Summary of U.S. Bonded Structures Workshop

Presented at 10/26/04 FAA Bonded Structures Workshop

FAA

Larry Ilcewicz
CS&TA, Composites

- U.S. Workshop Agenda,

  June 16-18, 2004 (Seattle, WA)

  Session 1: Applications and Service Experiences

  Session 3: Material & Process Qualification and Control

  Session 4: Design Development and Structural Substantiation

  Session 5: Manufacturing Implementation and Experience

  Session 6: Maintenance Implementation and Experience

Agenda for U.S. Bonded Structures Workshop (Seattle, WA)

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	Wednesday, June 16	Thursday, June 17	Friday, June 18
1st Hour		**Session 2** Four Technical Breakout Sessions *Groups in 4 separate rooms (8AM-Noon)* *All participants will attend each session, which are run by technical experts* *(Intro by leaders, 45 minutes discussion)*	**Session 5** Manufacturing Implementation & Experience
2nd Hour			**Session 6** Repair Implementation & Experience
Break (15 min.)			
3rd Hour		1) M&P qualification and control 2) Design development & substantiation 3) Manufacturing implementation 4) Repair implementation	**Session 7** Summary from Day 2 Breakout Teams Recap/Actions/Closure/Adjourn
4th Hour			
Lunch (1 Hour)			
5th Hour	FAA Welcome/Overview	**Session 3** Material & Process Qualification and Control	
6th Hour	FAA Survey/Continued Data Collection		
Break (15 min.)			
7th Hour	**Session 1** Applications & Service Experiences *Perspectives on critical safety issues, lessons learned and best engineering practice*	**Session 4** Design Development and Structural Substantiation	
8th Hour			

142 Participants in U.S. Bonded Structures Workshop (Seattle, WA)

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Last Name	AGENCY/CO.		Last Name	AGENCY/CO.
Abbott, Ric	Abbott Aerospace		Krone, James	Cessna
Adams, Don	Wyoming Test Fixtures		Laakso, John	Aplytek
Adelmann, John	Sikorsky Aircraft		Lagace, Paul	MIT
Ahner, Martha	Lockhheed Martin		Lamantea, Robert	Integrated Tech. Inc.
Aquino, Tim	Lockheed Martin		Langyang, Zhou	
Arakaki, Francisco Kioshi	Embraer Brazil		Larson, Phillip	AFRL/MLS-OL USAF
Ashizawa, Moto	AACE Consulting Engineer		Leibovich, Herman	Israel Aircraft Industries
Barton, Kathy	Goodrich Aerostructures		Littlefield, Andrew	US Army
Baylor, Jeffery	Convergent Mech. Solutions		Loken, Hal	E.I. Dupont
Berner, Jeff	Boeing		Mabson, Gerald	Boeing
Blohowiak, Kay	Boeing		Mahamouda, Salouhoo	University of Washington
Blosser, Randy	FAA		Marchionni, Hank	Lockheed Martin
Bogucki, Gregg	Boeing		Mazza, James	U.S. Air Force Research Lab
Bond, David	UMIST		McCarty, John	Composites Structures Consulting
Bossi, Richard	Boeing		Miller, Robert	Pratt & Whitney
Brey, Paul	Cirrus Design		Miyazaki, Jun	Japan Civil Aviation Bureau
Burcum, Jeffery	Northwest Airlines		Molinari, Maurizio	Transport Canada
Caiazzo, Tony	Materials Sciences		Monschke, Richard	FAA
Casterline, Eric	Heatcon Composite Systems		Moylan, John	Design Testing Laboratories
Cheng, Lester	FAA		Myslinski, Paul	Texas Composite Inc.
Chesmar, Eric	United Air Lines		Nagao, Yosuke	Japan Aerospace Exploration Agency
Choi, Jinkyu	Pratt & Whitney		Naik, Rajiv	Pratt & Whitney
Chris, Mark	Bell Helicopter Textron		Newton, Crystal	University of Delaware
Chung, Philip	Goodrich Aerostructures		Ng, Yeow	Wichita State University
Clark, Gregory	Boeing		Oakes, Gary	Boeing
Cole, Cynthia	The Lancair Company		Osborne, Rod	Boeing
Cole, Richard	Bristol Aerospace Ltd		Ostrodka, David	FAA
Cooke, Leslie	Toray Composites (America)		Peake, Steve	Fibercote
Coulter, Lawrence	AFRL/MLS-OL USAF		Pearson, Andrew	Elisen Technologies
Coxon, Brian	Integrated Tech. Inc.		Peplowski, Anthony	FAA
D'Arienzo, Vince	Bell Helicopter Textron		Poon, Cheung	NRC
Davies, Curtis	FAA		Poursartip, Anoush	Univ. British Columbia
Davis, Max	Royal Australian Air Force		Powers, Brian	ARL/WMRD
Epperson, Jim	Nordam		Rawlinson, Ray	GE-AE
Eshghi, Mel	Boeing		Razi, Hamid	Boeing
Fawcett, Alan	Boeing		Rider, Andrew	DSTO

