Composite Damage Tolerance and Maintenance Initiatives

Federal Aviation Administration

- *FAA/Industry Composite Safety and Certification Initiatives*
  - *Background*
  - *Safety management considerations*
- *Progress in Damage Tolerance and Maintenance Initiatives*
  - *FAA/EASA/Airbus/Boeing WG*
  - *Workshops, guidance & training*
- *Japan 2009 Workshop*
  - *Japan workshop objectives*
  - *Damage threats & inspection strategies*
  - *Damage tolerance & repair substantiation*
  - *Future needs in regulatory guidance, industry standards, and training*

Larry Ilcewicz
CS&TA
Federal Aviation Administration

June 4, 2009

Challenges for Composite Applications

- Lack of qualified resources for expanding applications
- Lack of practical standards and educational materials of relevance to industry applications
- Pressure to apply composites to new applications due to potential cost and weight savings
- Relatively high development costs not shared within the industry, putting pressures on some segments

A combination of the above issues pose safety risks that must be mitigated through pro-active efforts

- Recent FAA focus areas have been in areas of damage tolerance, maintenance and structural bonding

Ongoing FAA Composite Safety & Certification Initiatives

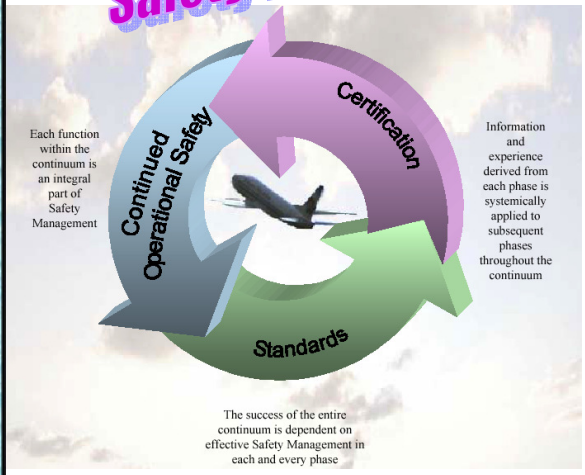
- Actively working with industry since 1999

Objectives

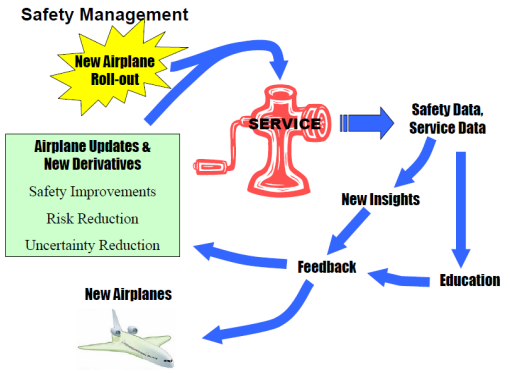
1) Work with industry, other government agencies, and academia to ensure safe and efficient deployment of composite technologies used in existing and future aircraft

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

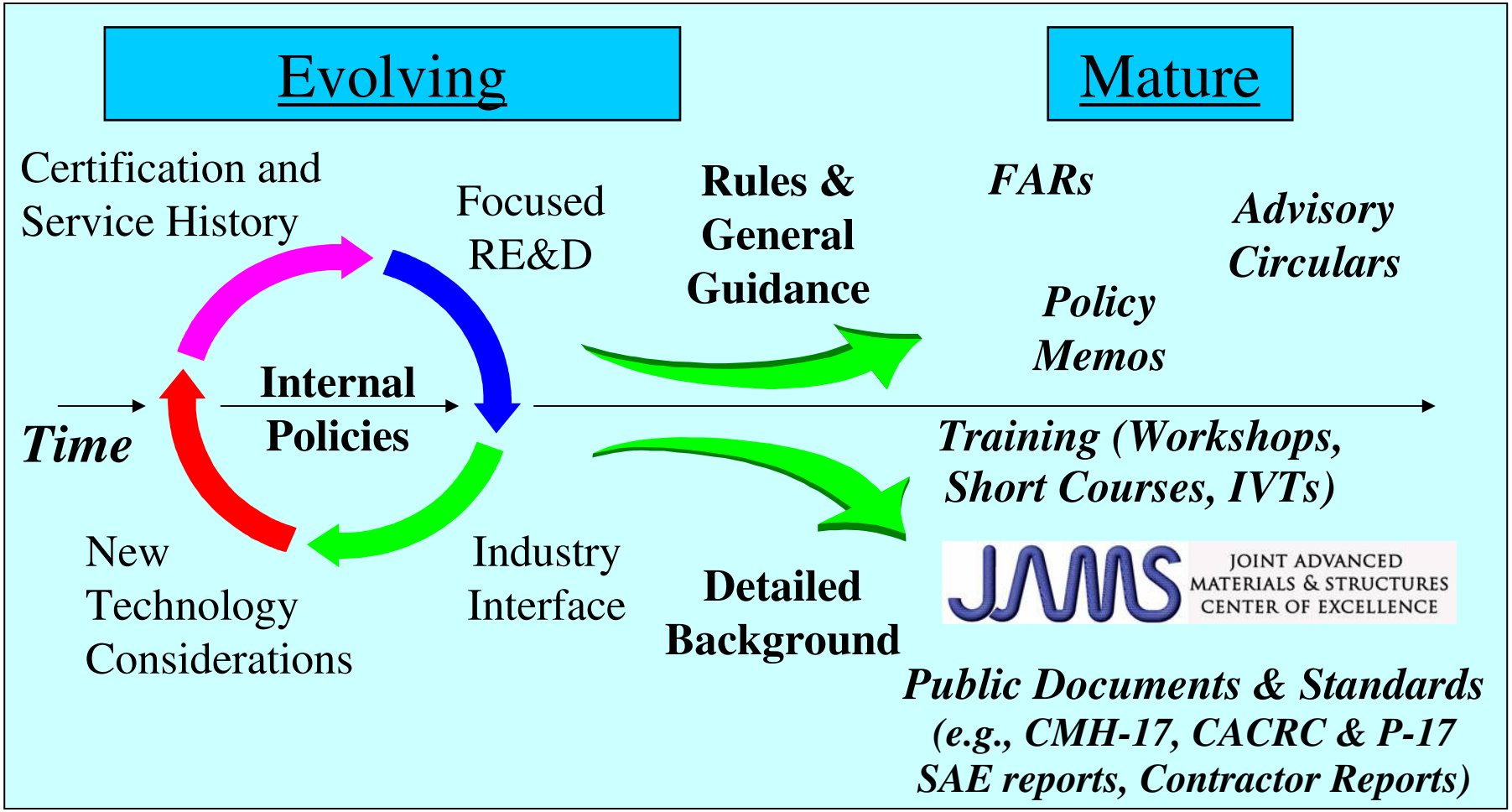
Approach Following Principles of Safety Management



- Safety management (airworthiness) Task Groups initiated within composite standards organizations



FAA Approach to Composite Safety and Certification Initiatives



Composite Technical Thrust Areas

Advancements depend on close integration between areas

Material Control, Standardization and Shared Databases

Damage Tolerance and Maintenance Practices
- Critical defects (impact & mfg.)
- Bonded structure & repair issues
- Fatigue & damage considerations
- Life assessment (tests & analyses)
- Accelerated testing
- Structural tear-down aging studies
- NDI damage metrics
- Equivalent levels of safety
- Training standards

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

Progress to Date
- 2 Advisory Circulars
- 6 Policy Memos
- 9 Workshops
- 3 Training Initiatives
- 3 Technical Reports
- CMH-17 Updates
- SAE CACRC Standard
- ~50 FAA R&D Reports

