

Composite Damage Tolerance and Maintenance Safety Issues



Federal Aviation
Administration

- *Background*
- *Damage threat assessment*
 - *Key composite behavior*
 - *Categories of damage*
 - *Structural substantiation*
- *Inspection & repair considerations*
- *Safety management*

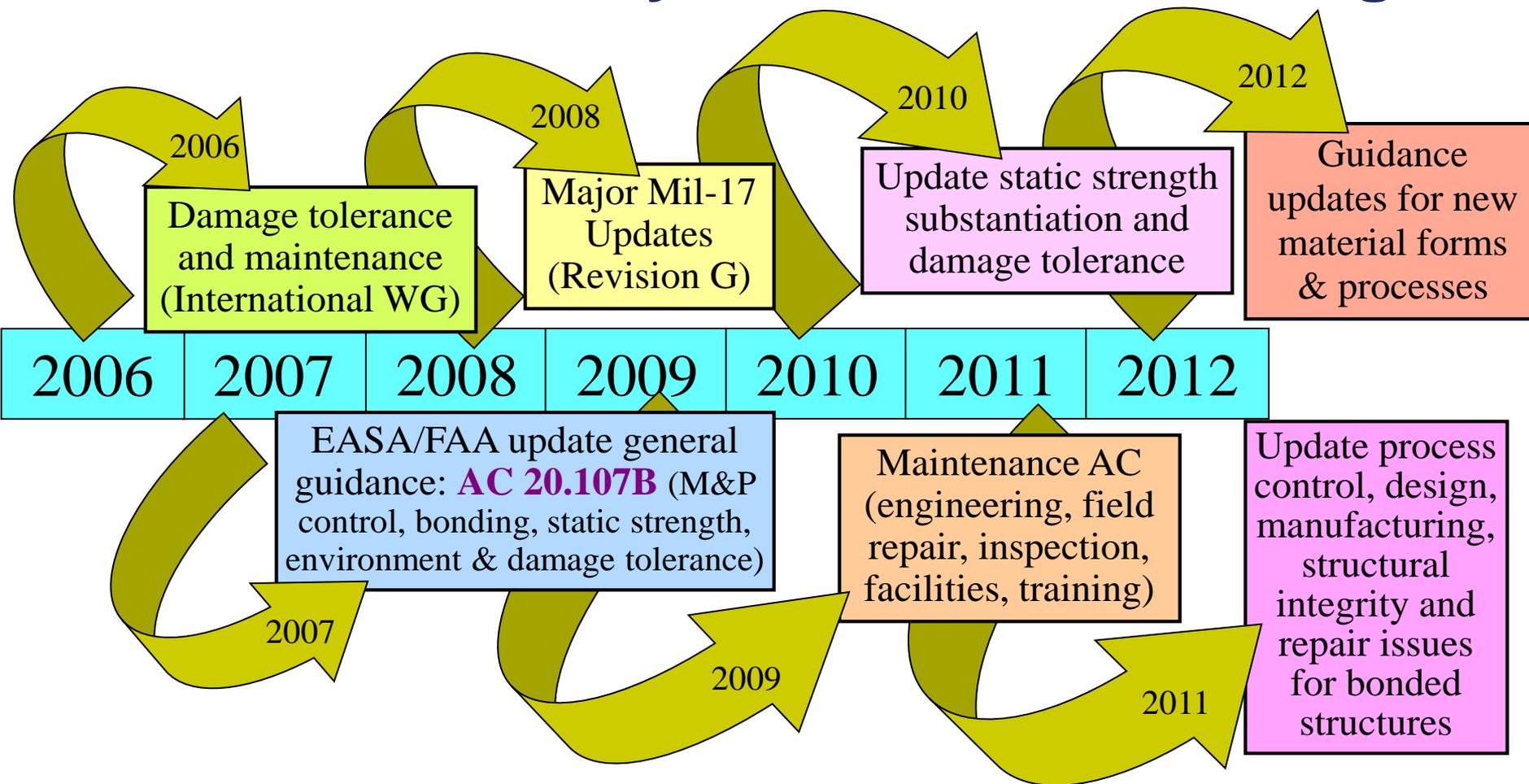
Larry Ilcewicz

CS&TA

Federal Aviation
Administration

July 19, 2006

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



Importance of Linking Damage Tolerance and Maintenance

- One of the main purposes for damage tolerance is to facilitate safe repair procedures

