashworthiness
Support from cabin safety research groups

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

Presented by L. Ilcewicz at 6/16/04 Bonded Structures Workshop
# FAA Approach to Composite Safety and Certification Initiatives

<table>
<thead>
<tr>
<th>Evolving</th>
<th>Mature</th>
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<tr>
<td>Certification and Service History</td>
<td>FARs</td>
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<tr>
<td>Focused RE&amp;D</td>
<td>Advisory Circulars</td>
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<tr>
<td>Rules &amp; General Guidance</td>
<td>Policy Memos</td>
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<td>Internal Policies</td>
<td>Training (Workshops, Short Courses, IVTs)</td>
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<tr>
<td>New Technology Considerations</td>
<td>Public Documents and Standards (e.g., Mil-Hdbk-17, SAE AMS, Contractor Reports)</td>
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<tr>
<td>Time</td>
<td>Detailed Background</td>
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<tr>
<td>Industry Interface</td>
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Presented by L. Ilciewicz at 6/16/04 Bonded Structures Workshop
## 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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</thead>
<tbody>
<tr>
<td>FAA Tech. Center</td>
<td>Curtis Davies</td>
<td>AAR-450 (FAA Technical Center)</td>
</tr>
<tr>
<td></td>
<td>Peter Shyprykevich</td>
<td>AAR-450 (FAA Technical Center)</td>
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<tr>
<td>International</td>
<td>John Masters</td>
<td>AEU-100 (Brussels Aircraft Certification Staff)</td>
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<tr>
<td>Directorates</td>
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<tr>
<td></td>
<td>Lester Cheng</td>
<td>ACE-111 (Small Airplane Directorate)</td>
</tr>
<tr>
<td></td>
<td>Mark James</td>
<td>ACE-111 (Small Airplane Directorate)</td>
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<tr>
<td></td>
<td>Richard Monschke</td>
<td>ASW-111 (Rotorcraft Directorate)</td>
</tr>
<tr>
<td></td>
<td>Richard Yarges</td>
<td>ANM-115 (Transport Airplane Directorate)</td>
</tr>
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<td></td>
<td>Hank Offermann</td>
<td>ANM-115 (Transport Airplane Directorate)</td>
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<tr>
<td></td>
<td>Jay Turnberg</td>
<td>ANE-110 (Engine &amp; Propeller Directorate)</td>
</tr>
<tr>
<td>Flight Standards</td>
<td>William Henry</td>
<td>AFS 350 (Aircraft Maintenance Division)</td>
</tr>
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<tr>
<td>ACOs, MIDOs &amp; CMOs</td>
<td>Randy Blosser</td>
<td>ANM-100D (Denver ACO)</td>
</tr>
<tr>
<td></td>
<td>Roger Caldwell</td>
<td>ANM-100D (Denver ACO)</td>
</tr>
<tr>
<td></td>
<td>Mark Freisthler</td>
<td>ANM-120S (Seattle ACO)</td>
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<tr>
<td></td>
<td>Fred Guerin</td>
<td>ANM-120L (Los Angeles ACO)</td>
</tr>
<tr>
<td></td>
<td>Angie Kostopoulos</td>
<td>ACE-116C (Chicago ACO)</td>
</tr>
<tr>
<td></td>
<td>David Ostrodek</td>
<td>ACE-118W (Wichita ACO)</td>
</tr>
<tr>
<td></td>
<td>Richard Noll</td>
<td>ANE-150 (Boston ACO)</td>
</tr>
<tr>
<td></td>
<td>Dick Vaughn</td>
<td>ANM-108B (Seattle CMO)</td>
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<tr>
<td></td>
<td>David Swartz</td>
<td>ACE-115N (Anchorage ACO)</td>
</tr>
<tr>
<td>CS&amp;TA</td>
<td>Larry Ilcewicz</td>
<td>ANM-115N (CS&amp;TA, Composites)</td>
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</table>

Composite Team has placed an emphasis on a need to address bonded structure issues (metal & composite)

Present at this workshop
Importance of NASA, Industry Standards Groups and Other Support Organizations