Flammability & Crashworthiness

Support to cabin safety groups

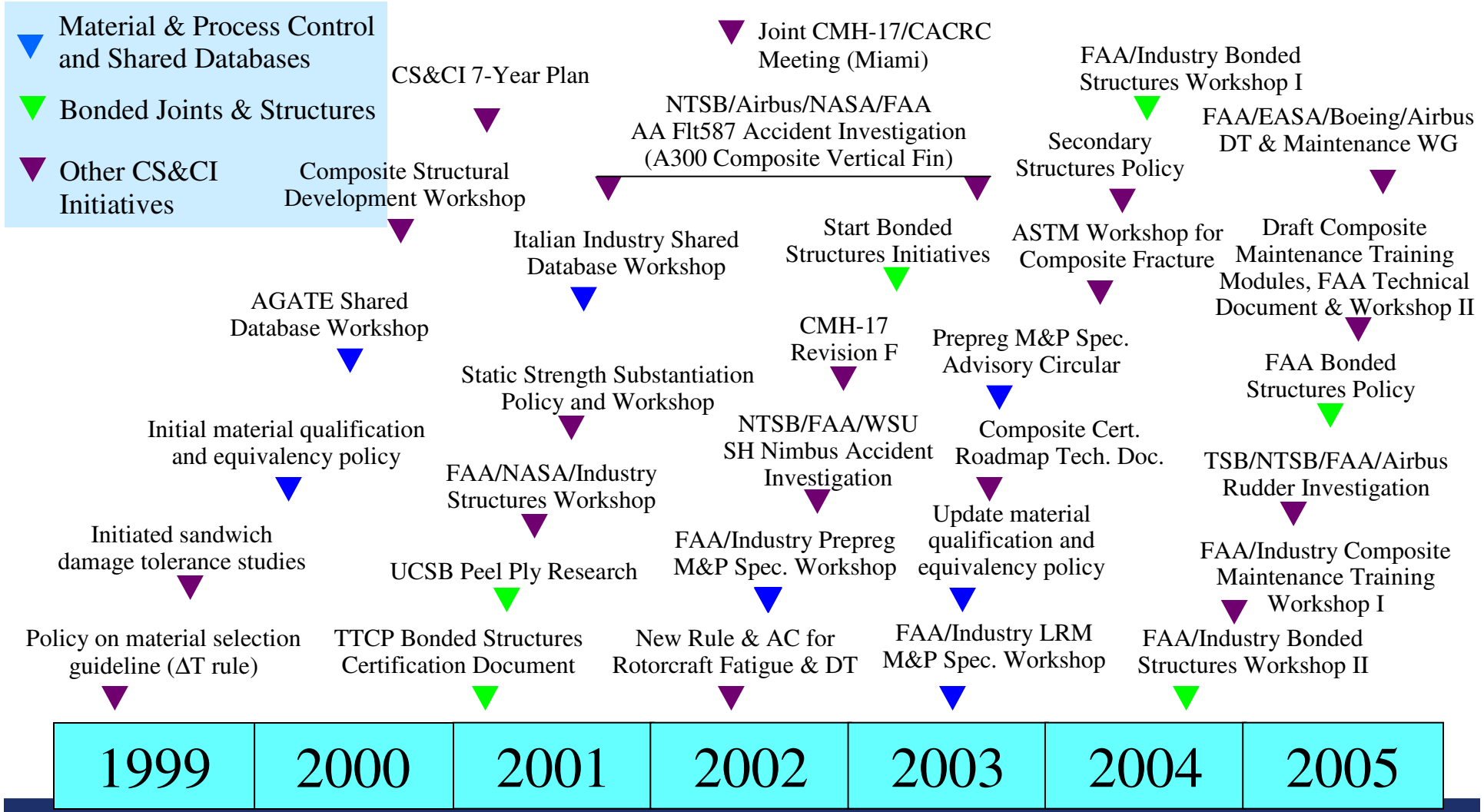
Bonded Joint Processing Issues

Advanced Material Forms and Processes

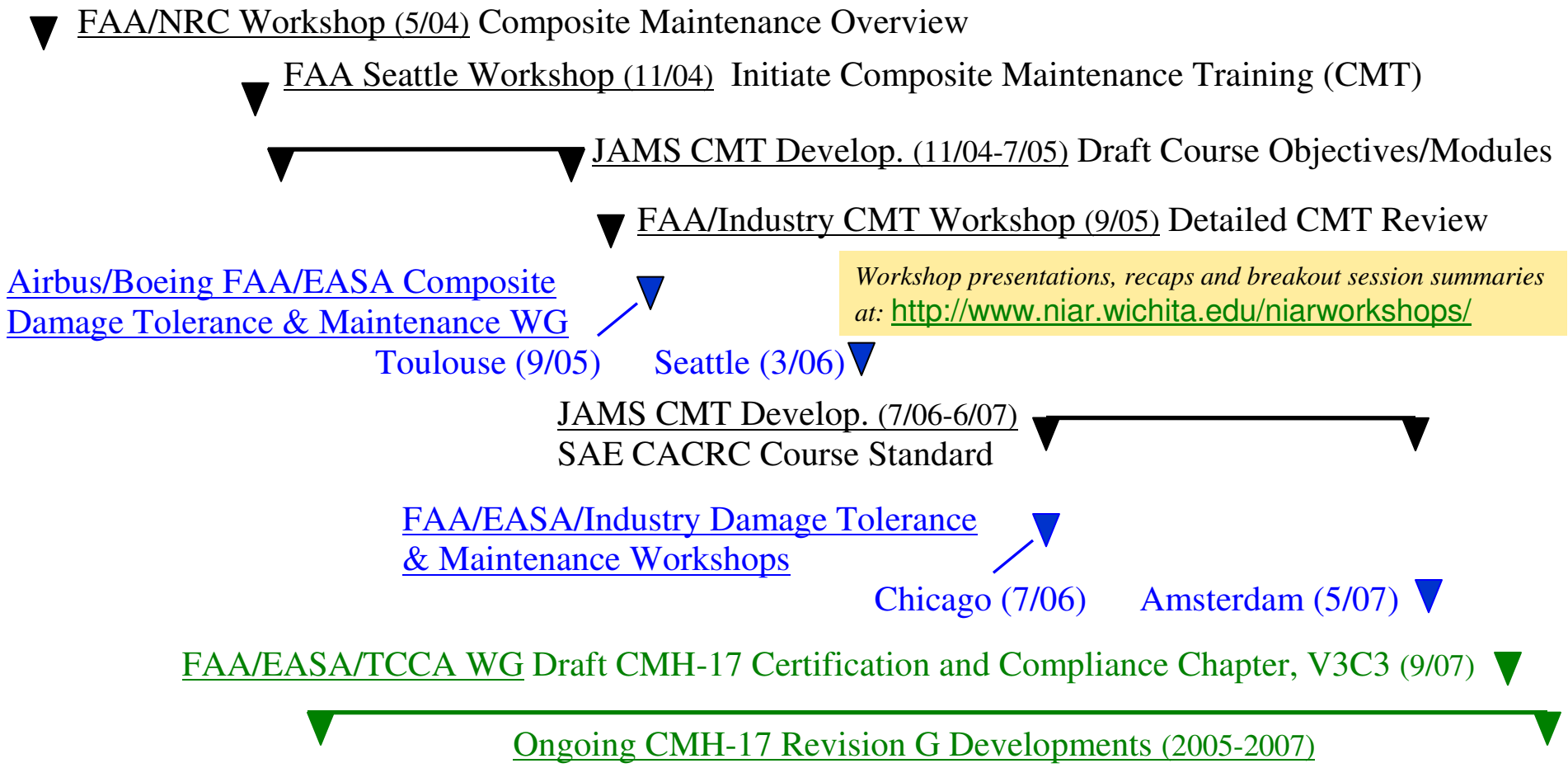
Significant progress, which has relevance to all aircraft products, has been gained to date