This Workshop is

- Findings from the field help improve damage

Intended to Gain Real-world Insights

– Structural safety, damage threat assessments, design

On Damage Tolerance & Maintenance

approved data all benefit from good communications

between OEM operations and maintenance personnel

From Experts in the Field

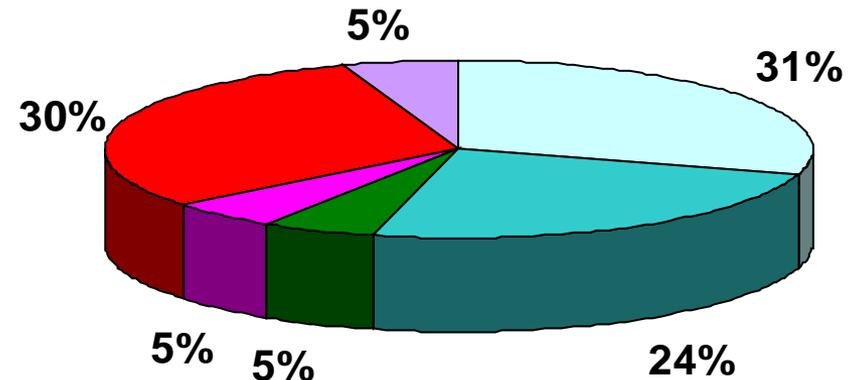
- Structural substantiation of damage tolerance, inspection and repair should be integrated

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



Total Costs = \$930K



- Industry Match (JAMS COE R&D)
- FAA JAMS COE R&D (\$)
- FAA Development Manpower (\$)
- Industry/EASA Review Manpower (\$)
- Industry/EASA Workshop Manpower & Travel (\$)
- FAA Workshop Manpower+Contracts+Travel (\$)

Training Development Costs: \$598K

11/04 & 9/05 Workshop Costs: \$332K

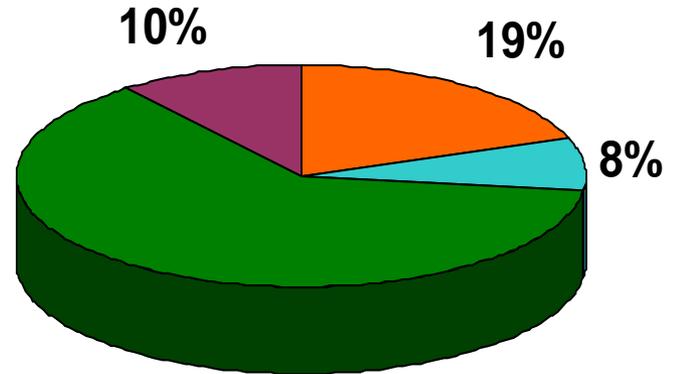
FAA/EASA/Boeing/Airbus Working Group for Damage Tolerance and Maintenance

- Started in 2005
 - New content for Mil-17 chapters on damage tolerance and supportability
 - Review of maintenance and repair training modules (AVS BP#1344B)
 - Update OEM source documentation (MPD, SRM, etc.) as appropriate



2006 Composite Damage Tolerance & Maintenance Workshop

Total Costs = \$670K



Industry/EASA WG Manpower+Travel (\$)	10%	<i>Airbus/Boeing EASA/FAA WG Costs \$182K</i>
FAA Manpower, Travel & Contracts (\$)	8%	
<hr/>		
Industry/EASA 7/06 Workshop Manpower+Travel (\$)	63%	<i>7-06 Workshop Costs \$488K</i>
FAA 7/06 Workshop Manpower+Contracts+Travel (\$)	19%	

