Composite Damage Tolerance and Maintenance Safety Issues

Federal Aviation Administration

- *Background*
  - *Composite Safety and Certification Initiatives*
  - *2006 Chicago Workshop*
- *Damage threat assessment*
  - *Categories of damage*
  - *Structural substantiation*
- *Inspection and repair*
- *Safety Management*
  - *Role of CACRC & CMH-17*

Larry Ilcewicz
CS&TA
Federal Aviation Administration

May 9, 2007

Ongoing Composite Safety & Certification Initiatives*

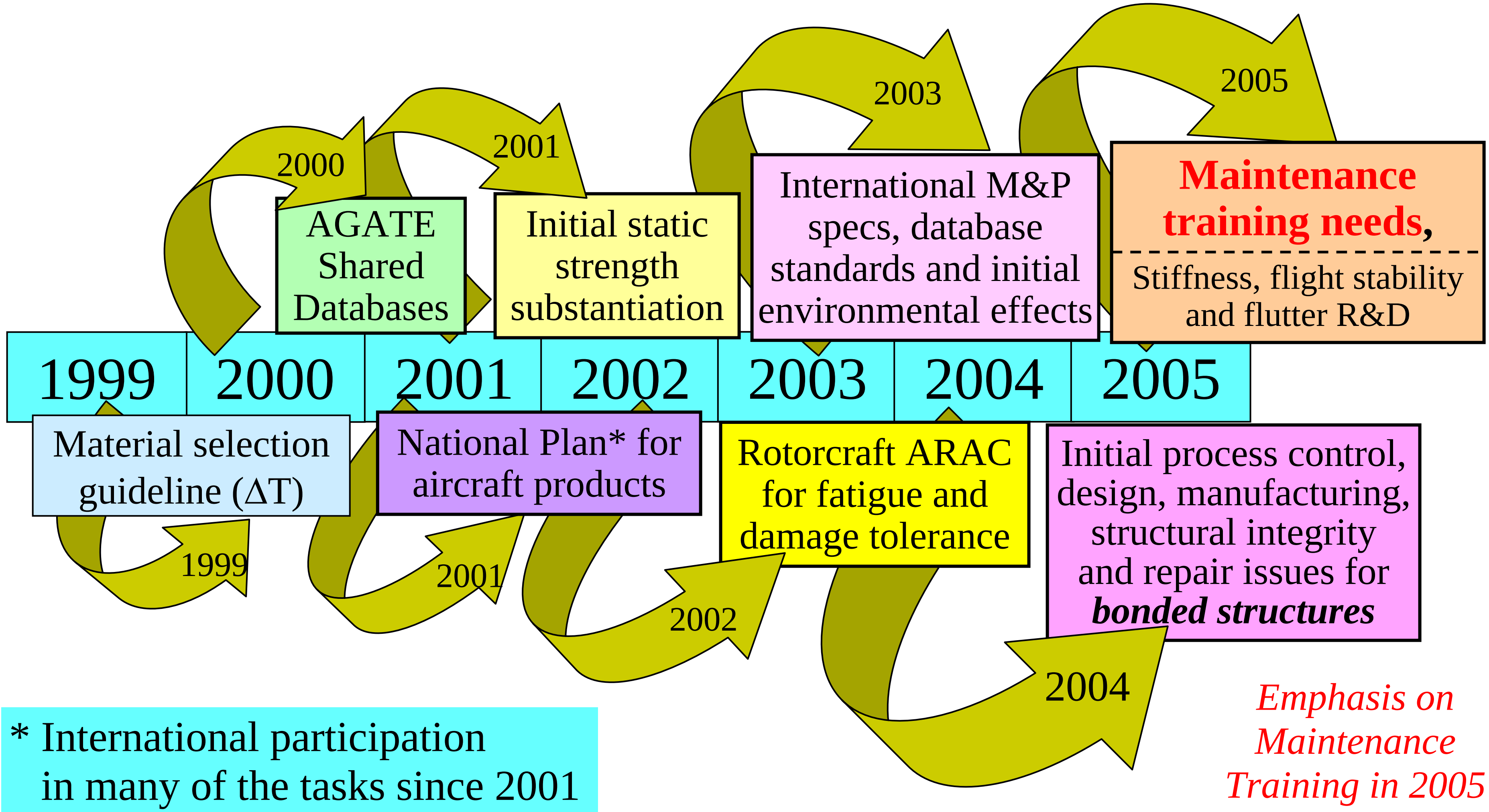
Objectives

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

** Efforts started in 1999 to address issues associated with increasing composite applications*

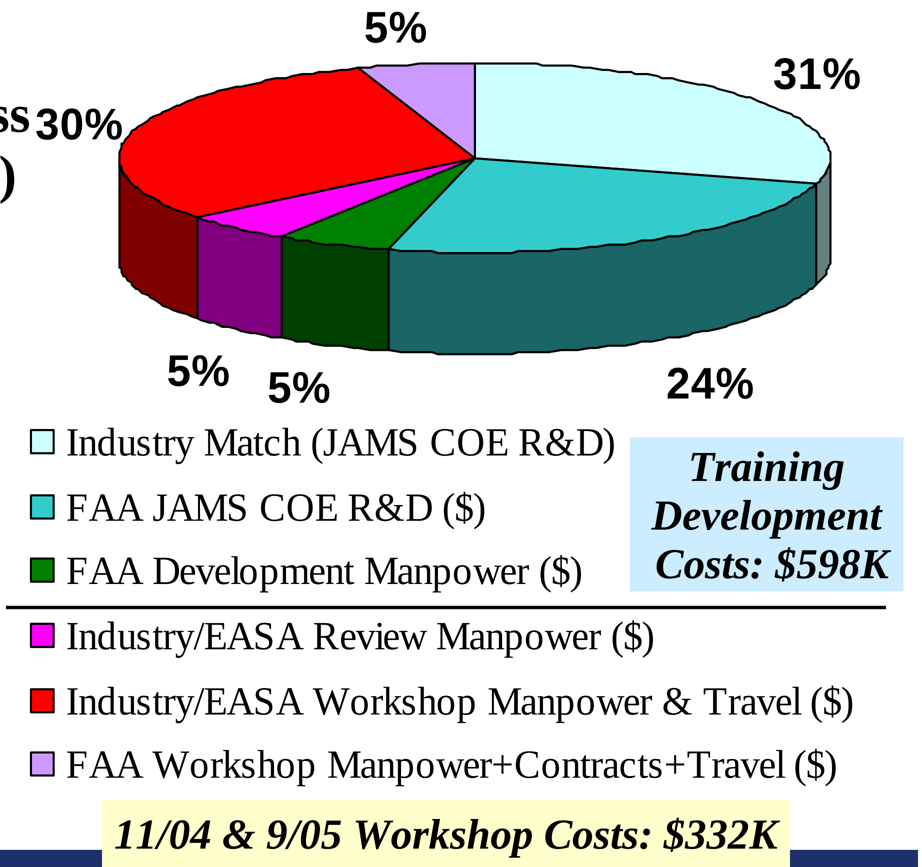
Past Milestones for Composite Safety & Certification Policy, Guidance & Training