Past Milestones for Composite Safety & Certification Policy, Guidance & Training

CS&CI Background



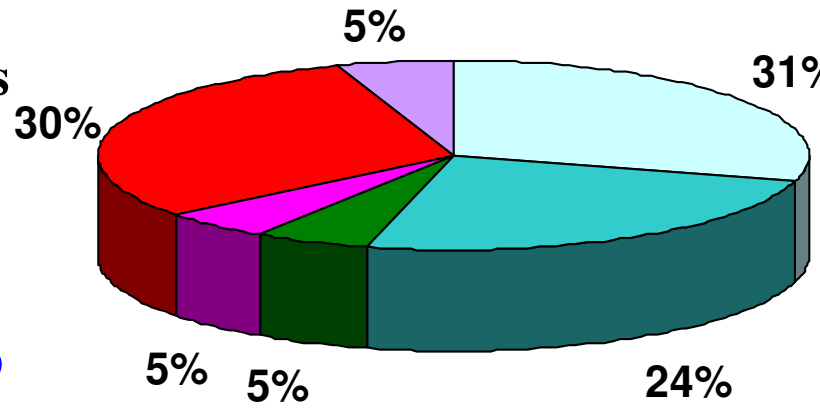
Recent Milestones for Composite Damage Tolerance and Maintenance Initiatives



Joint Efforts by Industry & Regulatory Experts to Standardize a Course on *Critical Composite Maintenance & Repair Issues*

- 2004: Initial workshops to define framework **(incl. course objectives on the key areas of awareness for engineers, technicians & inspectors)**
- 2005: 11 course modules drafted for workshop review
- 2006: Update modules and develop course standards with SAE CACRC
- 2007: Coordinated FAA/industry release of course standards
- 2008: Make course available to FAA/industry designees

Total Costs ~ $1500K (est. thru FY07)

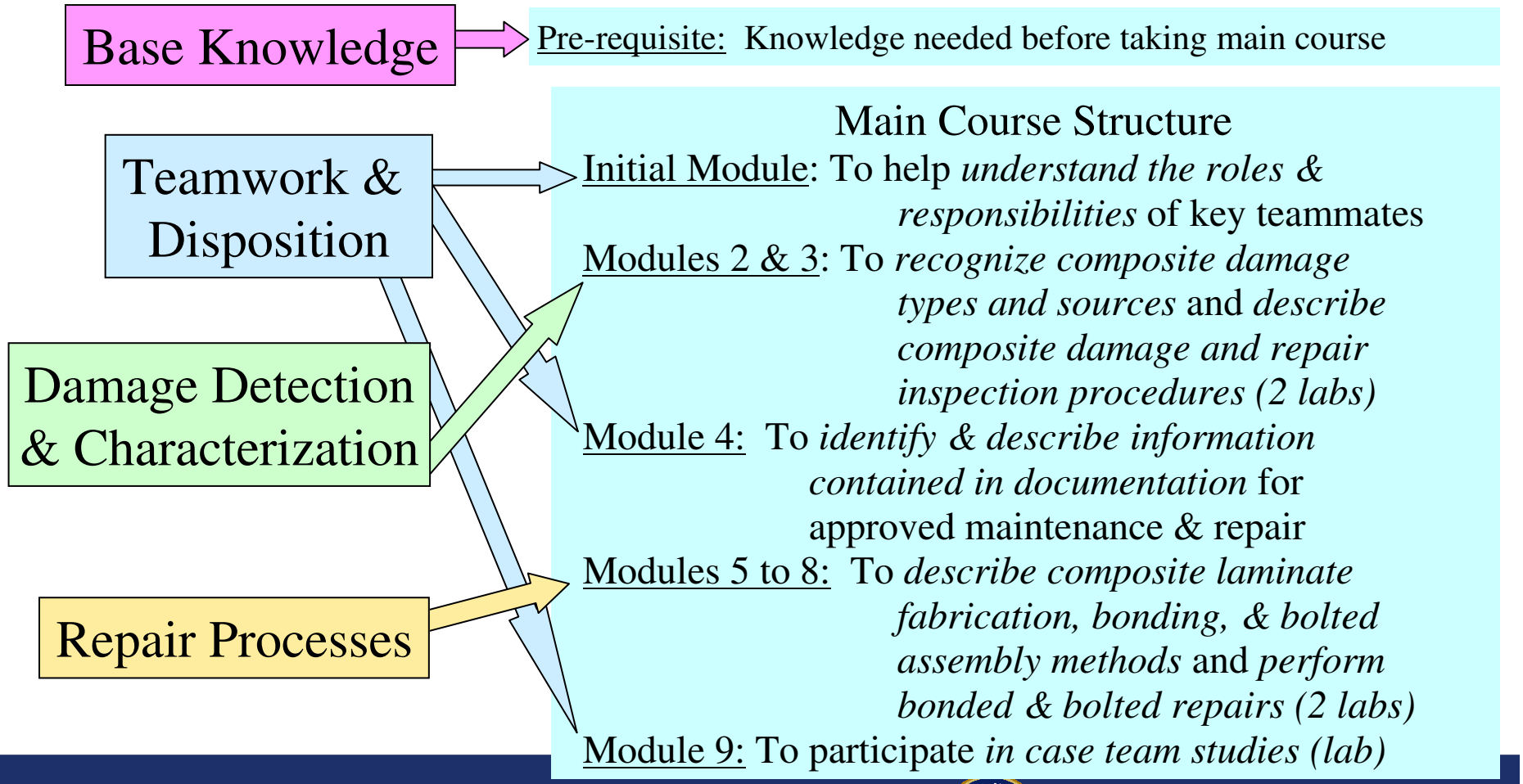


Training Development Costs: $900K

11/04 & 9/05 Workshop Costs: $525K

Composite Maintenance Awareness Course

Purpose: Course is intended to address aircraft safety & certification issues as opposed to building specific skills among team members



Advanced Composites Education

CMT Online Discussion (with Subject Matter Experts)

Week One: Skills	124	124

A new technician has been added to a maintenance and repair operation group. On the first day, his supervisor points out in the employee handbook the following statement:

"All aspects of composite maintenance and repair are interlinked such that each member of a repair team should understand his/her role and have the training needed to properly complete their tasks."

He is puzzled about what this means because he had the impression that he was there to repair secondary structure only, and needn't worry about 'interlinking'.

How do you respond to his reaction to the statement?

Week One: Slight Skin Damage	195	195

An aircraft shows a slight indentation on its skin, discovered during a routine walk-around of an aircraft. You note that the indent is observable up to 20 feet away, but looks, to the layman, to be minor. As a dedicated airline employee, you recognize the importance of getting the aircraft back into service quickly. Describe how you might react differently if the damage is on a metal versus composite material component.

FAA/EASA/Airbus/Boeing WG for Damage Tolerance and Maintenance

Objectives

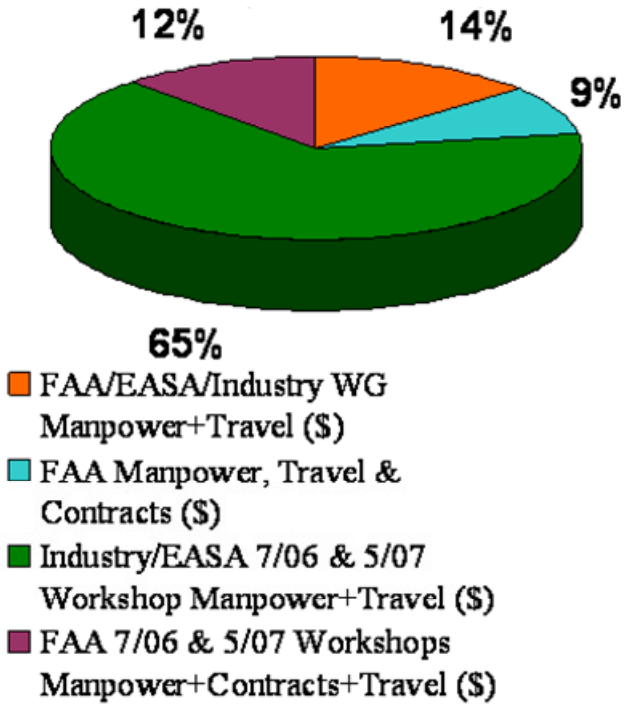
1. Agree on critical technical issues and areas of safety concern for damage tolerance & maintenance of composite structure on transport aircraft.
2. Identify key similarities and differences in methods used to substantiate damage capability for transport aircraft composite structures.
3. Identify the key elements necessary to substantiate maintenance inspection and repair procedures for composite aircraft structures.
4. Identify related content needed to update appropriate approved source (OEM) documentation (MPD, SRM, etc.) focused on field safety issues.
5. Identify related content needed to update the CMH-17 Damage Tolerance and Supportability chapters and the FAA composites maintenance training standards, as appropriate.
6. Identify areas for safety-related standardization of composite damage tolerance & maintenance and related research needed in the future.