- NASA has been a leader for composite applications
  - Significant research funding to composite safety & certification initiatives
  - Closely involved in the AA587, A300-600 accident investigation
  - Both aeronautics and space activities will be integrated in long-term plans

- Partnerships with industry are essential, e.g., Mil-Handbook-17, CACRC, SAE, ASTM, SAMPE, AGATE, SATS, RITA, SAS/IAB/AACE

- Continued support of other organizations will be sought
  (e.g., DOD, DARPA, JAA and other foreign research/standardization links)
FAA Strategic Plan: Safety Continuum

Safety management system linking certification standards, maintenance and operations

Each function within the continuum is an integral part of Safety Management.

Information and experience derived from each phase is systemically applied to subsequent phases throughout the continuum.

The success of the entire continuum is dependent on effective Safety Management in each and every phase.
Accident Investigations

- Detailed studies indicate there are generally many factors that combine to contribute to an accident
  - Precursors are often evident but are usually not obvious because they must combine with other factors
- Safety management must combine the skills of many disciplines
  - A systems approach with airplane level awareness can help mitigate the risk of accidents
  - Critical relevant information must be disseminated (i.e., lessons learned)
  - Industry standards groups can help promote consistent engineering practices and practical guidance
Major Milestones for Bonded Structure Policy, Guidance & Training in 2004 + 2007

- **2000**: Initial process control, design, manufacturing, structural integrity and repair issues for bonded structures
- **2001**: Rotorcraft ARAC for fatigue and damage tolerance
- **2002**: National Plan* for aircraft products
- **2003**: International M&P specs, database standards and initial environmental effects
- **2004**: Update damage tolerance substantiation & maintenance
- **2005**: Maintenance training needs, Stiffness, flight stability and flutter
- **2006**: Update environmental effects and material limits
- **2007**: Update process control, design, manufacturing, structural integrity and repair issues for bonded structures
- **2008**: Updates for new materials and processes

* International participation in many of the tasks since 2001
Use of Bonding for Structural Joining & Attachments in Commercial Aircraft

Small airplanes
• Long history of metal bonding in primary load bearing applications for some small airplanes/jets
• Extensive bonding in new prop-driven airplanes (composite 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 and propellers
• Combination of bolted and bonded structures in airframe and dynamic parts (major splices are bolted, many bonded attachments)

Transport aircraft
• Bonded attachments (stringers, sandwich panels) for composites, but major joints remain bolted
• Bonded fiberglass/aluminum (GLARE) laminate fuselage crown panels are planned for the A380

Bonded repair is common for all product types, e.g., sandwich panels

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### Levels of Application Criticality

<table>
<thead>
<tr>
<th>Flight Safety</th>
<th>Loads</th>
<th>Environment</th>
<th>Service Experience</th>
<th>Other Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>High shear</td>
<td>High temp, moisture and fluids</td>
<td>Bad service records</td>
<td>?</td>
</tr>
<tr>
<td>Single load path</td>
<td>Moderate peel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>Moderate shear</td>
<td>Standard temp, moisture and fluids</td>
<td>Limited good service records</td>
<td>?</td>
</tr>
<tr>
<td>Multi-load path</td>
<td>Some peel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary structure</td>
<td>Low shear</td>
<td>Benign environment</td>
<td>Good service records</td>
<td>?</td>
</tr>
<tr>
<td>No peel</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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2004 Bonded Structures Initiative

Justification and Purpose

• Bonding applications for the manufacture & repair of aircraft structures exist throughout the industry
  – New applications are expanding faster than the qualified workforce, making documentation and training a priority

• Technical issues are complex and cross-functional, requiring extensive teamwork for successful applications
  – Known production and service bonding problems highlight a need to properly document the associated technical issues

Collectively, the industry and regulatory agencies should be able to combine our bonding experiences and technical insights to the mutual benefits of improved safety and efficiency in development & certification
2004 Bonded Structures Initiative

Primary Deliverables

- Survey industry to benchmark critical technical issues and engineering practices for existing applications

- Bonded Structure Workshops in 2004 to review the survey and gather more insights from experts
  - To be coordinated with June Mil-17 meetings
  - Follow-on workshop in Europe (TBD)