2006 FAA Composite Damage Tolerance and Maintenance Workshop

Primary objective: Address safety concerns and technical issues for composite damage tolerance & maintenance

Secondary objectives

1. Discuss factors affecting the substantiation of damage tolerance and maintenance inspection & repair
2. Discuss elements of safety management
3. Discuss structural test protocols and supporting analyses
4. Discuss damage & defect types and inspection technology used for manufacturing, field inspection and repair
5. Identify needs for regulatory requirements and guidance
6. Identify needs for standards (guidelines, databases, and tests)
7. Provide directions for research and training developments



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. Proof of Structure – Fatigue/Damage Tolerance (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



List of Items to Consider in Defining Damage and Defect Threats

- Impact damage resistance
- Manufacturing mistakes
- Growth potential (including synergistic relations with fluid ingress & environments)
 - Environmental effects
 - High temperature zones
 - Fluid resistance
- Repair mistakes
- UV & lightning protection
- Discrete source threats
- Product size/damage location
 - Structural design detail
- Design criteria
- Damage detection and characterization methods
- Production quality control
 - Production technician training
- Repair quality control
 - Maintenance technician training
 - Inspector training
- Operations awareness

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

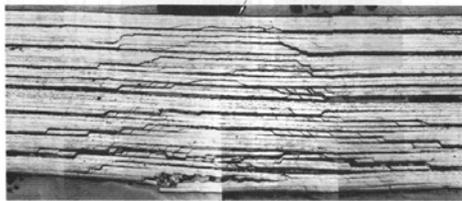


Categories of Damage

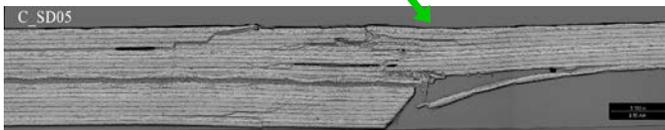
Category 1: Allowable damage
 that may go undetected by scheduled
 or directed field inspection
 (or allowable manufacturing defects)

Category 2: Damage detected
 by scheduled or directed field
 inspection at specified intervals
 (repair scenario)

**X-sec of BVID at
 Skin Impact Site**

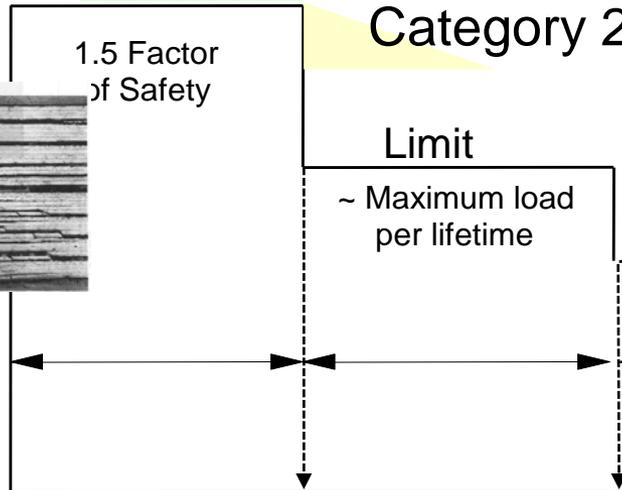


**X-sec of BVID
 Impact at Flange
 to Skin Transition**



Category 1

Category 2



Exterior Skin Damage



**Interior Blade
 stringer Damage**



Allowable
 Damage Limit
(ADL)

Critical Damage
 Threshold
(CDT)