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Last Name	AGENCY/CO.		Last Name	AGENCY/CO.
Fernlund, Goran	University of B.C.		Ridgard, Chris	Advanced Composites Group
Ferrari, Paulo Eduardo	Embraer Brazil		Rousseau, Carl	Lockheed Martin
Fevola, Simone	New Piper Aircraft, Inc.		Ruffner, Dan	Boeing
Flanagan, Gerry	MSC		Safarian, Patrick	FAA
Floyd, Joe	Boeing		Salah, Lamia	Wichita State University
Forness, Steve	Boeing		Schurr, Steve	Frontier Airlines
Freeman, William	NASA Langley		Seneviratne, Waruna	Wichita State University
Freisthler, Mark	FAA		Sheridan, Bill	Boeing
Fuss, Jim	Naval Air Depot		Sherraden, Janna	WSU NIAR
Gintert, Larry	CTC		Shyprekevich, Peter	FAA
Glenn, Robert	Gulfstream Aerospace		Sibal, Arun	Lockheeed Martin
Grace, Will	Boeing		Smith, Peter	Peter Smith & Associates
Granville, Dana	US Army Research Lab		Spoltman, Mark	Hartzell Propeller Inc.
Grimes, Glenn	Consultant		Srivastava, Rajiv	Florida International Univ.
Guerin, Fred	FAA		Stevenson, Bill	Wichita State University
Hahn, Gail	Boeing		Stuart, Michael	CYTEC
Harter, Pierre	Adam Aircraft Industries		Sullivan, Larry	Goodrich Aerostructures
Hart-Smith, John	Boeing		Swartz, David	FAA
Heitmann, Aaron	Boeing		Thevenin, Roland	Airbus
Hoggartt, John	Boeing		Thomas, Holly	Boeing
Hoke, Michael	Abaris Training Inc.		Tiam, Sam	Toray Composites (America)
Horton, Ray	Boeing		Tillman, Matt	Naval Air Systems Command
Hoyt, D.M.	NSE Composites		Tomblin, John	Wichita State University
Ilcewicz, Larry	FAA		Tudela, Mark	Air Force Research Lab
Iyer, Ramki	US Army, TACOM		Turnberg, Jay	FAA
James, Mark	FAA		Tuttle, Mark	University of Washington
Johnston, Andrew	National Research Council		VanVoast, Peter	Boeing
Jones, Kennedy	FAA		Violette, Melanie	Raytheon Aircraft Co.
Kathula, Anand	The Lancair Company		Vogt, John	Nordam
Keller, Russell	Boeing		Waite, Simon	UK CAA
Khan, Subhotosh	DuPont		Walker, Thomas	NSE Composites
Kim, Hyonny	Purdue University		Ward, Stephen	SW Composites
Kistner, Mark	Wright-Patterson AFB		Welch, John	Boeing
Koemler, Dieter	The Lancair Company		Yang, Charles	Wichita State University
Kostopoulos, Angie	FAA		Yarges, Richard	FAA