Background for WG Initiative on Damage Tolerance & Maintenance Guidance

- FAA/EASA/Airbus/Boeing Working Group chartered in 2005 to discuss safety issues associated with expanding application of composites to transport aircraft
  - Focus on industry practices for damage tolerance & maintenance
- Expanded to include other (~250) industry technical focal in two FAA/EASA/Industry DT and Maintenance Workshops
  - Chicago, IL (July 19-21, 2006)
  - Amsterdam, Netherlands (May 9-11, 2007)

Total Costs = $1500K

(est. thru FY08)



2006 and 2007 FAA Composite Damage Tolerance & Maintenance Workshop

	Wednesday, July 19	Thursday, July 20	Friday, July 21
1st Hour		**Session 2*** Substantiation of Structural Damage Tolerance	**Session 6** Technical Breakout Sessions (*Separate *working meetings covering technical subjects from Sessions 2 - 5*)
2nd Hour			
Break (15 min.)			
3rd Hour		**Session 3*** Structural Test Protocol	**Session 7** Breakout Team Summary Recap/Actions/Closure/Adjourn
4th Hour			
Lunch (1 Hour)			
5th Hour	FAA Initiatives Safety Management Airbus/Boeing/EASA/FAA WG Maintenance Training Update	**Session 4*** Substantiation of Maintenance Inspection & Repair Methods	
6th Hour			
Break (15 min.)			
7th Hour	**Session 1** Applications & Service Experiences	**Session 5*** Damage/Defect Types and Inspection Technology	
8th Hour			

~150 Participants

Chicago, IL, USA
July 19-21, 2006

	Wednesday, May 9	Thursday, May 10	Friday, May 11
1st Hour	**SAE Commercial Aircraft Composite Repair Committee** Overview of Progess & Plans	**Session 1 Applications & Field Experiences** *(continued)* Service History of Composite Structure Service Damage & Reliability of Repairs	**Session 5* Field Inspection and Repair QC** Test Standards & Inspector Qualifications Reliable NDI Technology Advances Material & Process Controls
2nd Hour			
Break (15 min.)			
3rd Hour	**Airbus and Boeing** Perspectives on Safe Industry Practices	**Session 2* Damage Tolerance** Design Criteria & Objectives Structural Test Protocol	**Session 6** Technical Breakout Sessions (*Separate *working meetings covering technical subjects from Sessions 2 - 5*)
4th Hour	**Airbus & Boeing (continued)** SAE CACRC Active Task Group Reports		
Lunch (1 Hour)			
5th Hour	**SAE CACRC** Active Task Group Reports	**Session 3* Damage in Sandwich Construction** Fluid Ingression Growth Mechanisms Analysis & Accelerated Tests	**Session 7 Breakout Team Summary Recap/Actions/Closure/Adjourn**
6th Hour	**FAA & EASA Initiatives**		
Break (15 min.)			
7th Hour	**FAA & EASA Initiatives** *(cont.)* Recent Progress/Safety Management	**Session 4* Repair Design and Processes** Repair Limits Design Criteria & Process Guidelines Structural Substantiation	
8th Hour	**Session 1 Applications & Field Experiences**		

~110 Participants

Amsterdam, Netherlands
May 9-11, 2007

Future milestones for Composite Safety & Certification Policy, Guidance & Training

Progress in Guidance & Awareness Training

Release CMH-17 Revision G

- *Advances in statistics, test methods and data reduction protocol*
- *Major Volume 3 re-organization*
- *New Volume 6 (Sandwich)*
- ***New certification & compliance chapter*** → 6 Hour Tutorial developed in 2008
- *New crashworthiness chapter*
- *New safety management chapter*
- ***Updates to damage tolerance & maintenance*** → FAA/EASA/Airbus/Boeing WG Inputs - Primary Deliverables

Implement Composite Maintenance Awareness Course

High Energy Blunt Impact Awareness

Release AC 20-107B (Composite Aircraft Structure)

NCAMP shared databases and specifications (CMH-17, SAE AMS)

Additional composite maintenance guidance

Composite damage tolerance guidance & policy

Guidance for new material and processes

Crashworthiness AC

2008	2009	2010	2011	2012

Damage Tolerance and Maintenance Updates to CMH-17 for Revision G

Chapter 12 – Damage Resistance, Durability, and Damage Tolerance

- Major revisions to clarify regulatory requirements and guidance, including approaches and issues to be covered by AC20-107B (damage categories)
- New content addressing typical industry practice for design criteria and substantiation, based on findings from ***FAA/EASA/Airbus/Boeing WG and previous workshops for Damage Tolerance and Maintenance***
- Enhanced discussions of deterministic and probabilistic structural damage tolerance compliance approaches
- Expanded discussions regarding inspection program issues, including development of inspection programs, Environmental/Accidental Damage (EDR/ADR) approaches, fleet leader programs, and POD studies.
- Substantial new content regarding durability and damage growth under repeated loading, including protocol for determining load enhancement factors for repeated-load substantiation.

Damage Tolerance and Maintenance Updates to CMH-17 for Revision G (cont.)

Chapter 13 – Defects, Damage, and Inspection

- New chapter to address basic descriptions of defect/damage types and their sources, and composite-related inspection methods
- Populated primarily with existing content from other chapters, with some new examples

Chapter 14 – Supportability, Maintenance and Repair

- Major reorganization to provide improved clarity and to broaden focus to the entire maintenance process
- Revised historical perspective, including recent assessments of service experience
- New content addressing safe maintenance considerations, maintenance documents and training needs
- New content discussing current industry practice with design criteria and substantiation, based on findings from ***FAA/EASA/Airbus/Boeing WG and previous workshops for Damage Tolerance and Maintenance***

Draft AC 20-107B: Composite Aircraft Structure

1. Purpose
2. To Whom This AC Applies
3. Cancellation
4. Regulations Affected
5. General
6. Material and Fabrication Development
7. Proof of Structure – Static
8. Proof of Structure – Fatigue and Damage Tolerance
9. Proof of Structure – Flutter
10. Continued Airworthiness
11. Additional Considerations

Appendix 1

Appendix 2

Appendix 3 (EASA CS 25.603, AMC No. 1, Para. 9 and No. 2: *Change of Material*)

AC 20-107A 11 pages
AC 20-107B 36 pages
(new sections highlighted by blue)

Content increased from 0.5 to 4.5 pages

Content increased from 1 to 3.5 pages

Content increased from 1 to 8 pages

2.5 pages

Content increased from 1.25 to 5 pages

Scheduled release 9/09

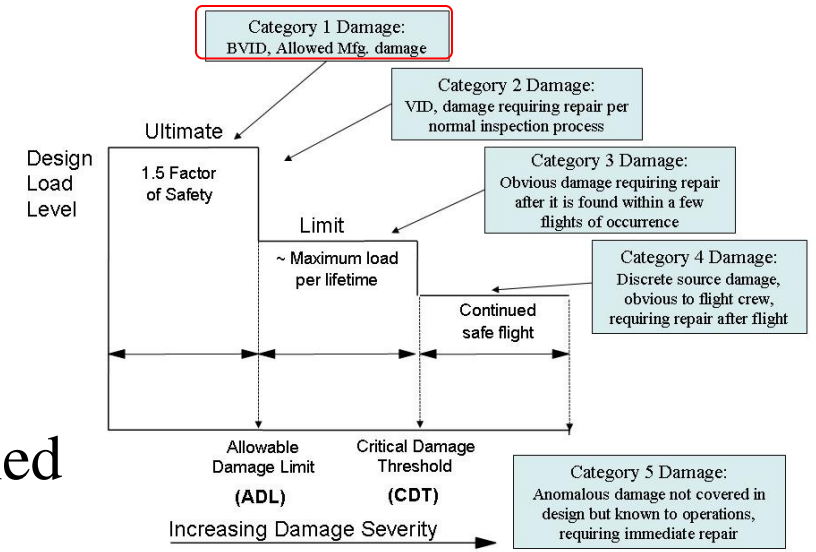
3.5 pages

Categories of Damage (defined for purposes of communication, e.g., workshops, AC 20-107B)