Increasing Damage Severity →

Categories of Damage

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

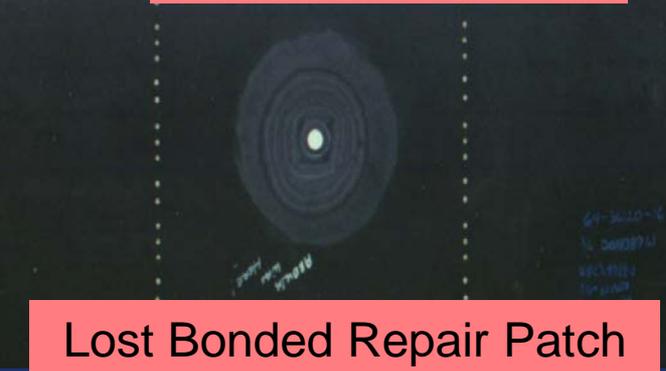
Category 4: Discrete source damage known by pilot to limit flight maneuvers (repair scenario)



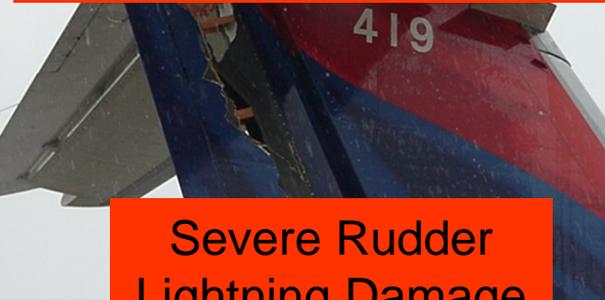
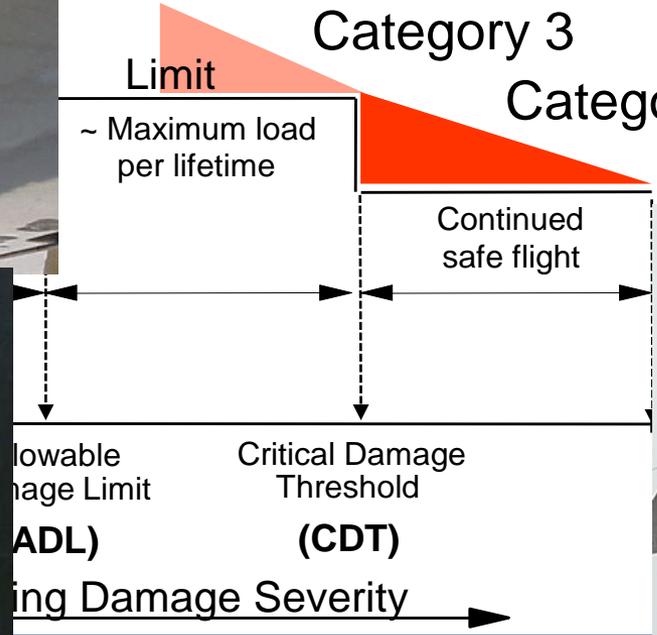
Accidental Damage to Lower Fuselage



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



Lost Bonded Repair Patch



Severe Rudder Lightning Damage

Categories of Damage

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



**Birdstrike
(flock)**



**Maintenance
Jacking Incident**



**Birdstrike
(big bird)**



**Propeller
Mishap**

Categories of Damage & Defect Considerations for Primary Composite Aircraft Structures

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

* All categories include requirements

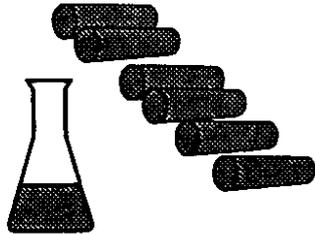
Factors Affecting Placement of Damage Threats in Categories

- 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

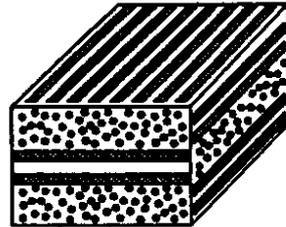
Materials, Structural Design Detail and Impact Event

Material variables



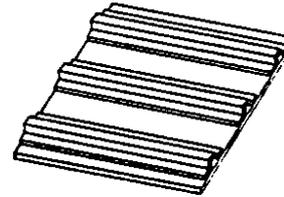
- ★ Fiber
 - AS4
 - IM7
- ★ Resin
 - 938 (3501-6)
 - 977-2
- ★ Fiber volume
 - 0.480
 - 0.565
- ★ Material form
 - Tape
 - Tow