Session 1: Applications and Service Experiences

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- **"Best Practices in Adhesive Bonding"** - Max Davis, Australian DGTA-AMB
- **"Cessna Bonding Experience" –** Jim Krone and Andrew Kasowski, Cessna
- **"Propeller Continued Airworthiness & Service Issues"** - Jay Turnberg, FAA
- **"Critical Factors Controlling Durability of Bonded Composite Joints --- Surface Preparation and Pre-Bond Issues"** - John Hart-Smith, Boeing

Session 1: Applications and Service Experiences

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- RAAF bonding experiences led to reliable engineering requirements, methods & procedures for current applications
  - Qualification methods must address long-term durability issues for specific materials, surface preparation and cure cycle
  - Quality control (QC) and technician training are also critical
- Cessna metal bonding experiences incrementally advanced from secondary structures to “fully bonded airframe” over 40 years
  - Emphasized importance of joint design, durability and process control
- Bonding experiences with composite propeller blades
  - Service difficulties due to processing problems with bonded field repairs
  - Complex blade root design has limited bonded joint fatigue life
- Years of experience with bonded composite structure identify the most likely causes of durability problems (disbonding)
  - Inadequate composite surface preparation and pre-bond moisture

Workshop Participants Recommended Changes to the Regulations

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- **Amend FAR Sec. 25.605** *
- *Fabrication methods.*
- *[(a)] The methods of fabrication used must produce a consistently sound **and durable** structure. If a fabrication process (such as gluing, spot welding, or heat treating) requires close control to reach this objective, the process must be performed under an approved process specification **that has been demonstrated to produce a structure that is strong and durable.***
- *[(b) Each new aircraft fabrication method must be substantiated by a test program **that demonstrates that the process used is capable of producing a structure that is strong and durable.]***

* Proposed by Max Davis, RAAF

Session 3: Material & Process Qualification and Control

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- **"Critical Materials & Processes Bonded Joint Issues“ -** Peter Van Voast & Kay Blohowiak, Boeing
- **"Adhesive Bonding Surface Prep Qualification Considerations“ –** Jim Mazza, USAF
- **"The Effect of Environmental Moisture on the Performance and Certification of Adhesively Bonded Joints" -** David Bond, UMIST UK
- **"Structural Adhesives at Lancair" –** Dieter Koehler, Lancair
- **"Adhesive Processing Considerations" –** Mark Chris, Bell Helicopters Textron

Session 3: Material & Process Qualification and Control

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- Boeing bonding experiences since 1950s
  - Early metal bond problems related to inadequate verification tests & QC
  - Current composite and metal bonding materials & processes are verified by extensive compatibility tests (incl. DCB & wedge tests for durability)
- USAF bonding developments (past and present)
  - Summary of Primary Adhesively Bonded Structure Technology (PABST)
  - Detailed discussion of wedge accelerated durability testing for metal bond
  - Current efforts evaluating composite DCB and flatwise tension testing
- Various effects of moisture (D. Bond, UMIST – also presenting today)
- Extensive bonding of Lancair small airplane structures
  - High load-transfer/low load joints (wing skin to spar, fuselage splices)
  - Control of min/max paste bondline thickness and reliable surface prep.
- Bell Helicopter Textron bonding experiences since 1950s
  - Tolerance testing of paste adhesive mixing ratios and bond assembly times to update spec limits & technician training

Air Force Bonded Composite Flatwise Tension Testing

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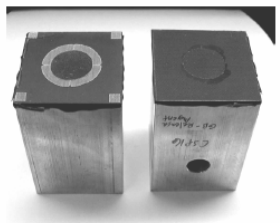
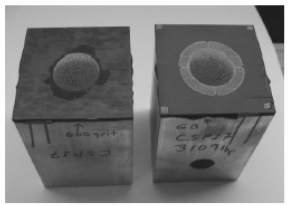
AF 163-2 Adhesive