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

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

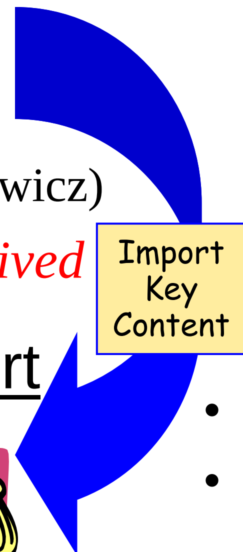
Total Costs = $930K (est. thru FY06)



Composite Maintenance Training Reports

FAA Technical Document

- Unofficial FAA document for informational purposes only
- Written by FAA (L. Cheng & L. Ilcewicz)
- *Not a formal reference that is archived*



FAA JAMS Technical Report

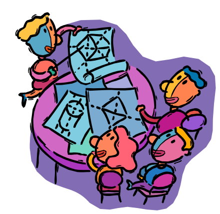
- FAA document of JAMS R&D used for educational purposes to support course development
- Written by Edmonds CC. (C. Seaton)
- *Formal reference that is archived*

SAE CACRC AIR Report

- *International standard to describe essential course content*
- Drafted & approved by CACRC
- Formal reference that is archived

Industry Interface, CMH-17 Mtgs. and FAA Workshops

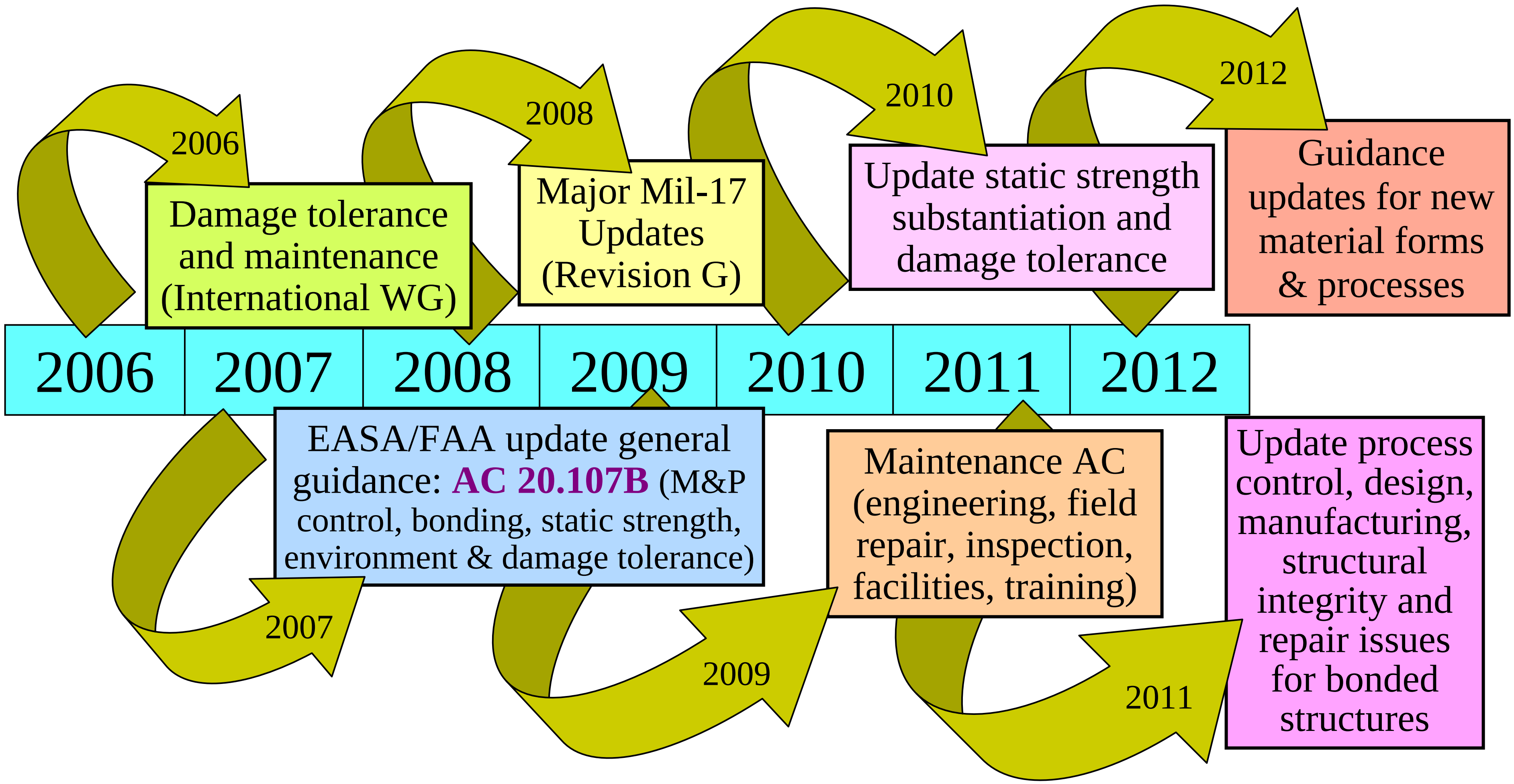
- *Basis for all reports & documents*
- Expert inputs and review of draft reports & course content



- Testimonials, graphics, videos & other teaching aids

- Edmonds CC. Beta courses

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



Importance of Linking Damage Tolerance, Maintenance and Operations

- One of the main purposes for damage tolerance is to facilitate sa[illegible] procedures
- Structural substantiation of damage tolerance [illegible]
- [illegible] from the field help improve [illegible] tolerance and maintenance practices in time
  - *Str[illegible] design criteria, [illegible] documented repairs and approved data all benefit from good communications between OEM, operations and maintenance personnel*

Boeing/Airbus/FAA/EASA 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 Mil-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.