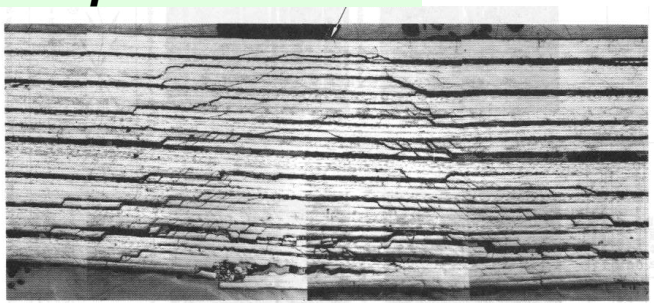
Category	Examples
Category 1: Allowable damage that may go undetected, or allowable mfg defects	**BVID, scratches, gouges, and allowable mfg. defects that retain ultimate load for life**
Category 2: Damage with sufficient residual strength to be detected by scheduled or directed inspection	**VID (ranging small to large), deep gouges, mfg. defects/mistakes, major *local* heat or environmental degradation that retain limit load until found**
Category 3: Obvious damage detected within a few flights by operations focal	**Damage obvious to operations in a "walk-around" inspection or loss of form/fit/function that retain *near* limit load strength until found by operations**
Category 4: Discrete source damage known by pilot to limit flight maneuvers	**Damage in flight from events that are obvious to pilot (rotor burst, bird-strike, lightning, severe in-flight hail)**
Category 5: Severe damage created by anomalous ground or flight events	**Damage occurring due to rare service events or to an extent beyond that considered in design, which must be reported by operations for immediate action**

Category 1 Damage

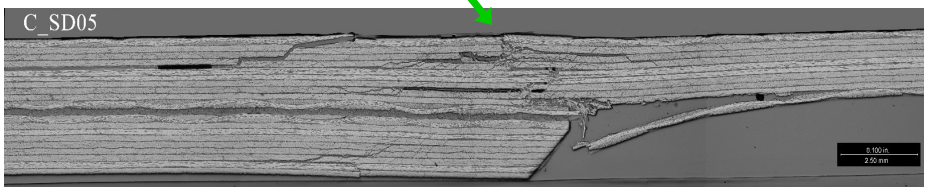
- Allowable damage
- Small and difficult to detect
- May go undetected
- Ultimate load capability is maintained
- Good for lifetime of airframe
- Examples include: BVID, small delaminations, porosity, small scratches, small gouges, allowable defects



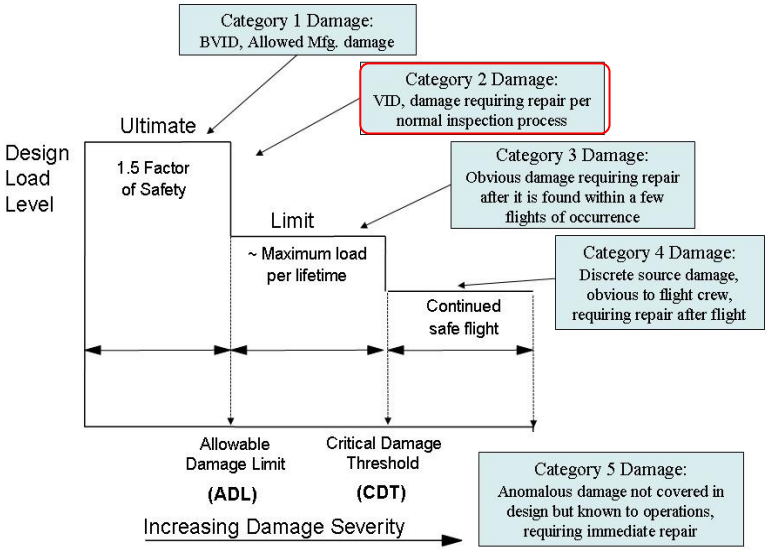
X-sec of BVID at Skin Impact Site



X-sec of BVID Impact at Flange to Skin Transition



Category 2 Damage



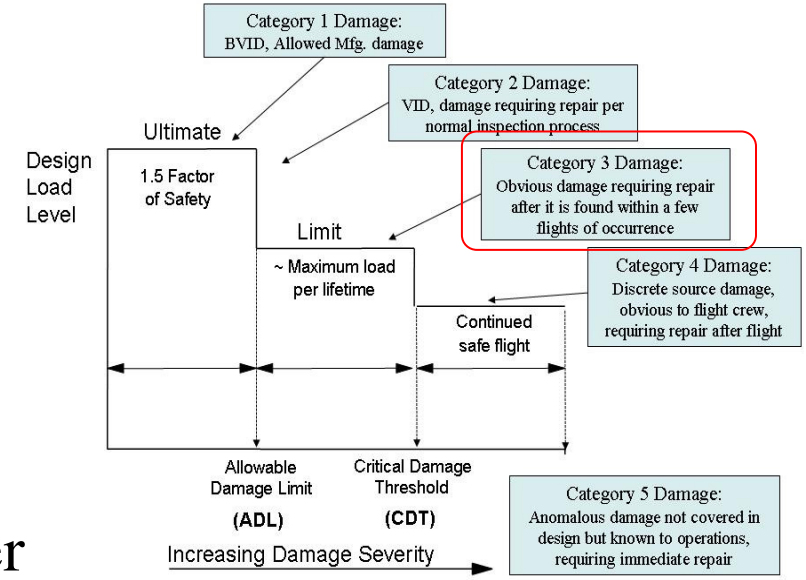
- Small damage
- Detectable via scheduled or directed inspection
- Capability between Limit & Ultimate
- Needs to be repaired when found
- Examples include VID, deep gouges, deep scratches, small delamination.

Exterior Skin Damage

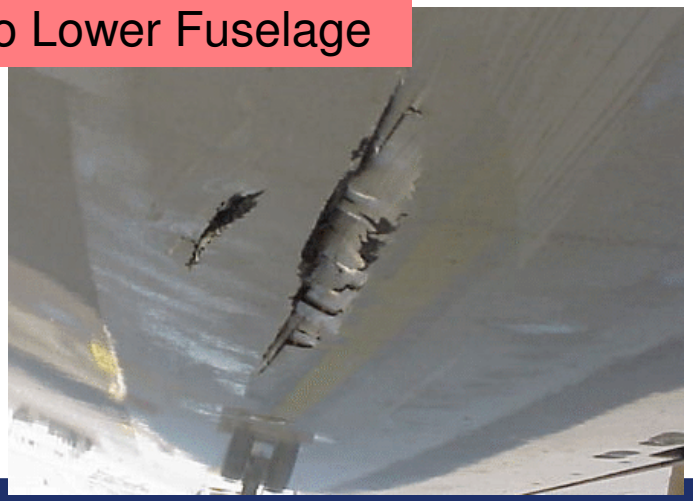
Interior Blade stringer Damage

Category 3 Damage

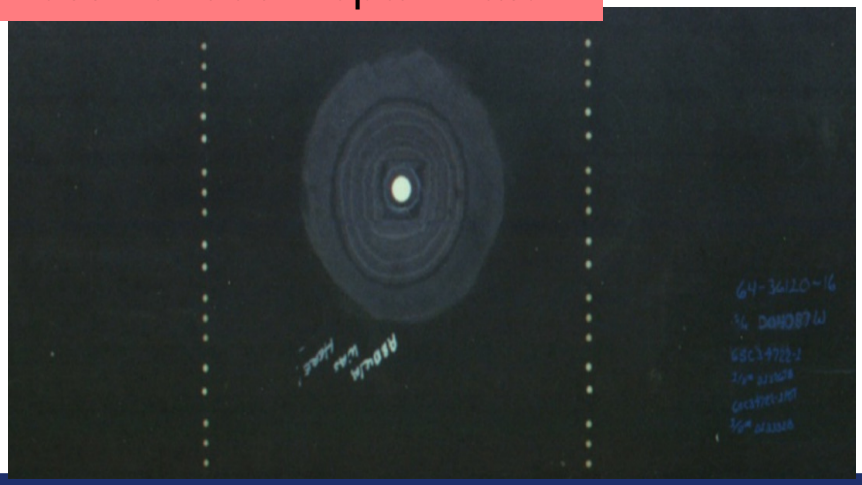
- Visible damage
- Detected within a few flights
- Capability is *near* limit load
- Needs to be detected quickly and immediately repaired
- Examples include large VID and other obvious damage that will be caught during walk around.