- Develop FAA Technical Center Report(s) on critical technical issues and existing engineering practices

- Late 2004 FAA policy covering safety issues and certification considerations for bonded structure
2004 Bonded Structure Initiative

Objectives for 6/04 Workshop & Follow-on Report(s)

Primary objective

Collect & document technical details that need to be addressed for bonded structures, including critical safety issues and certification considerations

Secondary objectives

1) Give examples of proven engineering practices
2) Identify needs for engineering guidelines, shared databases and standard tests & specs
3) Provide directions for research and development

Background: The primary objective relates to a FAA goal for outlining what needs to be considered for aircraft safety and certification. Secondary objectives are intended to help industry develop guidelines, standards and training in addressing the critical issues.
2004 FAA Adhesive Bonding Workshop

Speaker Instructions

• Items to include at the start of your presentation
  – Briefly describe your background and experiences with adhesively bonded structure
  – Provide a synopsis of the bonded structural applications to be covered by examples in your presentation
  – Identify the critical safety issue(s) and/or certification consideration(s) you plan to address

  *To provide linkage with the primary workshop objective*

• The remainder of your presentation may contain
  – Additional details on your experiences and applications
  – Advice on best engineering practices and other items related to bonded structures *(see secondary objectives)*
Technical Scope

• General aviation, rotorcraft and transport aircraft (coordinated with military groups)

• Structural applications of bonding (manufacturing and/or repair when at least one side of the joint is pre-cured or metal)
  – 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 – Repair
  – Design – Maintenance
  – Analysis and failure prediction
  – 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

2a) Focussed research to survey industry on the critical technical issues and benchmark engineering practices

2b) Workshop to collect more inputs & draft reports for industry review

3) Draft policy on critical safety issues & certification considerations

4) Training for industry and government workforce

» Initial research and industry review (light yellow boxes), used to gain agreement on critical issues, generalize industry experiences and identify needs (standards and longer-term research)
### Progress and Plans in the Bonded Structures Initiative through 2004

<table>
<thead>
<tr>
<th>Oct. to Dec. 2004</th>
<th>Draft FAA policy for Bonded Structures, FAA workshop in Europe, update reports</th>
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<tbody>
<tr>
<td>July to Sept. 2004</td>
<td>Draft FAA TC Bonded Structures Report(s) and plan follow-on activities</td>
</tr>
<tr>
<td>June 2004</td>
<td>FAA workshop to review survey and collect insights from bonding experts at Mil-17 mtg.</td>
</tr>
<tr>
<td>Apr. to May 2004</td>
<td>Develop workshop agenda &amp; invite speakers</td>
</tr>
<tr>
<td>Feb. to Mar., 2004</td>
<td>Select team, setup AACE grant &amp; survey industry</td>
</tr>
<tr>
<td>Oct. 2003 to Jan. 2004</td>
<td>Meet with industry and military groups to develop detailed plans and ID experts to support work</td>
</tr>
<tr>
<td>July to Sept. 2003</td>
<td>Introduce plans to industry and collect initial technical inputs at composite M&amp;P control workshop (Chicago)</td>
</tr>
<tr>
<td>May 2003</td>
<td>Developed strategy &amp; resource requests for near term work</td>
</tr>
<tr>
<td>Feb. 2001</td>
<td>TTCP document on “Certification of Bonded Structures”</td>
</tr>
<tr>
<td>2000 to 2003</td>
<td>FAA research per the “Don Oplinger Plan”</td>
</tr>
</tbody>
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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
  - Chairman: Jack Lincoln, WPAFB
  - 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
Synopsis of Progress to Date

- Structural bonding has been used in fabrication and repair of many types of commercial and military aircraft components
  - Safety issues & certification considerations are application dependent
- FAA Bonded Structures Initiatives in 2004 are being used to benchmark the industry
  - Document critical safety issues and certification considerations
  - Document examples of proven engineering practices
  - Identify needs (databases, standards, focused research)
- FAA will continue to pursue the identified needs with other government agencies, industry and standards organizations
- Our long-term goal is to establish guidance, detailed documentation and training, which is useful for the certification and continued airworthiness of bonded structures
Certification and Continued Airworthiness

