Service Experience With Early BCA Composite Applications

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Intro / Overview

- **BCA Experience with Advanced Composites in Service**
  - **707 Boron Epoxy Foreflap**
  - **737 CFRP Flight Spoilers**
  - **727 Elevators**
  - **737 Horizontal Stabilizers**
- **Update on CMH-17 Activities**
  - **Chapter 13 Defects, Damage & Inspection**
  - **Chapter 14 Supportability & Maintenance**

Boeing 707 Boron Epoxy Foreflap

- IRAD funded
- Used non-traditional laminates in a sandwich monocoque
- Only a few built / Only one placed in revenue service; flew on NWA for a short period
- Performed well
- Removed from service when NWA elected to sell the airframe

Western Airlines 737-200 CFRP Flight Spoiler

- **IRAD Funded**
- **Very small step; only replaced aluminum skins**
- **Used non-traditional laminates**
- **Performed well in service for a few years; removed when airframe sold**
- **Springboard to bigger things**

NASA 737 Flight Spoilers

- Approximately 160 units deployed to Aloha, Air New Zealand, Frontier, Lufthansa, Piedmont, and VASP. Several airlines also had ground racks with coupon specimens
- 3 Graphite epoxy systems and one graphite thermoplastic system
- All in-service units inspected annually by Boeing P.I. Three units removed from service each year and tested to destruction to demonstrate adequate strength and stiffness
- As of final tracking date, 6/30/1989, the fleet had 2,593,741 flight-hours and 3,499,941 landings
- High time unit had 42,007 hours
- Units with thermoplastic resin suffered from Skydrol® degradation; removed from service; promptly forgotten
- Remaining units with epoxy resin systems remained in service many years; some may be flying today

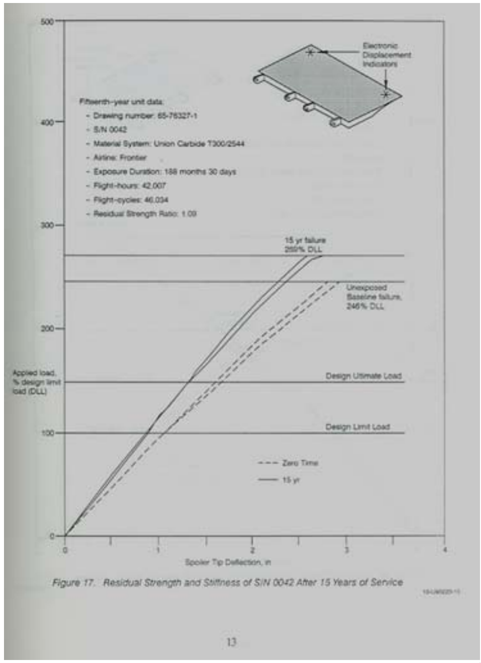

Figure 17. Residual Strength and Stiffness of S/N 0042 After 15 Years of Service

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Background
ACEE Composites Program

- The comprehensive NASA **A**ir**C**raft **E**nergy **E**fficiency program was initiated by NASA in late 1975 with the main purpose of developing new technologies to reduce fuel consumption in commercial transport aircraft
- The ACEE Composites program focused on achieving fuel efficiency through the use of lighter materials in existing aircraft structural components
- The ACEE Composites program targeted six aircraft secondary and medium primary components: the upper aft rudder of the Douglas DC-10, the inboard ailerons of the Lockheed L-1011, the elevators of the Boeing 727, the vertical stabilizers for the Lockheed L-1011 and Douglas DC-10 and the horizontal stabilizer of the Boeing 737

727 CFRP Elevator

- **5 shipsets built and certified / 4 placed in revenue service / one held as spares**
- **Performed well with original carrier until fleet sold in 2001**
- **Certification basis for these parts largely remains in place today**
- **I think of these as the "forgotten" components. (Bigger is better syndrome)**

Background ACEE 737 Composite HS Program

- As part of the ACEE program, Boeing redesigned, manufactured, certified, & deployed five shipsets of 737-200 horizontal stabilizers using graphite-epoxy composites
- Boeing 737 Composite Stabilizer Program Objectives:
  - Achieve a 20% weight reduction with respect to the existing metal structure
  - Manufacture at least 40% (by weight) of the components from composite materials
  - Demonstrate cost competitiveness of the structure
  - Obtain FAA certification for the structure
  - Evaluate the structure in service

737 HS Fleet Status

- Five Shipsets were manufactured and certified in August 1982
- None in service at this time