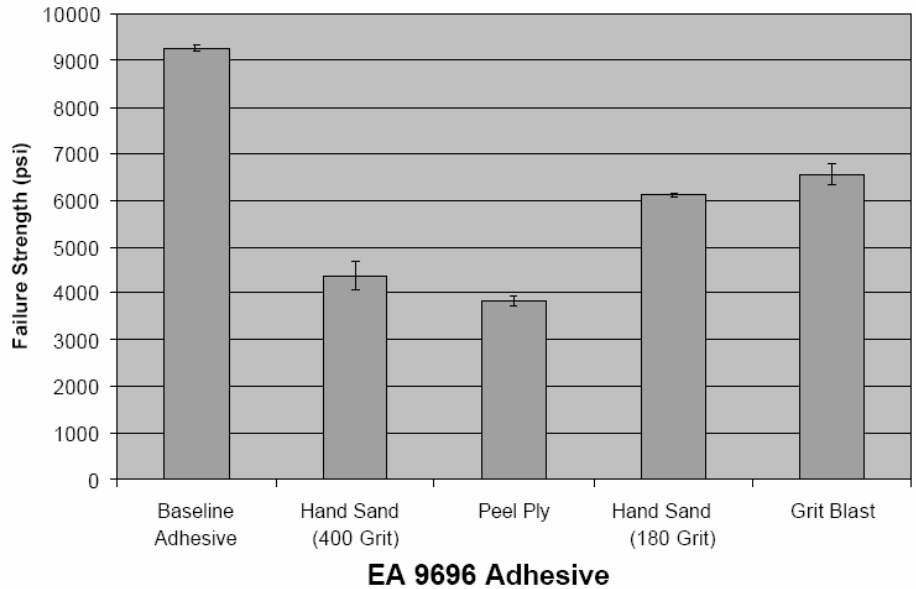
Grit-Blast (good)



Release Agent (bad)

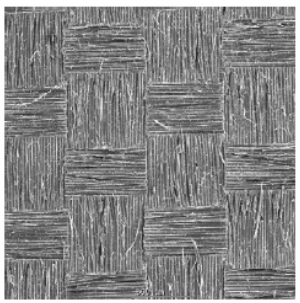


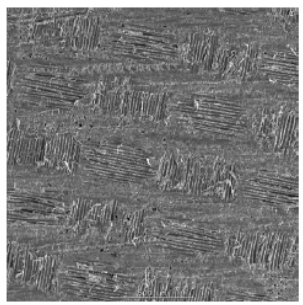
Light Sand (mediocre)



EA 9696 Adhesive

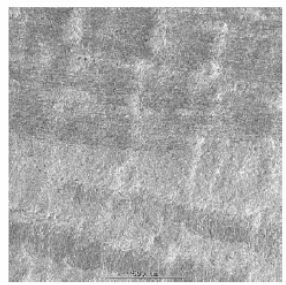
Peel Ply Imprint





Light Abrade

"Proper" Abrade



Grit Blast

Session 4: Design Development and Structural Substantiation

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- **"Bonded Joints Analysis, Data, and Substantiation - Industry Practice and Technical Issues"-** D.M. Hoyt, NSE Composites & Steve Ward, SW Composites
- **"Adhesive Bonding Experience at Cirrus Design" –** Paul Brey, Cirrus Design
- **"Cobonding Primary Structure, Processing Issues and Related Tests"** - Al Fawcett, Boeing
- **"Certifying Bonded Structure - A New Company's Approach"** - Pierre Harter, Adam Aircraft

Session 4: Design Development and Structural Substantiation

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- Session addressed a range of product types and design detail
- Summary of analysis methods, design data & substantiation tests
  - Ranging from simple sizing methods to more complex analyses
  - A need to consider manufacturing defects and service damage has led to past reliance on tests but new analysis methods appear promising
- Extensive bonding of Cirrus Design small airplane structures
  - Expanding production (500 airplanes in 2004) and service history
  - Damage disposition, repair, design/process/tool changes, workforce training
- Boeing experience in co-bonded composite aircraft structure
  - Rigorous controls needed to use peel ply for surface prep. (single source materials, intense receiving inspection, peel tests, workforce training)
  - Hypothetical flow diagram for adhesion failures discovered in service
- New small airplane applications by Adam Aircraft
  - Importance of full scale tests for complex structural detail
  - Need for shared databases and standard composite “wedge test”