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

Justification: expanding transport applications justify a need for communication on composite damage tolerance and maintenance between OEM and regulatory bodies

- Lack of trained resources with practical experiences
- Cost advantages from more common and efficient procedures

Three Meetings
9/05 Toulouse
3/06 Seattle
1/07 Cologne

Two Workshops
7/06 Chicago
5/07 Amsterdam

Approach

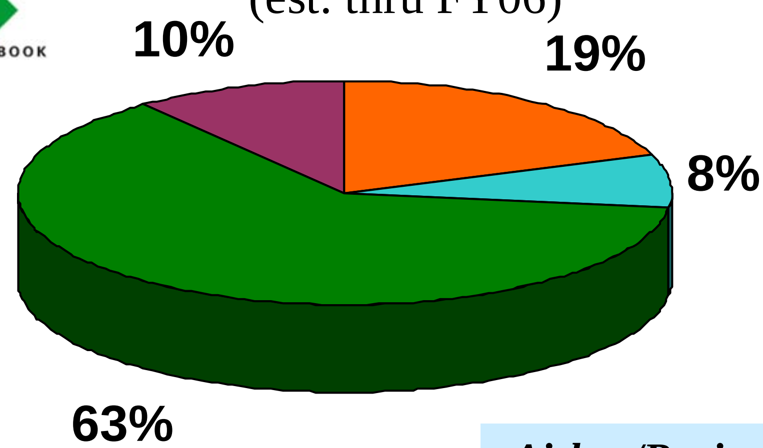
- Bring key members of the OEM and regulatory bodies together for initial assessment of objectives 1) thru 3) and define deliverables *[9/05 Toulouse & 3/06 Seattle]*
- Review progress with key members of the user community (airlines, MRO, AEG and AFS) *[1/07 Cologne; related 7/06 Chicago & 5/07 Amsterdam workshops]*
- Prioritize WG deliverables and finalize a working plan *[9/05 Toulouse & 3/06 Seattle]*
- Use existing standards organizations (Mil-17, SAE CACRC) and educational institutions (FAA JAMS COE) to publish standards and provide training

FAA/EASA/Boeing/Airbus Working Group for Damage Tolerance and Maintenance

- Started in 2005
  - New content for CMH-17 chapters on damage tolerance and supportability
  - Maintenance and repair training standards (CACRC report & FAA documents, AVS BP Items)
  - Update OEM source documentation (MPD, SRM, etc.) as appropriate
- 2006 Composite Damage Tolerance & Maintenance Workshop

Total Costs=$670K

(est. thru FY06)



- Industry/EASA WG Manpower+Travel ($)
- FAA Manpower, Travel & Contracts ($)

Airbus/Boeing EASA/FAA <u>WG Costs</u> $182K

- Industry/EASA 7/06 Workshop Manpower+Travel ($)
- FAA 7/06 Workshop Manpower+Contracts+Travel ($)

7-06 Workshop <u>Costs</u> $488K

2006 FAA Composite Damage Tolerance and Maintenance Workshop (Chicago)

	Wednesday, July 19	Thursday, July 20	Friday, July 21
1st Hour		**Session 2*** Substantiation of Structural Damage Tolerance	**Session 6** <u>Technical Breakout Sessions</u> (*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			

Presentations, recaps and breakout session summaries at:
http://www.niar.wichita.edu/chicagoworkshop/

Highlights of Chicago Workshop Presentations

- 5 categories of damage were defined for communication purposes
- More similarities than differences between Boeing and Airbus approaches to design criteria and structural substantiation
- Fluid ingression may include complex, time-related degradation
- Example problems with "operations end of safety net" were given
- Industry standards needs for "Next Generation aircraft"?
  - Accredited and OEM Sanctioned Engineering tools and Training programs
  - Accepted data sources, including specified limits
  - MRO will undergo a paradigm shift to be more reliant on OEM support
  - Need to design repairs for existing facilities & training environment
- Examples of what is needed for repair structural substantiation
- Open discussions on importance of shared composite damage data
  - Essential NDT inspection needed for visible damage disposition
- Some regulatory concerns over composite damage design criteria

Chicago Workshop Breakout Sessions

- Substantiation of Structural Damage Tolerance
  - Lots of discussion on larger damage categories (3 to 5)
  - Potential damage growth (large hidden damage, real-time environment)
  - Flutter and other aero-stability issues are not well understood (e.g., control surface PSE & non-PSE elements posing threats)
- Substantiation of Maintenance Inspection & Repair
  - Need better way to report damage events and expand training
  - Need better definition & documentation of *allowable damage*
  - Improved repair substantiation protocol including: i) short cycles, ii) training needs, and iii) standards for less critical levels
- Structural Test Protocol
  - WSU R&D seeks industry input for guidelines: large scale test substantiation of fatigue, damage tolerance, static strength, inspection and repair
  - Updated guidance is needed for LEF & fatigue load truncation
  - Need guidelines on roles of analysis in structural substantiation
- Damage/Defect Types and Inspection Technology
  - NDI need: efficient wide-area method for detecting large, critical damage
  - NDI need: in-process and post-process QC for bond integrity
  - NDI need: methods to assess heat damage & fluid contamination
  - R&D & guidelines are needed for visual inspection protocol

2006 Chicago Workshop Summary

- FAA is committed to CS&CI with industry, academia and government groups (~150 participants in workshop)
  - Damage tolerance and maintenance initiatives are active
- Five ***categories of damage*** were proposed for damage tolerance and maintenance consideration
  - Integrated efforts in structural substantiation help ensure complete coverage for safety
- Coordinated inspection, engineering disposition and repair is needed for safe maintenance
  - Actions by operations is essential for detection of critical damage from anomalous events
- Principles of safety management are needed for future developments (policy, guidance and training)