Shipset / Production Line #	Entry into Service	Airline	Current Status
1 / 1003	2 May 1984	A	Parked (60000 hours, 45000 flights)
2 /1012	21 March 1984	A	Parked (62000 hours, 47000 flights)
3 / 1025	11 May 1984	B	Damaged beyond repair 1990; partial teardown completed in 1991 (17300 hours, 19300 flights)
4 / 1036	17 July 1984	B & C	Stabilizers removed from service 2002 (approx. 39000 hours, 55000 flights); partial teardown of R/H unit at Boeing
5 / 1042	14 August 1984	B & D	Stabilizers removed from service 2002 (approx. 52000 hours, 48000 flights); teardown of L/H unit at Boeing; teardown of R/H unit at NIAR, Wichita State

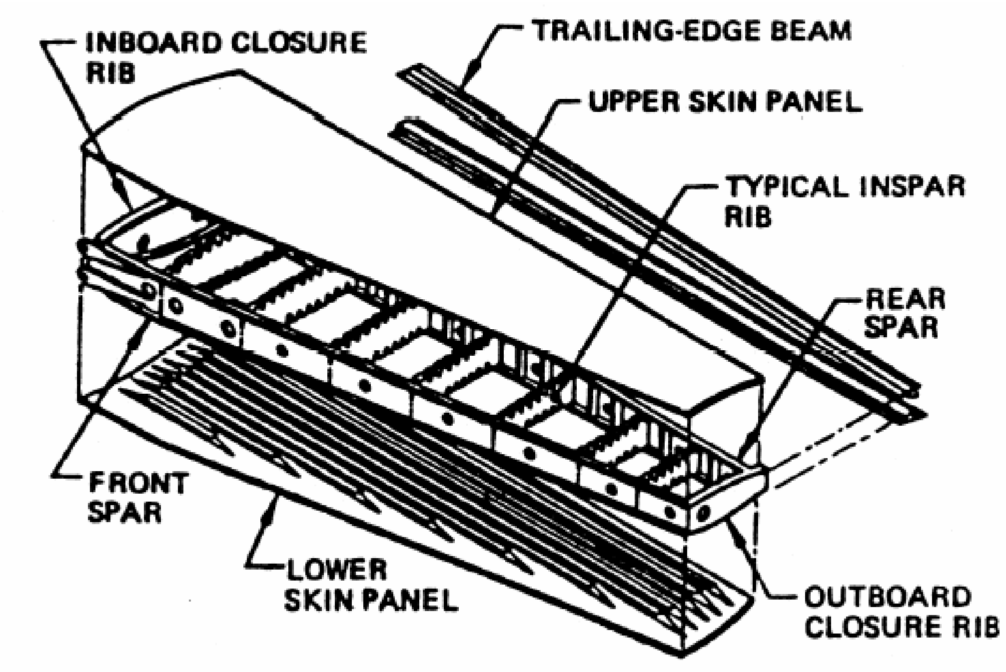
737 Stabilizer Description

STRUCTURAL ARRANGEMENT

- **Stiffened Skin Structural Box arrangement with I-section stiffener panels: the entire skin/ stiffener combination was co-cured**
- **Bolted Titanium spar lugs: this concept used two titanium plates bonded and bolted externally to a pre-cured graphite-epoxy lug**
- **Back to back "C" sections secondarily bonded to form spars**
- **Honeycomb ribs**
- **Loads fed through spar lugs**