Example of Cirrus Design Production Rate Increase

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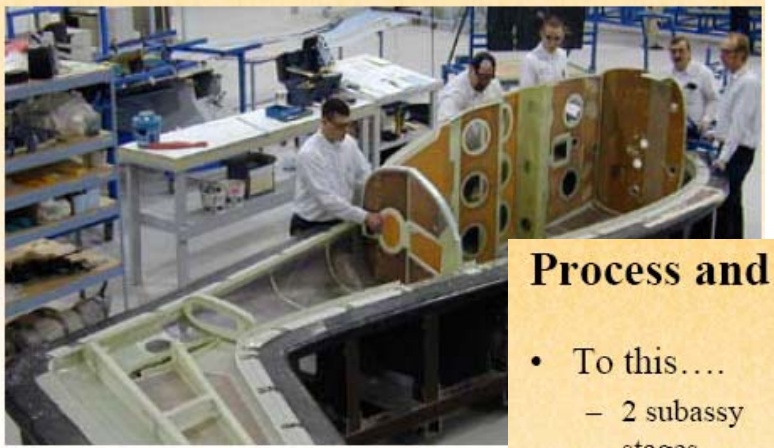
Process and Design Evolution

- As an example, our fuselage bonding process went from this….
  - 5 subassy stages
  - 2 complete tool sets
  - 5 initial cure oven runs per unit
  - 24 technicians on 3 shifts to produce 10 units per week



Process and Design Evolution

- To this….
  - 2 subassy stages
  - One tool set
  - Initial cure in tooling
  - 6 technicians on one shift to produce 10 units per week

Session 5: Manufacturing Implementation & Experience

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- **"Structural Metal Bonding at Cessna Aircraft" –** Jim Krone, Cessna
- **"Bonding from a Honeycomb Core Perspective" –** Hal Loken, Dupont
- **"Perspectives on Bonded Structures" –** Steve Forness, DER

Session 5: Manufacturing Implementation & Experience

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- Synopsis of current Cessna metal bond manufacturing practices based on forty years of experience
  - "Process control mentality" with activities for each step (phosphoric acid anodizing, bond primer application, doublers lay-up, bagging & tooling, cure, post-cure inspection)
  - Risk mitigation (rigorous training, process re-qualification, regular maintenance of facilities & equipment) and issues affecting rate
- Perspectives on bonding honeycomb sandwich panels
  - Synopsis of applications and examples of good & unacceptable bonded honeycomb failures
  - Bonding issues include honeycomb surface contamination and solvent exposure, followed by evaporation that leaves insoluble contaminates
- Complex bonding of large integrally-stiffened X-37 structures
  - Need for integrated efforts of design, materials, processing, tooling and inspection specialists to avoid unacceptable manufacturing defects

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Consensus opinion on issues in manufacturing implementation

- Surface preparation **90 VOTES**
  - Environmental cleanliness and control, contamination
- Cure control **40 VOTES**
  - Local variations in temperature and pressure, porosity
- Dimensional control (adhesive layer thickness) and Bonding Fixtures **39 VOTES**
  - Dimensional control of substrates, verification of fit
  - Application of preloads, bondline thickness control, defects
- NDI/quality control **32 VOTES**
  - Cured bondline evaluation, tracking outcome and bond process variables
- Scaling of processes to larger/smaller structures **26 VOTES**
  - Scaling of a developed process to a larger (smaller) structure
- General (Human Factors) **25 VOTES**
  - Equipment maintenance, training of personnel, documentation of process, handling/storage/disposal of materials
- Handling of the adhesive **13 VOTES**
  - Storage, aging
- Dispensing adhesive **4 VOTES**
  - Sequence and timing of bonding process steps, gap filling

MANY WERE UNCOMFORTABLE WITH THE CONCEPT OF RANKING

Session 6: Maintenance Implementation & Experience

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- **"Repair and Maintenance Implementation: Airline Experiences" -** Eric Chesmar, United Airlines & CACRC
- **"Certification of Adhesive Bonded Repairs for Environmental Durability" -** Andrew Rider, DSTO