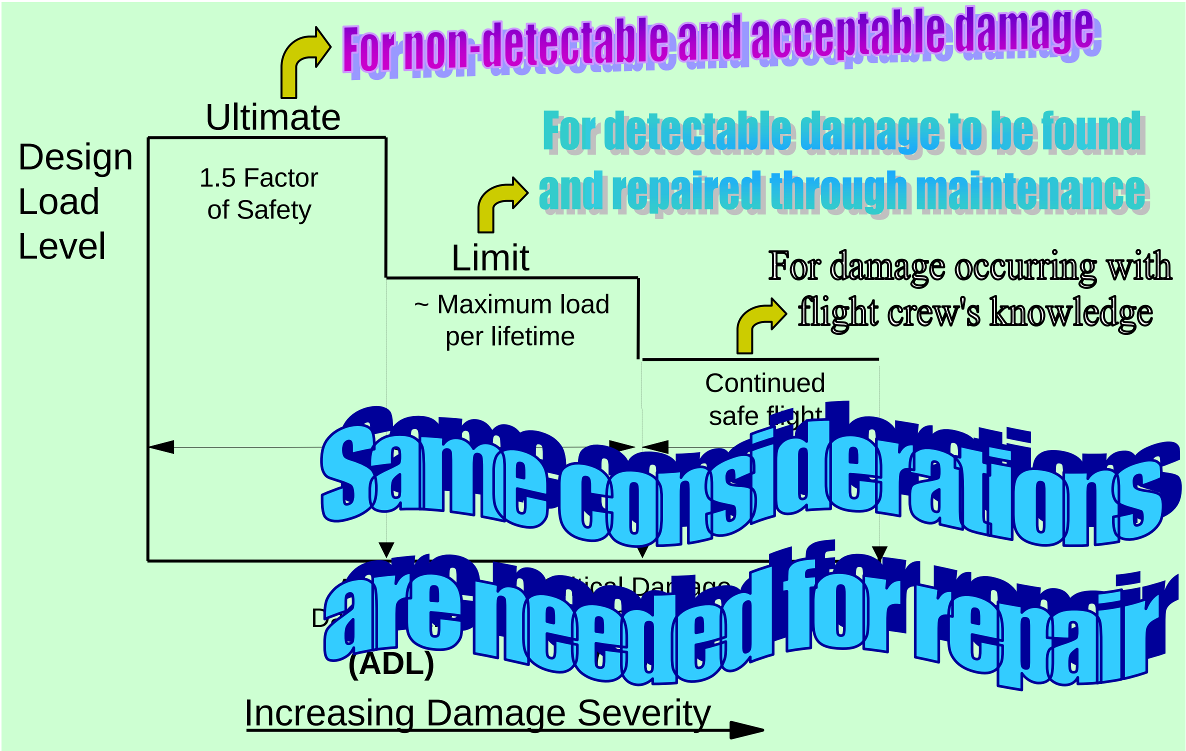
Damage Threat Assessment for Composite Structure

FAR 25.571 Damage Tolerance & Fatigue Evaluation of Structure … must show that catastrophic failure due to fatigue, corrosion, ***manufacturing defects, or accidental damage*** will be avoided through the operational life of the airplane.

AC 20-107A Composite Airplane Structure: 7. <u>Proof of Structure – Fatigue/Damage Tolerance</u> (4)*…inspection intervals should be established as part of the maintenance program. In selecting such intervals the residual strength level associated with the assumed damages should be considered.*

General Structural Design Load and Damage Considerations

- *Lost Ultimate load capability should be rare* (with safety covered by damage tolerance & practical maintenance procedures)
- Fatigue evaluations to identify damage scenarios and demo life
- Damage tolerance evaluations to show sufficient residual strength for damage threats (accidental, fatigue, environmental and discrete source)
- Both support maintenance (e.g., inspection intervals and replacement times)



Key Composite Behavior

- Relatively flat S-N curves & large scatter for repeated load cases
- Environmental effects require careful consideration
- Relatively large manufacturing defects and impact damage are considered in design criteria
- Compression & shear residual strength are affected by damage *(from small to large damage)*
- Similar tensile residual strength behavior to metals *(e.g., strength versus toughness trades)*
- Limited service experiences yield unknowns

Categories of Damage & Defects to Consider for Primary Composite Aircraft Structures

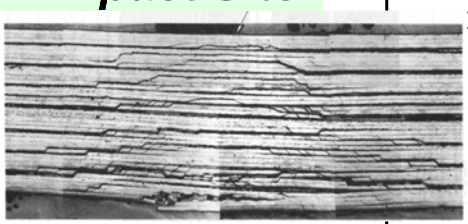
Category	Examples (not inclusive of all damage types)
Category 1: Allowable damage that may go undetected by scheduled or directed field inspection (or allowable mfg defects)	Barely visible impact damage (BVID), scratches, gouges, minor environmental damage, and allowable mfg. defects that retain ultimate load for life
Category 2: Damage detected by scheduled or directed field inspection @ specified intervals (repair scenario)	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 (repair scenario)	Damage obvious to operations in a "walk-around" inspection or due to loss of form/fit/function that must retain limit load until found by operations
Category 4: Discrete source damage known by pilot to limit flight maneuvers (repair scenario)	Damage in flight from events that are obvious to pilot (rotor burst, bird-strike, lightning, exploding gear tires, severe in-flight hail)
Category 5: Severe damage created by anomalous ground or flight events (repair scenario)	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

Categories of Damage

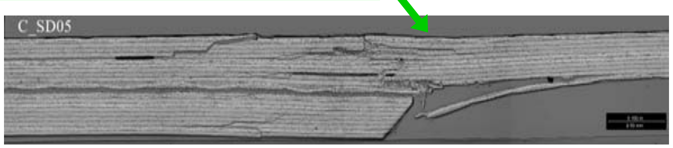
<u>Category 1</u>: *Allowable damage that may go undetected by scheduled or directed field inspection* (or allowable manufacturing defects)

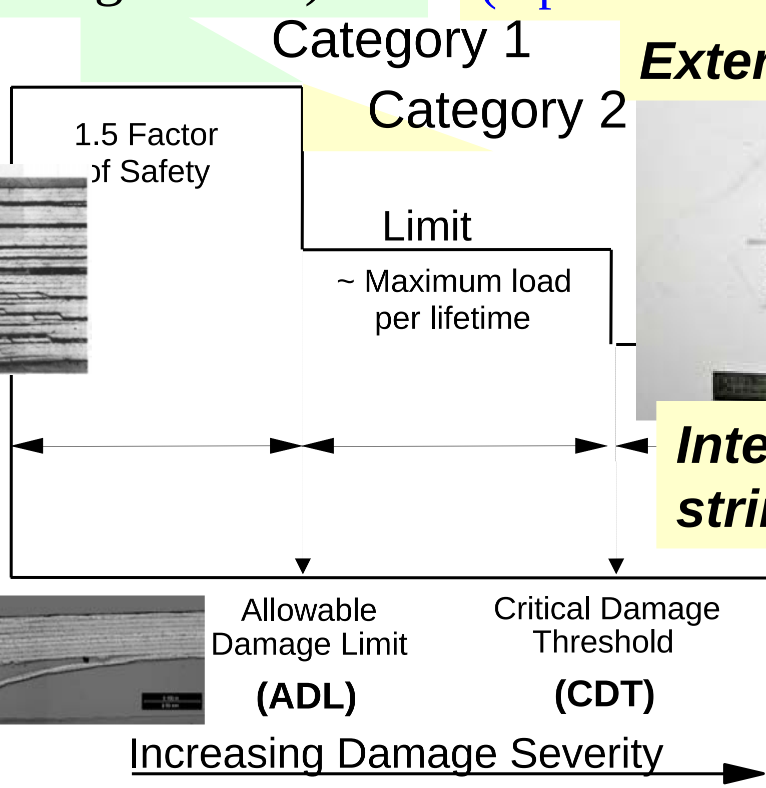
<u>Category 2</u>: *Damage detected by scheduled or directed field inspection at specified intervals* (repair scenario)