- **Certification**
  - **Step 1**: components of a product’s design are qualified, conformed, and substantiated to get a *Type Certificate* (extensive FAA oversight)
  - **Step 2**: approval of the quality control system that ensures every product produced conforms to its type design leads to a *Production Certificate*
  - During aircraft production and beyond, special design and production approvals are sought for changes, modifications, repairs, or improvements
  - **Step 3**: each aircraft must also have an *Airworthiness Certificate*, which certifies it conforms to type design and is in safe operating condition

- **Service problems** are addressed with industry during the aircraft’s life

Data, analysis & procedures defining the aircraft product and demonstrating it meets Federal Regulations

Repeatable production of certified aircraft products

Additional info may be needed for changes occurring during production or the product life cycle
Technical Subjects Covered in the Bonded Structures Workshop

- Material & Process Qualification and Control
- Regulatory Considerations
  - Proof of structure: static strength
  - Fatigue and damage tolerance
  - Design and construction
  - Materials and workmanship
  - Durability
  - Material strength properties & design values
  - Production quality control
  - Instructions for continued airworthiness
  - Maintenance and repair
- Design Development and Structural Substantiation
- Manufacturing Implementation and Experience
- Repair Implementation and Experience

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Critical Bonding Issues  
**Material & Process Qualification and Control**

- Material selection and process definition
  - Bonding processes lead to a complex material system (substrate, adhesive and an interface region that is more complex than either)

- Qualification testing

- Material control

FAR 23/25/27/29.603 Materials  
FAR 33.15 & 35.17 Materials  
FAR 33/35.19 Durability  

**FAR 25.603 (Paraphrased): Suitability & durability of materials used for critical parts must**

(a) be established by experience or tests.
(b) conform to approved specifications that assure strength and other design properties
(c) account for service environmental conditions
Critical Bonding Issues  
*Material & Process Qualification and Control*

- Process control  
- Major changes to materials or processes

**FAR 23/25/27/29.605 Fabrication methods**

FAR 25.605: “(a) Fabrication methods must produce consistently sound structure. If a fabrication process (such as gluing, ...) requires close control to reach this objective, the process must be performed under an approved process spec  
(b) Each new aircraft fabrication method must be substantiated by a test program”

**FAA Research at UCSB: Bonding Surfaces Previously Subjected to Removable Layers**

<table>
<thead>
<tr>
<th>Specimen Type</th>
<th>G1c (in-lb/in^2)</th>
<th>G1c (J/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEP</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>NAT</td>
<td>10</td>
<td>500</td>
</tr>
<tr>
<td>SRB</td>
<td>8</td>
<td>1000</td>
</tr>
<tr>
<td>VLP</td>
<td>6</td>
<td>1500</td>
</tr>
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</table>

**Traveling Wedge Test**

- Peel plies: NAT and VLP
- Release Fabric
- Release Film

![Graph showing G1c values for different specimen types with error bars indicating standard deviation.](image-url)
Critical Bonding Issues

Design Development and Structural Substantiation

- Design and construction
  - Criteria and guidelines
  - Structural detail and redundancy
  - Manufacturing/tooling constraints
  - Design for maintenance
  - Systems interface
- Design data and allowables
  - Defect and damage considerations
  - Environmental effects
- Analysis methods
- Proof of structure
  - Analysis validation
  - Static strength & deformation
  - Damage tolerance & fatigue
  - Long-term durability
- Service experience

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Critical Bonding Issues

Design Development and Structural Substantiation

Subpart B: Design and Construction
FAR 23/25/27/29.601 General and Construction
FAR 35.15 Design features

FAR 25.601: “The airplane may not have design features or details that experience has shown to be hazardous or unreliable. The suitability of each design detail or part must be established by tests.”