Session 6: Maintenance Implementation & Experience

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- Airline problems and concerns with composites and bonding
  - SAE CACRC documents based on 1995 surveys
  - Structural design features that don't recognize the need to inspect and repair, leading to maintenance difficulties
  - Bonded repair problems related to surface contamination and pre-bond moisture (difficulty removing water, oil, hydraulic fluids)
  - Bagging and heat application difficulties for on-airplane repairs
  - Levels of training for technicians involved in bonded repairs
- RAAF DSTO use of service data in the certification of bonded repairs for environmental durability
  - Desire to move away from a failsafe approach for certifying repair to one where the bond is given full credit for maintaining a reliable life
  - Correlating wedge test results that meet rigorous acceptance criteria with the performance of repairs in service (tear-down inspections)
  - Development of surface analytical tools for pre-bond QC

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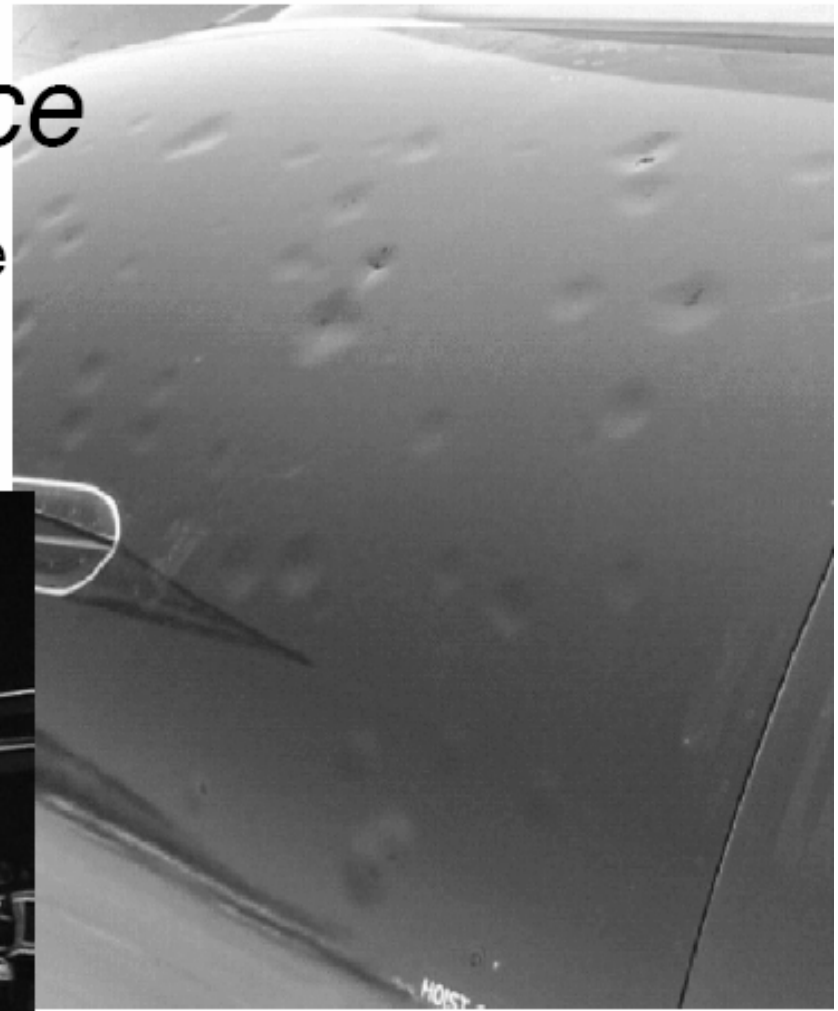
Airline Experience

- Airlines understand the concept of out-of-service for repair

E. Chesmar, UAL, 18 June 2004



Summary

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- Ric Abbott Thoughts
  - Excellent presentations for wide scope of applications
  - Agreed bond surface preparation, cleanliness and technician training are among most critical safety issues
  - Full-scale tests are needed to substantiate scaling issues
  - Recommended research on quality inspection procedures, damage tolerance analysis methods and test standards
- Safety management of bonded structures includes:
  - Qualify bond structural integrity and long-term durability
  - Coordinated design development and substantiation
  - Robust manufacturing and maintenance implementation
  - Continuous updates based on service experience