X-sec of BVID at Skin Impact Site



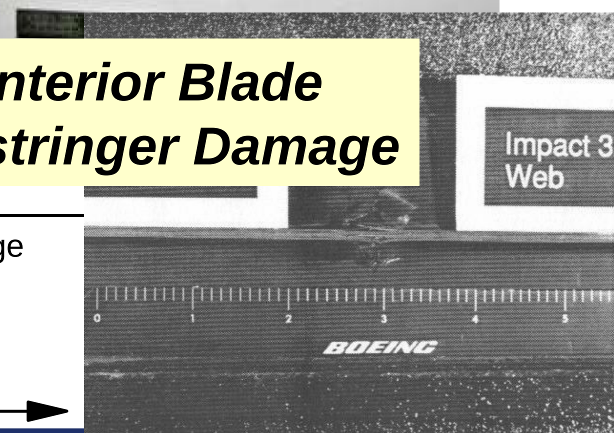
X-sec of BVID Impact at Flange to Skin Transition





Exterior Skin Damage

Interior Blade stringer Damage



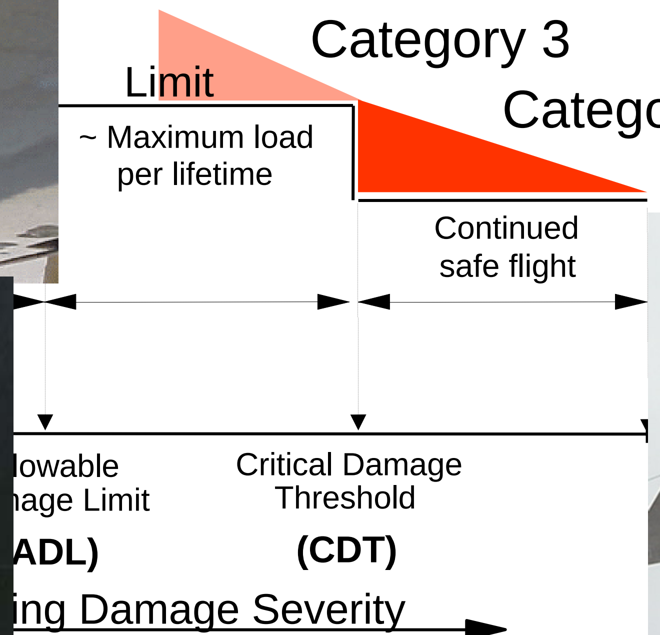
Categories of Damage

Category 3: Obvious damage detected within a few flights by operations focal (repair scenario)

Category 4: Discrete source damage known by pilot to limit flight maneuvers (repair scenario)

Accidental Damage to Lower Fuselage

Lost Bonded Repair Patch



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

Severe Rudder Lightning Damage

Categories of Damage

Category 5: Severe damage created by anomalous ground or flight events (repair scenario)

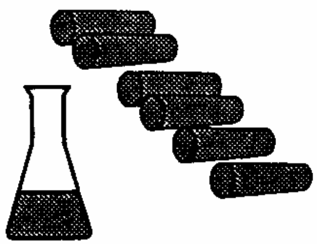
Factors Affecting Placement of Damage Threats in Categories

- Design requirements, objectives and criteria
- Structural design capability
  - Impact damage resistance
  - Detectability of different damage threats
  - Residual strength
  - Damage growth characteristics
- Inspection methods
  - Visual detection methods ➔ generally larger damage sizes
  - NDI ➔ needed if Category 2 damage can't be visually detected
- *Other considerations: service experience, costs, customer satisfaction and workforce training*

Factors Affecting Impact Damage

Materials, Structural Design Detail and Impact Event

Material variables



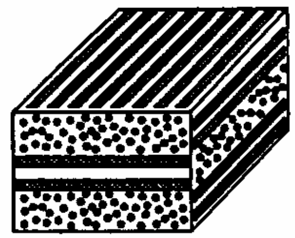
★ Fiber
- AS4
- IM7

★ Resin
- 938 (3501-6)
- 977-2

★ Fiber volume
- 0.480
- 0.565

★ Material form
- Tape
- Tow

Laminate variables

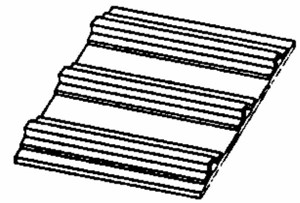


Stiffener layup
- Hard
- Soft

Skin layup
- Hard
- Soft

★ Thickness
- Thick (approximately 0.2 in)
- Thin (approximately 0.1 in)

Structural variables

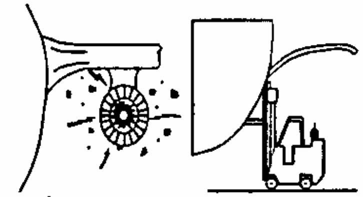


★ Stiffener type
- Blade
- Hat

Stiffener spacing
- 7 in
- 12 in

★ Stiffener adhesive layer
- With
- Without

Extrinsic variables



Impact mass
- 0.5 lbm
- 12.0 lbm

★ Impact energy (skin/stiffener)
- 80 in-lb/200 in-lb
- 1,200 in-lb/2,000 in-lb

Impact temperature
- 70°F
- 180°F

★ Impact diameter
- 0.25 in
- 1.0 in

★ Impactor tup shape
- Flat
- Spherical

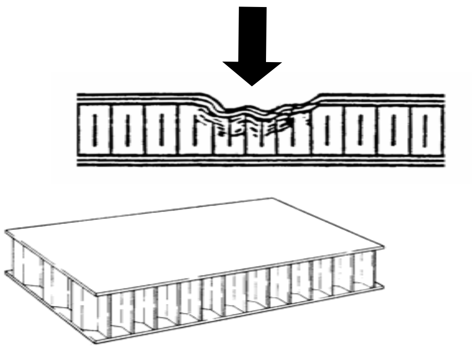
Impactor stiffeness
- 0.5 Msi
- 30 Msi

★ Factors critical to type and extent of damage, as well as its detectability. Note there were many interactions, which were as important as the main effects.

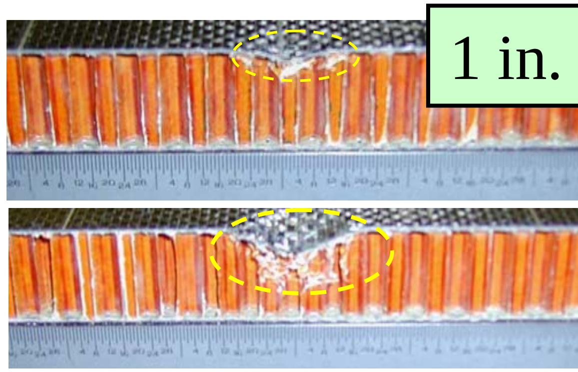
"Impact Damage Resistance of Composite Fuselage Structure," E. Dost, et al, NASA CR-4658, 1996.