Laminate variables



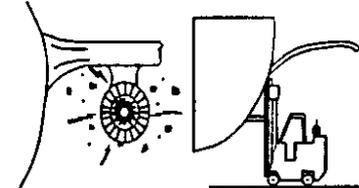
- ★ Stiffener layup
 - Hard
 - Soft
- ★ Skin layup
 - Hard
 - Soft
- ★ Thickness
 - Thick (approximately 0.2 in)
 - Thin (approximately 0.1 in)

Structural variables



- ★ Stiffener type
 - Blade
 - Hat
- ★ Stiffener spacing
 - 7 in
 - 12 in
- ★ Stiffener adhesive layer
 - With
 - Without

Extrinsic variables



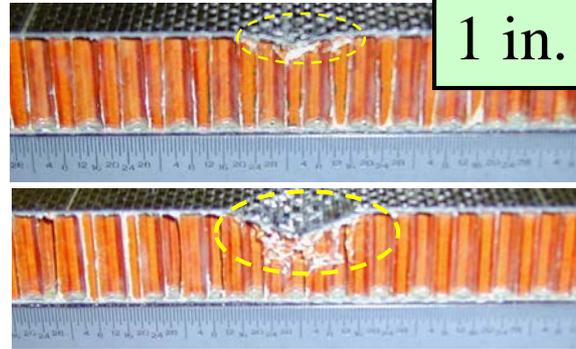
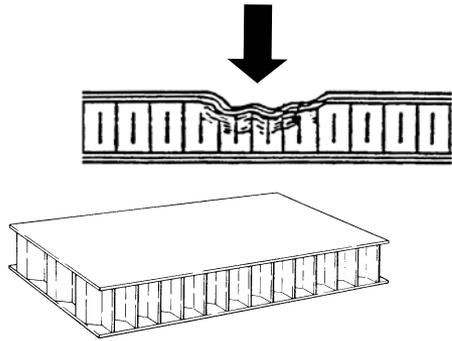
- ★ Impact mass
 - 0.5 lbm
 - 12.0 lbm
- ★ Impact energy (skin/stiffener)
 - 80 in-lb/200 in-lb
 - 1,200 in-lb/2,000 in-lb
- ★ Impact temperature
 - 70°F
 - 180°F
- ★ Impact diameter
 - 0.25 in
 - 1.0 in
- ★ Impactor tip shape
 - Flat
 - Spherical
- ★ Impactor stiffness
 - 0.5 Msi
 - 30 Msi

★ 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.

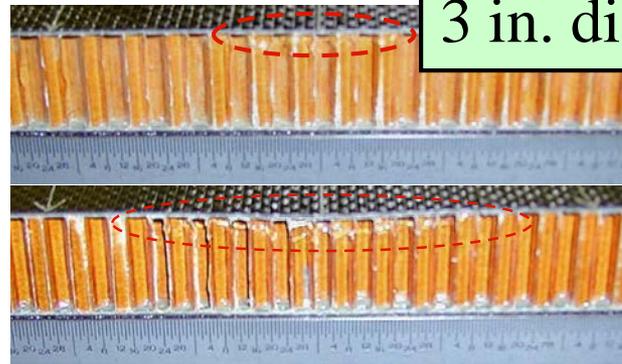
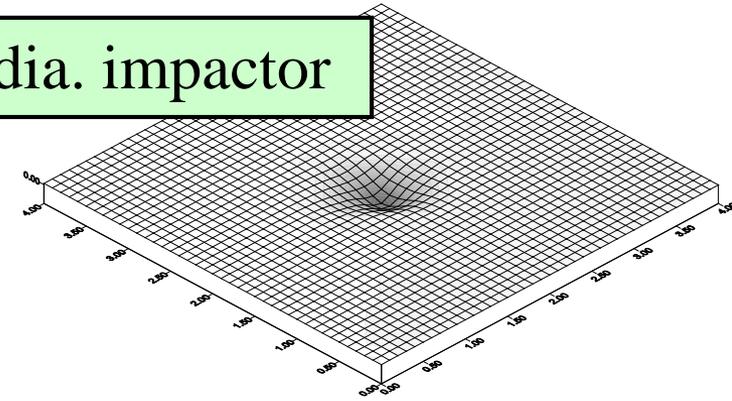
"Impact Damage Resistance of Composite Fuselage Structure," E. Dost, et al, NASA CR-4658, 1996.