Accidental Damage to Lower Fuselage

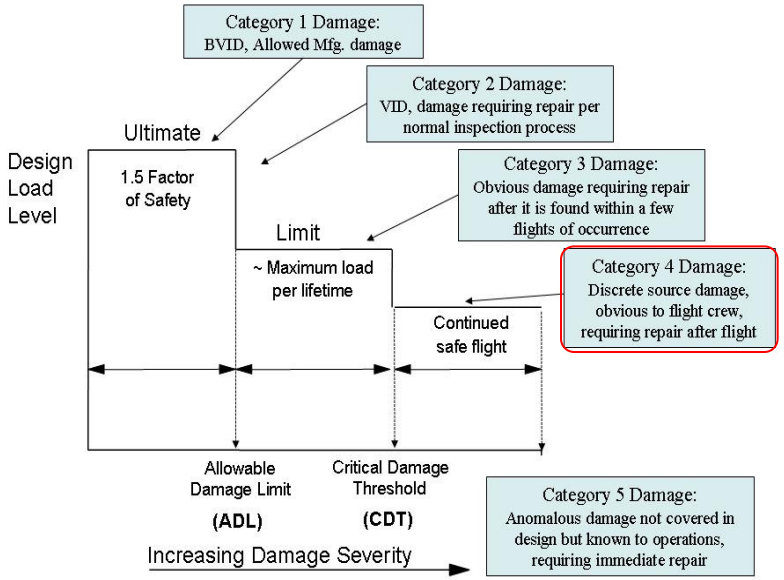


Lost Bonded Repair Patch



Category 4 Damage

- Discrete Source damage
- Bounded design criteria
- Capability near Limit (specified "get home" loads)
- Examples include" rotor burst, design bird strikes, exploding MLG or NLG tires, sever in flight hail



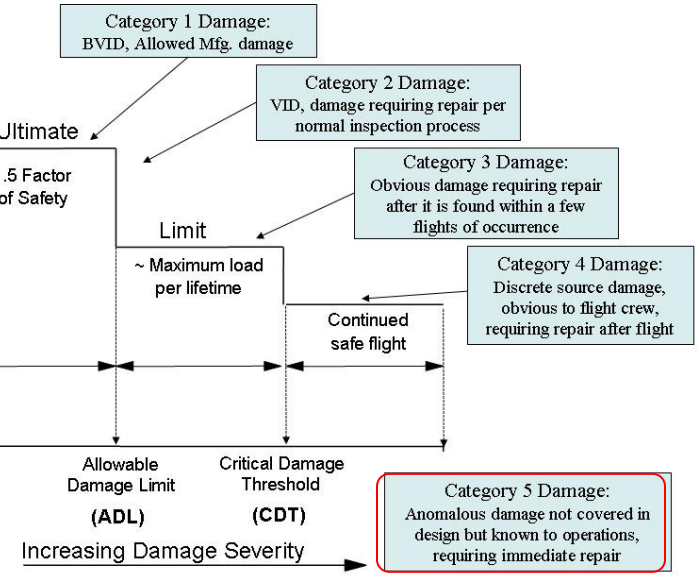
Rotor Disk Cut Through the Aircraft Fuselage Belly and Wing Center Section to Reach Opposite Engine

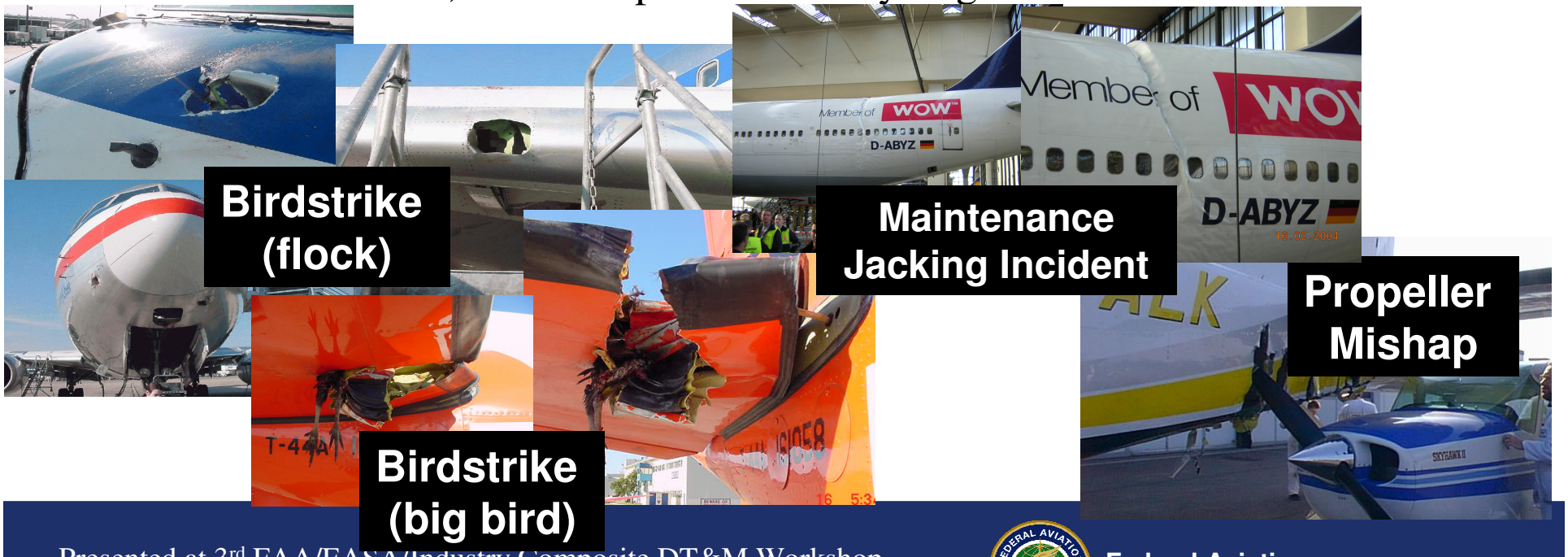
Severe Rudder Lightning Damage

Category 5 Damage

- Severe damage
- Unbounded "Rare Event"
- Capability may be below limit load
- Beyond design considerations

  e.g. severe collisions with service vehicles, flight overload conditions, severe impacts with very large birds or flocks of birds





Para. 8: Proof of Structure – Fatigue/Damage Tolerance

8a. Damage Tolerance Evaluation

(2) Structural tests for damage growth, *cont.*

– Figures from 8a. (2)