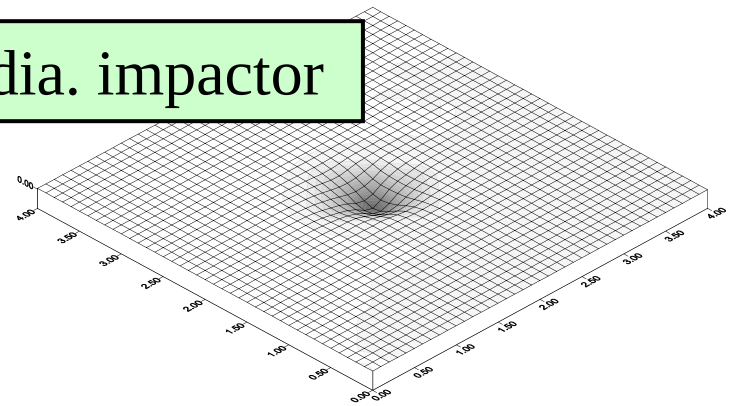
Factors Affecting Placement of Damage Threats in Categories

Foreign-Object Impact is Complex

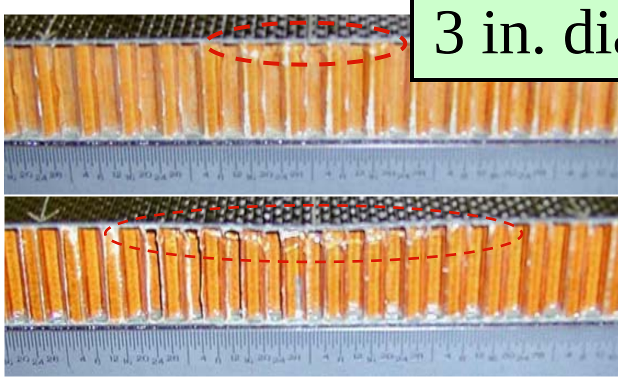


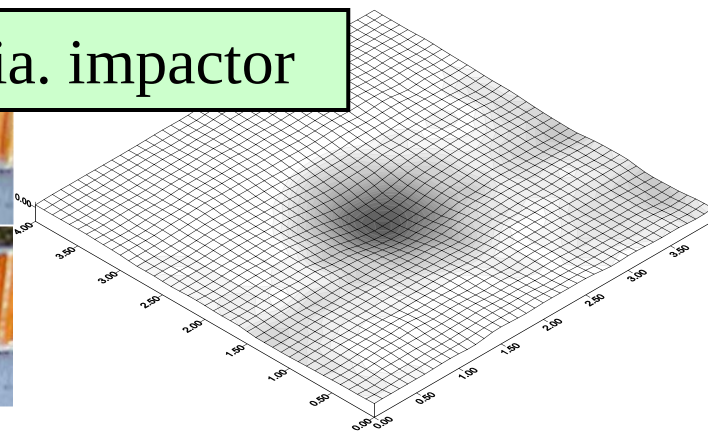
1 in. dia. impactor





3 in. dia. impactor





Some NDI may be needed to place damage at the left into Category 2

Other Factors Affecting Placement of Damage Threats in Categories

- Effects of real-time aging and long term environmental degradation could lead to life limits lower than substantiated using repeated load tests
- Failsafe design considerations may be needed to place large hidden damage into Category 2 *(e.g., large hidden damage from blunt impact, requiring internal visual inspection)*
  - Bonded joints
  - Broken elements
- Category 3, 4 and 5 damages generally require special inspections of structural elements near obvious damage *(e.g., remote points reacting high energy impact forces)*

Key Elements of Composite Structural Substantiation

- Design criteria, requirements and objectives must be established based on informed engineering judgment
  - Design guidelines, known damage threats, safety assurance
    =f (design, manufacturing & maintenance variables/interactions)
- Building block analyses & tests have proven efficient
  - Understand the limits of analysis
    Difficult to assign a metric to critical composite damage types (e.g., impact, local heat degradation, lightning strike)
    Difficult to predict design detail & damaged residual strength
    Repeated load strength and life has traditionally required tests
    Issues for reduced composite airframe stiffness & flutter resistance
  - Large scale test substantiation of rationale analysis for proof of structure (static, fatigue and damage tolerance)

Recommended Strategies for Composite Maintenance Technology Development

Design for Repair

Early development of maintenance procedures

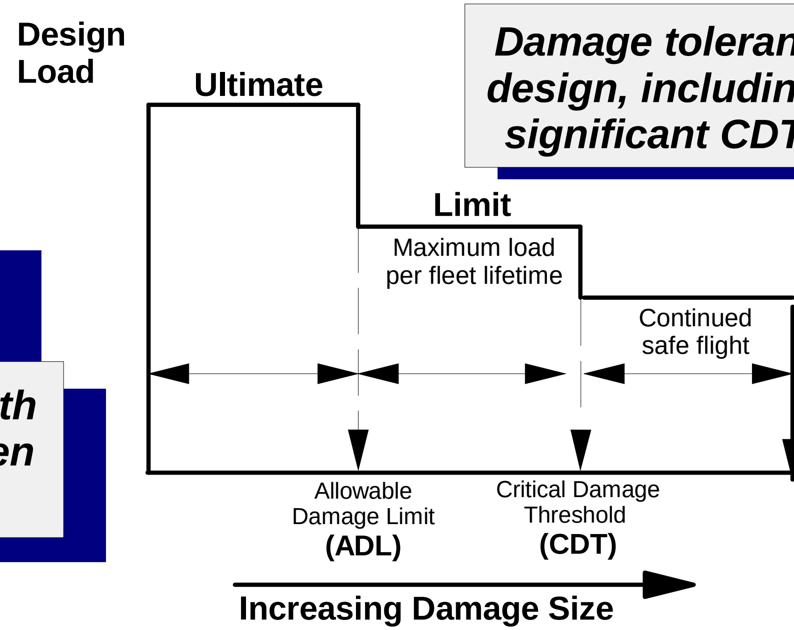
***Efficient, low-cost NDI procedures to locate damage** (that always find CDT)*

Reliable and simple NDE to quantify effects of damage

Cost-effective repair with minimal down time when damage is found

Well-defined ADL

Damage tolerant design, including significant CDT



Taken from: "Composite Technology Development for Commercial Airframe Structures," L.B. Ilcewicz, Chapter 6.08 from *Comprehensive Composites* Volume 6,, published by Elsevier Science LTD, 2000.