Factors Affecting Placement of Damage Threats in Categories

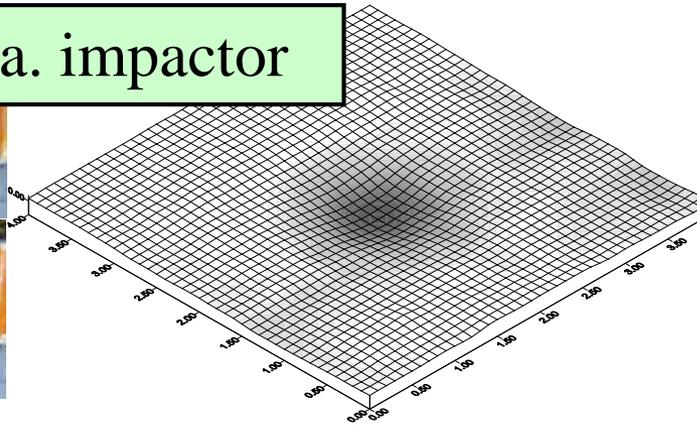
Foreign-Object Impact is Complex



1 in. dia. impactor



3 in. dia. impactor



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

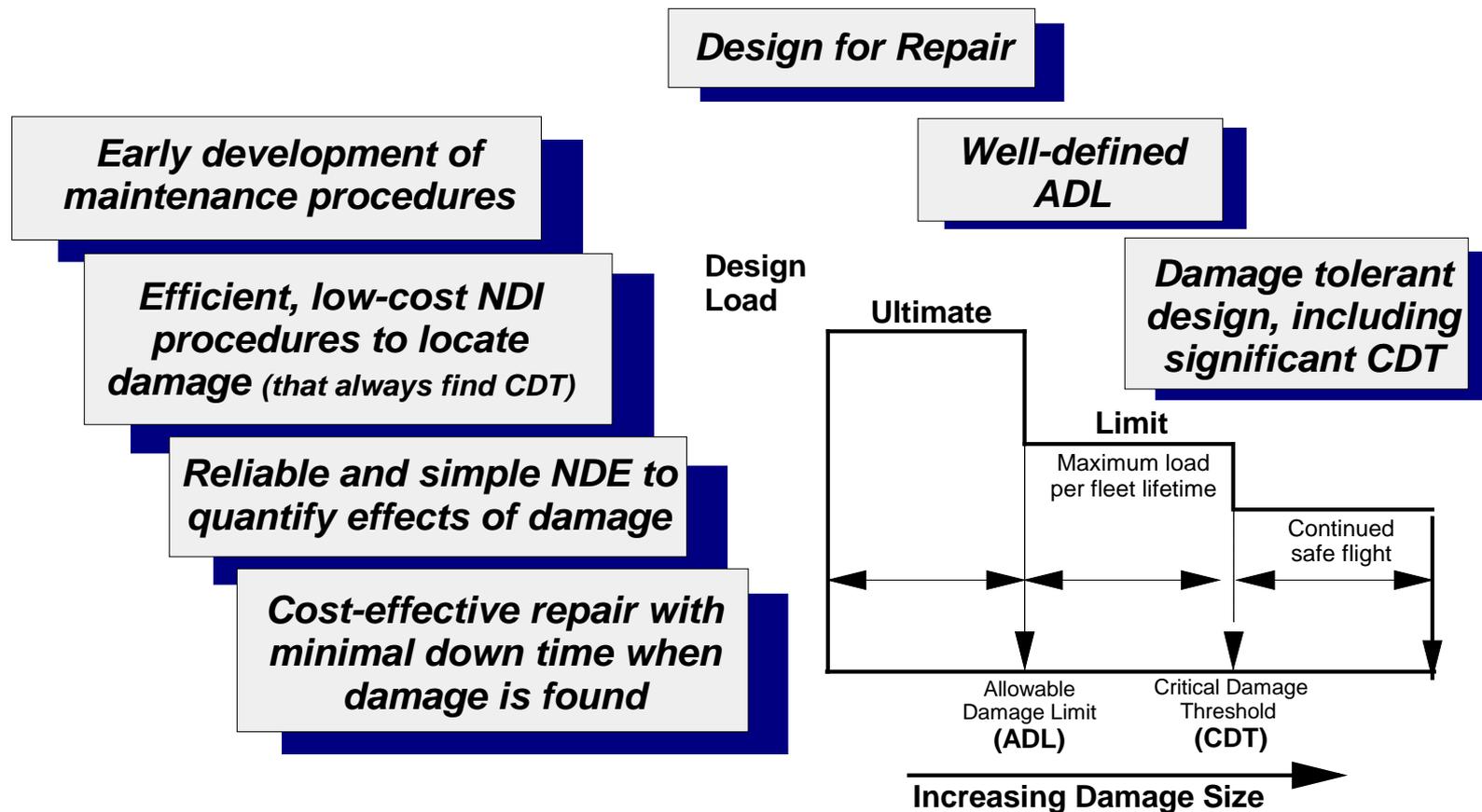
Other Factors Affecting Placement of Damage Threats in Categories