FAR 23.573 Damage tolerance and fatigue evaluation of structure paragraph (a) Composite airframe structure

FAR 23.573 (a)(5): “For any bonded joint, the failure of which would result in catastrophic loss of the airplane, the limit load capacity must be substantiated by one of the following methods –” (each paraphrased)

(i) Structural redundancy  (ii) Proof loading  (iii) NDI
Critical Bonding Issues

*Design Development and Structural Substantiation*

- All damage tolerance and fatigue rules* imply catastrophic failure due to fatigue, environmental effects or accidental damage will be avoided during the aircraft operational life.

- *Lost Ultimate load capability should be rare* with safety covered by damage tolerance & practical maintenance procedures.

* 23.573, 25.571, 27/29.573

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Critical Bonding Issues

Design Development and Structural Substantiation

• A well-qualified structural bonding process and strict material & process controls are paramount

*Fatigue and damage tolerance methods cannot cover for an “unacceptable bonding process”*

  **Reason 1**: the degradation of “weak bonds” is generally not predictable or repeatable in mechanical tests

  **Reason 2**: bad chemistry, real time and environmental effects dominate the degradation process

  **Reason 3**: large area debonding is unacceptable for a large number of structural details (i.e., degradation is not “rare”)

• Fatigue and damage tolerance methods are useful for structure using a qualified bonding process that is under control

  **Reason 1**: to cover *rare, local debonding*, which occur for good processes

  **Reason 2**: to provide sufficient fail-safety & coverage for accidental damage
Critical Bonding Issues

Manufacturing Implementation and Experience

- Scaling of process details found to yield reliable adhesive bonds (e.g., time limits, cure temp./contact pressure, bondline thickness control)
- Factory environmental cleanliness controls
- Tooling and equipment
- Quality control
- Nondestructive inspection
- Manufacturing defects (bonded structure discrepancies)
- Skills and training of production workforce
- Process documents and records

Part 21, Subpart G: Production Certificates
FAR 21.139 Quality Control (Paraphrased)

In order to get a production certificate, applicants must establish and maintain a quality control system so that each product meets the design provisions of the pertinent type certificate.
Critical Bonding Issues
Repair Implementation and Experience

- Accessibility for maintenance inspection and repair
- Field implementation of bonded repair process details
  - Shop tooling and equipment
  - Environment & cleanliness control
  - Material acceptance & control
  - Cure temp./contact pressure for variable structural detail
  - Quality control
  - Repair defect disposition
- Nondestructive inspection
- Service damage disposition (allowable damage and repair limits)
- Skills & training of workforce
- Maintenance documents and records

FAA Research at WSU: CACRC Repair Investigation

FAA Part 43 Maintenance, Preventive Maintenance, Rebuilding and Alteration
Support During & After the Workshop

• Rules of engagement during the workshop
  – Please pose major points during your presentation or in your first chances at questions or comments
  – All speakers will respect the time of others
  – Some priority for questions and comments will be given to those who haven’t spoken yet
  – Let your voice be heard but if time doesn’t allow it, consider communicating with us after the workshop

• Communications following the workshop
  – Public website will post workshop presentations www.niar.wichita.edu/faa
  – Please send your thoughts and notes to WSU
  – All inputs will be considered in drafting FAA Report(s), which will be written and reviewed by selected experts
Future Plans

- Draft FAA Technical Center Reports
  - **Primary content:** information collected on bonding issues critical to safety & certification (before/during/after workshop)
  - **Secondary content:** Give examples of proven engineering practice, future R&D directions and standards support needs
  - Following a rigorous review process, publicly release reports for purposes of training, coordination and standardization

- Draft FAA policy to summarize critical bonding issues
  - Released per FAA internal and public processes

- Continue to work on composite safety and certification initiatives related to bonded structures
Summary

- Composite safety & certification initiatives (CS&CI) are progressing with international help
  - Bonded structure work integrates all technical thrust areas
  - 2004 initiatives will benchmark critical bonding issues
    
    TTCP document and FAA R&D provides a starting point
    Survey and workshop leading to technical center report(s)

- Safety management of bonded structures includes:
  - Adequate qualification/control of materials and processes
  - Coordinated design development and substantiation
  - Robust manufacturing and maintenance implementation
  - Continuous updates based on service experience

Thank-you for your help