Some Critical Damage Types Don't Require Sophisticated Detection Methods

- Operations or maintenance personnel are usually aware of a significant flight or ground incident

In-flight Hail

Ground Vehicle Collision

The Seattle Times

WEDNESDAY
DECEMBER 28, 2005
Metro Edition

homish, Island, Kitsap
nties | 75¢ elsewhere

INDEPENDENT AND LOCALLY OWNED SINCE 1896 | seattletimes.com

"Absolutely terrifying" flight after ground-crew mistake

PLANE MAKES EMERGENCY RETURN TO SEA-TAC

Baggage handlers blamed for gash in jet's side

BY JENNIFER SULLIVAN
AND MELISSA ALLISON
Seattle Times staff reporters

Alaska Airlines Flight 536 was 20 minutes out of Seattle and heading for Burbank, Calif., Monday afternoon when a thunderous blast rocked the plane.

Passengers gasped for air and grabbed their oxygen masks as the plane dropped from about 26,000 feet, passenger Jeremy Hermanns said by phone Tuesday.

"This was absolutely terrifying for a few moments," said Hermanns, 28, of Los Angeles. "Basically your ears popped, there's a really loud bang and there was a lot of white noise. It was like

JEREMY HERMANNS

In a photo taken aboard the plane, Jeremy Hermanns uses an oxygen mask.

An Excellent Safety Message

She said Alaska conducted safety briefings with employees at Sea-Tac on Tuesday "to discuss the importance of rapid and thorough reporting of any ground incidents, whether there is apparent aircraft damage or not."

The airline also is reviewing details from Monday's incident with the NTSB and working with the agency to ensure aircraft safety, she said.

Incident Problem Description

Awareness of Critical Accidental Damage

- Service vehicle collisions & severe, in-flight impact incidents may cause damage that needs immediate repair
  - Foreign object impact phenomena is complex
- OEM damage tolerance requirements & criteria are based on threat assessments for specific structure
- Maintenance & operations are usually not familiar with damage tolerance requirements and design criteria
  - Limited controls on composite training for maintenance
  - Little or no composite training for operations
  - Composite marketing messages can pose safety threats

Solutions: Source documentation, training, news control, R&D

Inspection & Disposition Considerations

- Questions to drive damage detection
  - Are there advantages possible with more sophisticated NDI?

    What inspection technologies are needed for the least detectable Category 2 & 3 damages?
  - Based on info for a self evident event, are there reasons to suspect damage?

    Are there Category 5 damages that are not visibly detectable from the exterior?
- Questions after damage is detected
  - What is the full extent of damage?
  - Are special inspections needed for non-obvious damage?
  - Does the damage require repair?
  - Is there a substantiated repair for the specific damage?

    If not, what engineering steps are needed for repair substantiation? (primary vs. secondary, design, analysis, test data)

Visual inspection is the most common detection method for composite structure

Not easily understood by newcomers to the field

Visaul inspection is not sufficient to map the full extent of damage (NDI techniques are usually needed)

Repair Considerations

- Questions once damage has been characterized
  - Is the damage within allowable limits?
  - Is the damage within repairable limits
  - Are substantiated design and process details available?

    If not? Who can provide such information?

    Does proposed repair have required structural integrity?

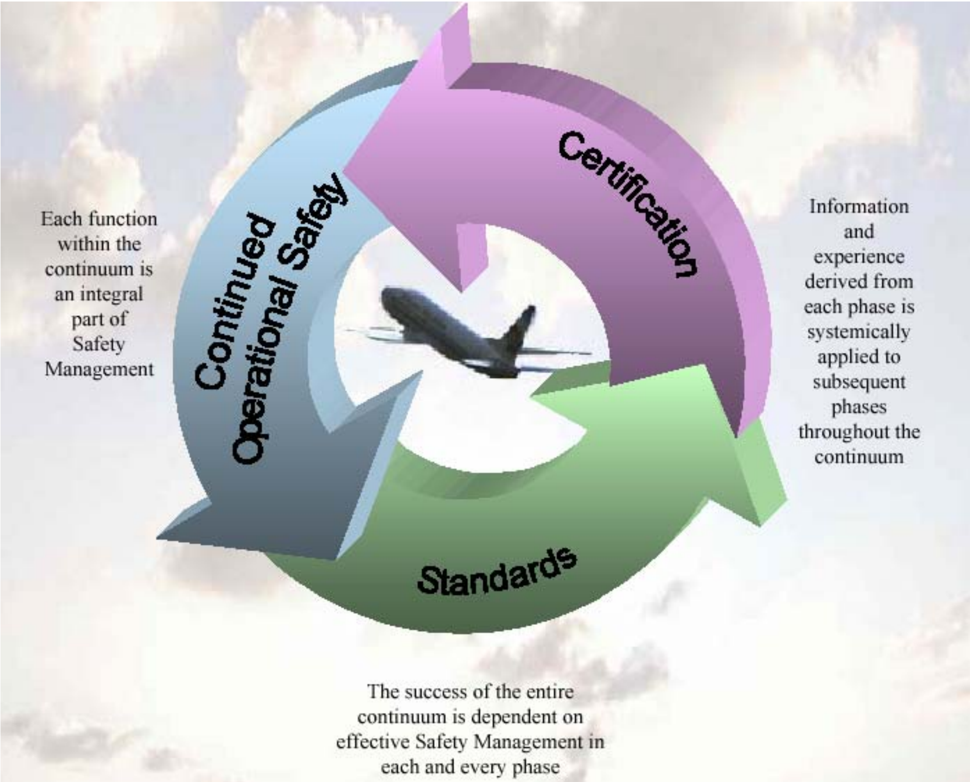
- Questions to complete a substantiated repair
  - What materials, tooling, equipment, process instructions and processing aids are needed?
  - What in-process QA must be followed?
  - What post-process QA inspections are needed?
  - What technician, QA & NDI inspector skills are needed?