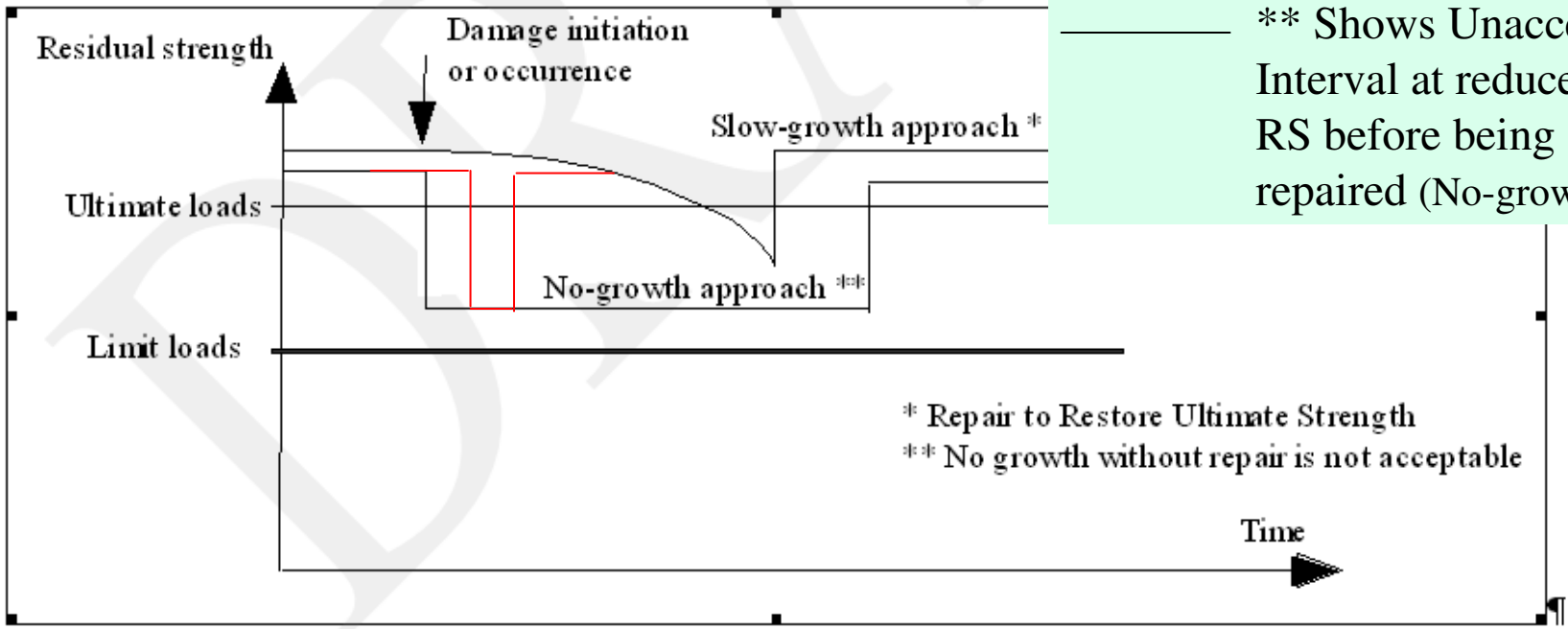


Figure C. Schematic diagram of residual strength versus time illustrating an undesirable state of significant accidental damage that is left in the structure without repair for too long of time.

——— Shows Acceptable Interval at reduced RS before being repaired (No-growth case).

——— ** Shows Unacceptable Interval at reduced RS before being repaired (No-growth case).

FAA Technical Paper on Awareness & Reporting of Significant Impact Incidents Involving Composite Airframe Structures

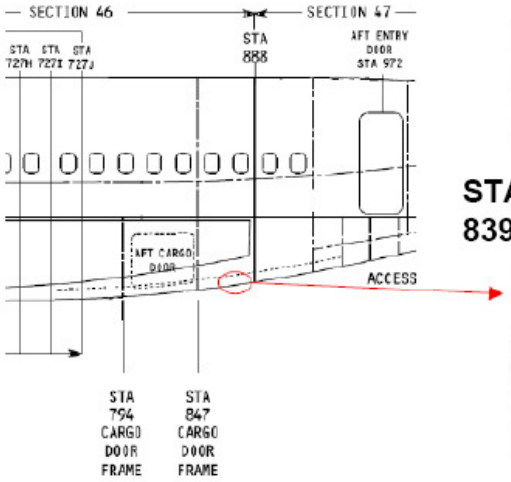
(effort initiated by FAA/EASA/Airbus/Boeing WG)

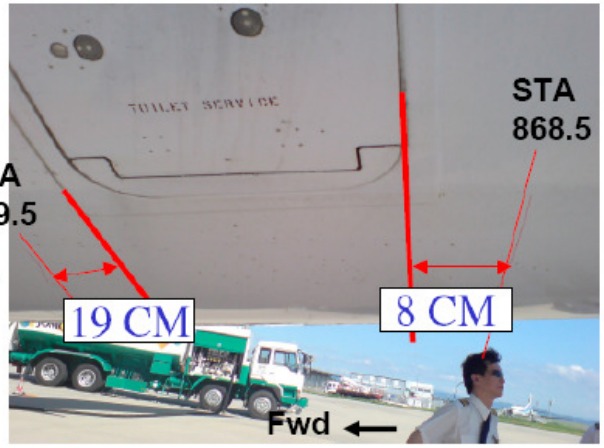
Not all damaging events (e.g., severe vehicle collisions) can be covered in design & related maintenance practice

- Safety must be protected for severe accidental damage outside the scope of design (defined as Category 5 damage) by operations reporting
- Awareness and a "No-Blame" reporting mentality is needed
- Category 5 damage requirements:
  a) damage is *obvious* (e.g., clearly visual) and *reported* &/or
  b) damage is *readily detectable* by required pre-flight checks &/or
  c) the *event* causing the damage is otherwise *self-evident* and *reported*
  e.g., obvious, severe impact force felt in a vehicle collision

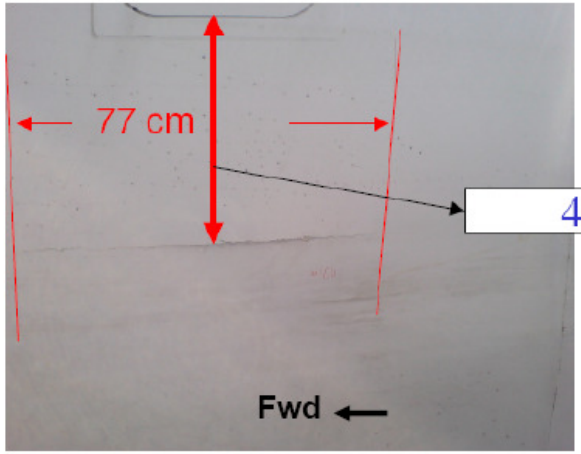
Damage is not always visually obvious…
e.g., service vehicle collision with fuselage

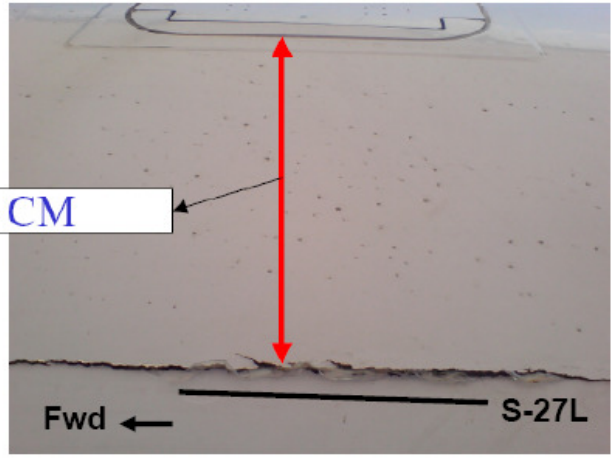
even in metallic Structures as shown here.





How would such high energy manifest itself in damage to a composite fuselage ??





Problem Definition: What is meant by a "Self-Evident Event" has different meaning to different people?

1) Damage can be classified as visually obvious to ground service personnel involved in the damaging event

2) Damage will be detected by obvious loss of structure form, fit and function in required pre-flight checks.

3) Damage will be reported for conditional inspection because event causing damage is very "self-evident" to those involved (e.g., impact force felt in vehicle collision).

1) and 2) Likely found by pilots or line maintenance personnel focused on safe operation

3) ***Likely realized by operations or service personnel focused on ?$#/@?***

Must Eliminate Misconceptions…..