- 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



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





nomish, 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

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.



JEREMY HERMANN'S

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

An Excellent Safety Message →

Maintenance

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
 - Advantages possible with more sophisticated NDI?
 - Inspection technologies needed for the least detectable Category 2 and 3 damages?
 - Are there Category 5 damages that are not visibly detectable from the exterior?
- Questions to ask after damage is detected
 - What is the full extent of damage?
 - Is a special inspection needed for non-obvious damage?
 - Does the damage require repair?
 - Is there a substantiated repair for the specific damage?
 - What engineering steps are needed for repair substantiation?
(primary vs. secondary, design, analysis, test data)

How to Determine What Role NDI Should Take in Composite Maintenance?

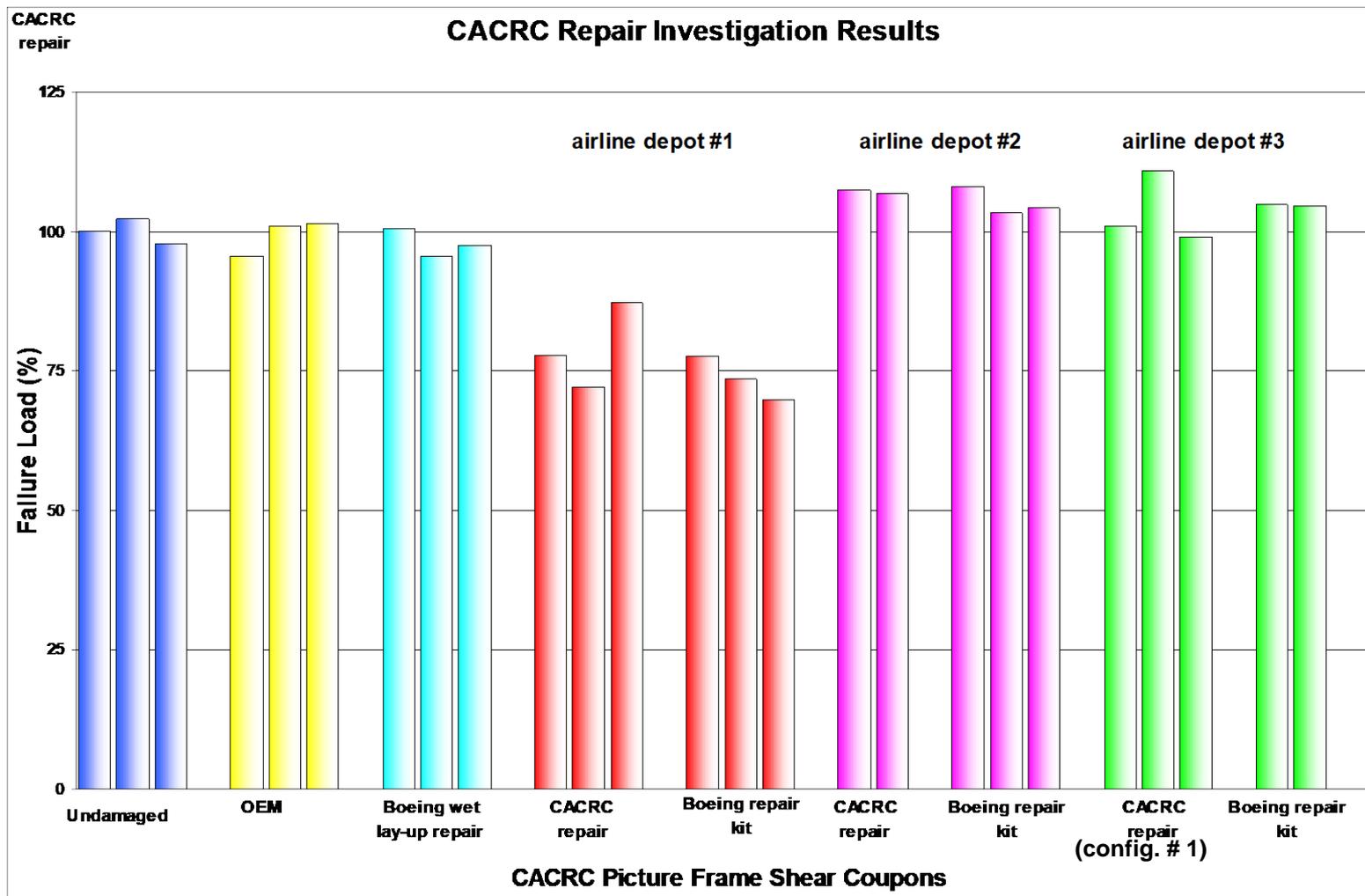
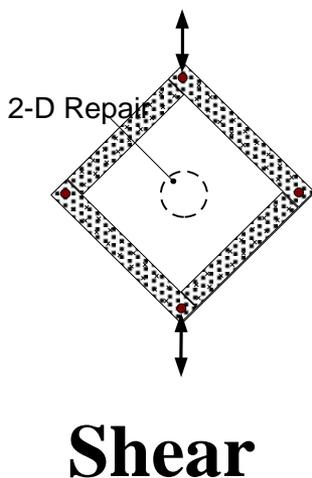
- Dependent on structural design details & design criteria
- Damage threat assessments are needed to focus any inspection
 - Very difficult to inspect large areas with sophisticated NDI devices that require special skills
- Maintenance costs (time, skills, equipment) will rise if NDI is being used to avoid weight penalties for larger damage
- NDI should be part of a “systems solution”



Repair Considerations

- Questions to ask 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?
- Questions to ask to complete a substantiated repair
 - What materials, tooling, equipment, process instructions and processing aids are needed?
 - What technician, QA & NDI inspector skills are needed?
 - What in-process quality assurance must be followed?
 - What post-process quality assurance inspections are needed?
 - Does the repair have the necessary structural integrity?

Test Results from FAA Research on Bonded Repair of Composite Sandwich Panels



FAA Strategic Plan: Safety Continuum

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

Safety management system to link certification standards, maintenance and operations

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* combines the awareness and 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., service data, lessons learned*)
 - Industry standards groups can help promote consistent engineering practices and practical guidance

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 envelope
- 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 for educational purposes to generate revenue that helps develop more standards
- 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
 - FAA strategy: continue to support CACRC with resources and research funding of standards & repair process trials



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 will be used for future developments (policy, guidance and training)