It is very difficult to assign damage metrics to composites

Composite reveresed engineering methods are not available

Substantiated repairs meet the same reqmts. as base structure

FAA Strategic Plan: Safety Continuum



Safety management system to link certification standards, maintenance and operations

- Studies indicate many factors combine to cause an accident
  - Precursors are often evident but are usually not obvious
- *Safety management* combines the awareness and skills of many disciplines
  - Systems approach with airplane level awareness to mitigate risks
  - Critical relevant info must be disseminated *(i.e., service data, lessons learned)*
  - Industry standards groups can help promote safety management through consistent engineering practices and practical guidance

Categories of Damage & Defect Considerations for Primary Composite Aircraft Structures

Category	Substantiation Considerations	Elements of Safety Management*
Category 1: Damage that may go undetected by field inspection methods (detection not required)	Demonstrate reliable service life Retain Ultimate Load capability Used to define retirement	Design-driven (with safety factor) Manufacturing QC Maintenance interface
Category 2: Damage detected by field inspection (repair scenario)	Demonstrate reliable inspection Retain Limit Load capability Used to define maintenance	Design for rare damage Manufacturing QC Maintenance action
Category 3: Obvious damage detected within a few flights by operations (repair scenario)	Demonstrate quick detection Retain Limit Load capability Used to define operation actions	Design for rare large damage Operation action Maintenance action
Category 4: Discrete source damage and pilot limits flight maneuvers (repair scenario)	Defined discrete-source events Retain "Get Home" capability Used to define operation actions	Design for rare known events Operation immediate action Maintenance action
Category 5: Severe damage created by anomalous ground or flight events (repair scenario)	Repair generally beyond design validation *(known to operations)* May require new substantiation	Requires operations awareness for safety (immediate reporting) Maintenance & design action

* All categories include requirements

Safety Concerns for Composite Airframe Structures

- Unanticipated accidental damage threats that are not covered by design criteria
  - Damage that can't be found with maintenance inspection procedures and lowering structural capability below URS
  - Damage that is not obvious and lowering structural capability to near LRS
- Environmental damage developing/growing with time
- Systematic structural bonding process problems that are not localized or contained to limited aircraft
- Severe damage occurring in flight, incl. take-off & landing, without knowledge of flight crew (overloads)

Safety Concerns for Composite Airframe Structures, *continued*

- Repeated service loads outside the design envelop
- Severe damage occurring on ground without proper reaction by operations personnel (e.g., ground vehicle collision, work stand impact, engine run-up/runway debris)
- Severe damage occurring in flight without immediate detection by operations personnel on the ground (e.g., in-flight breakaway & impact by secondary structure)
- Application of unsubstantiated repair designs and processes by field personnel
  - Repairs and/or damage outside approved data sources
  - Unqualified engineers, technicians and/or inspectors

Links with Mil-Handbook-17 (CMH-17), SAE CACRC and Safety Management

- Mil-Handbook-17 (Composite Materials Handbooks, CMH-17)
  - ~ 100 industry engineers meet every 8 months
  - Airbus/Boeing/EASA/FAA WG deliverables to update CMH-17, Vol. 3 Chapters on Damage Tolerance & Supportability for Rev. G
  - New CMH-17 Safety Management WG has been initiated
  - *FAA strategy: use CMH-17 as a forum to develop guidance and establish educational services to offset costs*
- SAE CACRC (Commercial Aircraft Composite Repair Committee)
  - ~ 50 industry engineers meet every 6 months (~7 WG)
  - Airlines have dropped out of CACRC over time, requiring more OEM and MRO leadership for organization to survive
  - Establish CACRC Safety Management WG?
  - *FAA strategy: use CACRC as a forum to develop guidance and support industry composite maintenance standards & training efforts*

FAA Perspectives on Existing CACRC Publications and Standards

- In combination, publications and standards developed by the CACRC provide an excellent educational basis in composite airframe maintenance
  - Practical design and process guidelines
  - Currently ***not*** engineering handbooks (reason: product-specific details of design, analysis and process substantiation)
  - In time, the publications and standards can be adopted for specific applications through the certification efforts that substantiate their use on a given product
- Some CACRC references also document past service problems and solutions
  - Provide safety and economic perspectives

Coordinated FAA and CACRC Efforts
(workshop used to review and collect inputs)

- Future composite maintenance guidance, policy and training development in areas driven by industry needs
  - Related research (examples shown below)

Structural Substantiation Protocol

Impact Threat Assessment

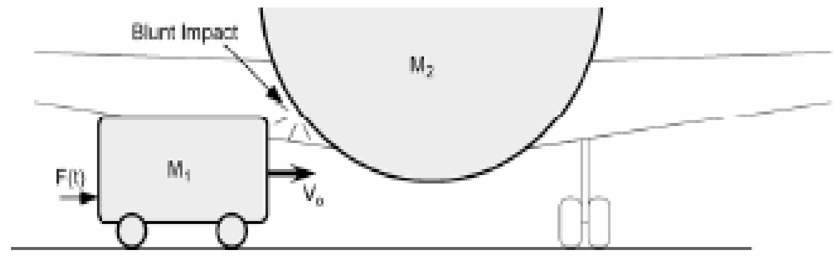
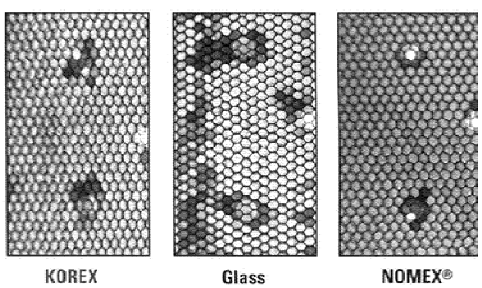
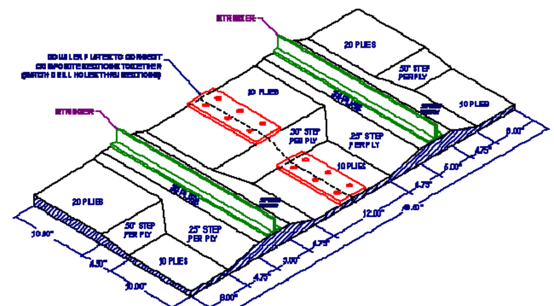


Figure 1. Blunt Impact on Aircraft Fuselage

Sandwich Fluid Ingression



NDI Standards



Prime Considerations in Developing the Amsterdam Workshop Agenda

- Integrated with CACRC
  - Review progress and plans
  - More emphasis on repair design, process and quality control
- More European influence
- More involvement of airlines and MRO
- Additional OEM composite repair personnel
- Cover areas of applications and service experience not covered in Chicago (engines and propellers)
- More emphasis on composite issues for the existing fleet

Summary

- FAA is committed to composite safety and certification initiatives with industry, academia and government groups
  - Damage tolerance and maintenance initiatives are active
- Five categories of damage are proposed for damage tolerance and maintenance consideration
  - Integrated efforts in structural substantiation help ensure complete coverage for safety
- Coordinated inspection, engineering disposition and repair is needed for safe maintenance
  - Actions by operations is essential for detection of critical damage from anomalous events
- Principles of safety management and industry forum (CMH-17 & CACRC) will be used for future initiatives