- "I don't see any damage so it must be OK"
- "It's not my job to report it"
- "It looks fine to me"
- "Don't worry, it's way over designed"
- "I can't report it or I will lose my job"

Solution Path for Vehicle Collisions Classified as Category 5 Damage

Layers of Safety Management are needed

- Damaging events outside the scope of those considered in design must be of a magnitude that ensures reporting *(i.e., design to sufficient impact damage resistance and damage tolerance)*
- Simple training is needed to ensure the *essential "reporting" role of operations and aircraft service personnel without blame*
- Source documentation and training for line maintenance, inspectors and structural engineers needed to disposition such events to ensure *proper application of conditional inspection and repair procedures*

1) Impact Event is Reported	Awareness by ground crews, service crews, air crews, and/or ramp personnel
2) Line Maintenance Ensures Proper Evaluation	Line and Dispatch personnel trained to seek skilled disposition assistance
3) Engineering Evaluation & Repair (if necessary)	a. Engineers, OEM, technicians, inspectors with proper training b. Allowable Surface Damage Limits do **NOT** apply c. Initial inspection is to detect **MAJOR** internal damage

3rd Composite Damage Tolerance and Maintenance Workshop Objectives

- To promote damage tolerance engineering practices that facilitate safe & practical maintenance procedures
- To improve how structural substantiation of damage
- To use findings from the field to help improve damage tolerance & maintenance practices in the future
  - *Structural safe-life, damage tolerance, design criteria, inspection, repair, structural analysis and approved data all benefit from good communications between OEM, operations and maintenance personnel*

This Workshop is Intended to Gain Real-world Insights On Damage Tolerance & Maintenance From Experts in the Field

Workshop Session 1
Applications and Service Experiences

- Layers of safety management needed for continued airworthiness have direct links with acquired knowledge from OEM developments, maintenance experiences & operations awareness
  - Limits of damage tolerance design criteria & related maintenance procedures must be understood by operations (+ their necessary role)

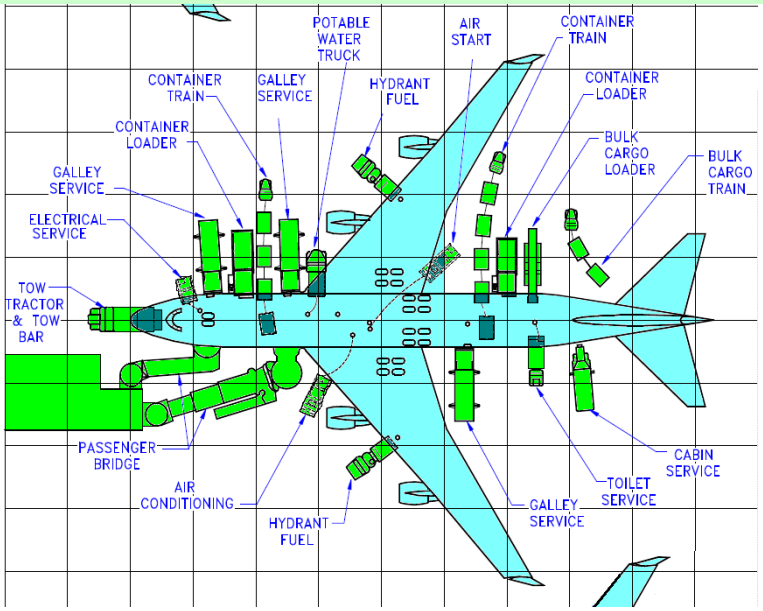
Air Transat Flight 961

- Four presentations for Tokyo, Japan
  1. Japan Airlines made this Workshop possible
  2. Airbus is sharing essential safety data on a rare composite growth phenomena (root cause & eng. solution) not available in previous forum
  3. Lufthansa has been a leader supporting the SAE CACRC and FAA Safety Initiatives, with years of experience essential to standardization
  4. Boeing is showing leadership for the future in sharing details related to expanded applications of composites to primary airframe structure

Workshop Session 2
Damage Threats & Inspection Strategies

- Primary composite threats relate to discrete source events, accidental impact and environmental damage
  - Rare cases of small defect growth
- Various impact threats pose complexities that don't simply lead to a universal impact standard
  - Inspection complicated by dependence on details of the impact event
- Three presentations for Tokyo, Japan
  1. Unique considerations for sandwich designs (extensive Airbus experience)
  2. Environmental threats can differ depending on the active routes and certain times of the year, e.g., Japan lightning strike experiences
  3. How to manage various threats and unify the layers of safety management involving design, maintenance and operations

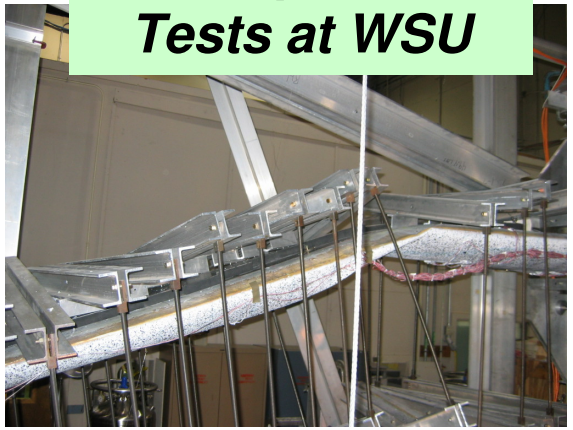
Impact Threats & Vulnerabilities



Workshop Session 3
Damage Tolerance & Repair Substantiation

- Composite damage tolerance and repair substantiation data/analysis are generally not publicly available
  - Highly dependent on design details
  - Semi-empirical, expensive & proprietary

Starship Canard Tests at WSU



- Five presentations for Tokyo, Japan
  1. Boeing experience in the details of ***bolted*** repair design and analysis
  2. Wichita State University practical research on structural analysis and test protocol, which links to a major development/certification cost center
  3. Years of NASA experience supporting the development and application of composite technologies to all types of commercial aircraft applications
  4. Airbus experience in the details of ***bonded*** repair design and analysis
  5. CACRC leadership for a path forward in structural substantiation from secondary to primary structures with differing levels of damage

Workshop Session 4: *Regulatory Guidance, CACRC Standards and Related Training*

- Guidance advancements, standard developments and training initiatives rely on *proactive, joint efforts by government and industry specialists*
  - Realistic focus needed to meet most critical needs
- Five presentations for Tokyo, Japan
  1. AC 20-107B has added definitive guidance related to subjects covered in this workshop
  2. United has been a leader supporting the SAE CACRC and FAA Safety Initiatives, with years of experience essential to standardization
  3. Boeing and Airbus are key teammates for expanding practical standards that enable more efficient composite maintenance practices
  4. Safety concerns exist for those organizations that believe they can reverse engineer bonded composite aircraft structure
  5. Practical training is needed to educate the existing workforce for expanding composite applications

Workshop Breakout Sessions

- Four parallel sessions to be performed during Friday afternoon and recapped with the full group before workshop closure
- Some presentation by leaders will initiate the discussion but the time should be well spent depending on participant interests
  - Allowing workshop participants that didn't get a chance to present the time to express their views
  - Leaders instructed to allow more time for technical areas of discussion that were truncated during the others sessions
- Please let your voice be heard
  - We are all limited in composite skills by our past experiences
  - What may be trivial to an individual is educational to those not familiar with a particular detail of the technology
  - Safety management starts with open communication

Summary and Recommendations

- Additional industry support is needed to implement *Composite Safety & Certification Initiatives*
  - Mitigate the safety risks of rapidly expanding applications without sufficient workforce guidance and training
  - Composite standards orgs. need ***the right volunteer experts***
  - Practical training per a cost-efficient and complete ***set of composite courses with working knowledge***
- Near-term focus on emerging operational safety threats
  - Guidance, policy and training for composite damage tolerance and maintenance
  - Levels of safety management are needed to properly address the emerging threat from critical accidental damage threats not covered in design (e.g., operations awareness & reporting)
  - Japan Workshop provides an essential industry forum