MATERIAL

- **NARMCO T300/5208 (Almost all fabric)**

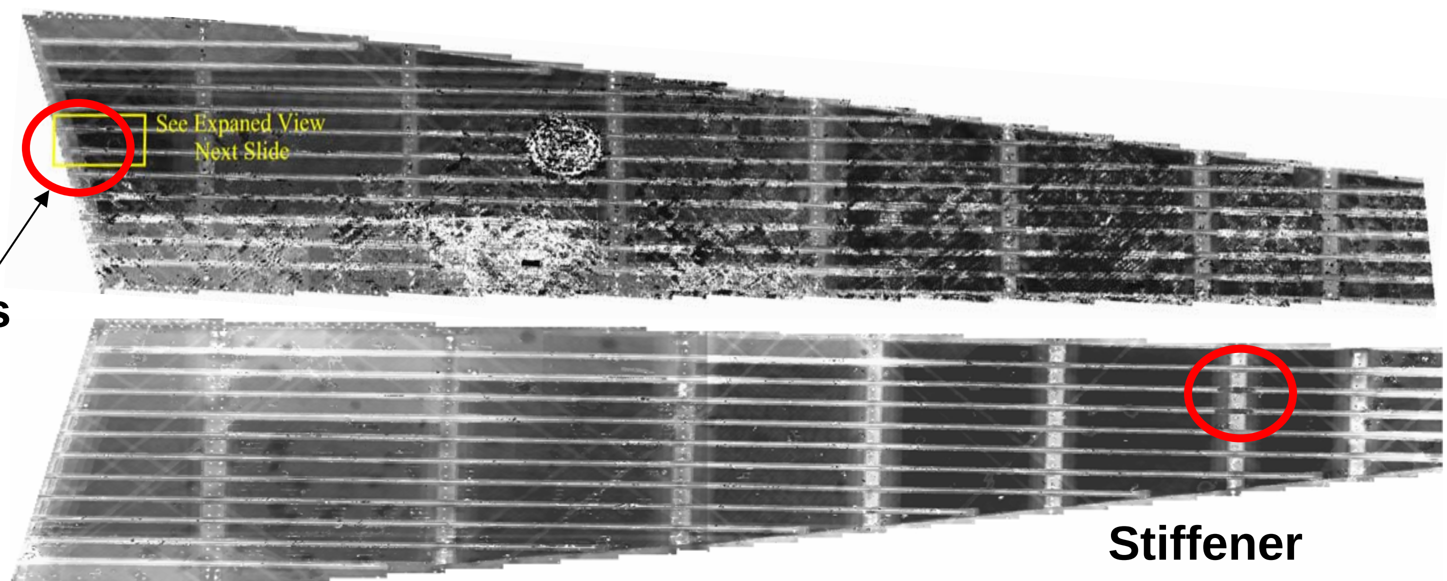


"Teardown" Approach

- Inspect
  – Field Level
  – Depot Level
  – Factory Level
  – Advanced Techniques
- Disassemble
- Physical and Mechanical Test
  – Tg, Microscopy, Tension, Compression, Rail Shear, 3-Stringer Compression Crippling

Production NDI Results

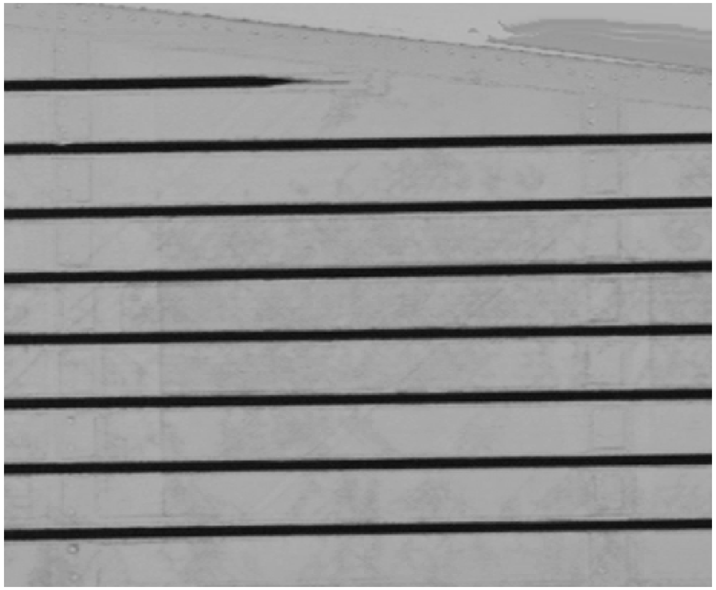
- **NDI with thickness mapping scan revealed stiffener disbonds**
  - **Known disbonds confirmed, other anomalies identified**



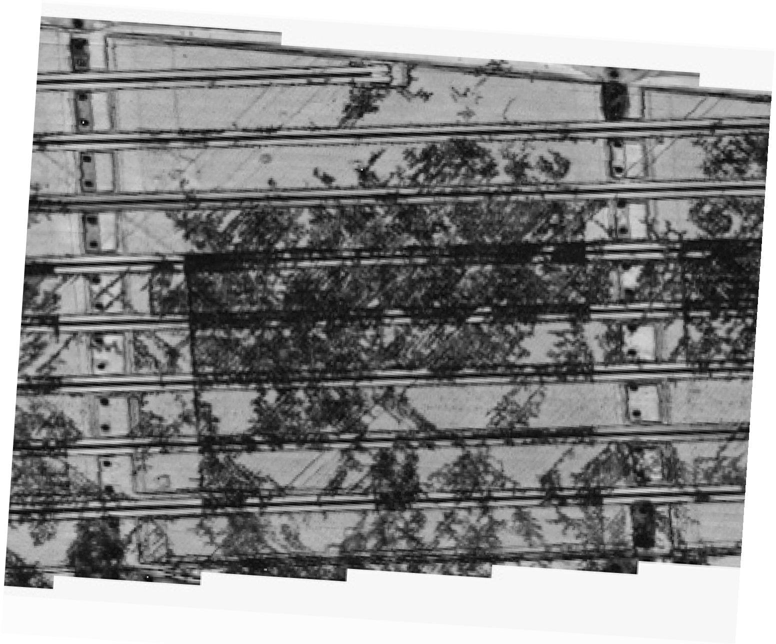
Right hand stabilizer (Teardown at WSU)

NDI – Then vs. Now

- **NDI has become more sensitive, standards more rigorous**
- **Today's materials and manufacturing processes <u>can</u> produce laminates with far less porosity levels**



1980's Sensitivity

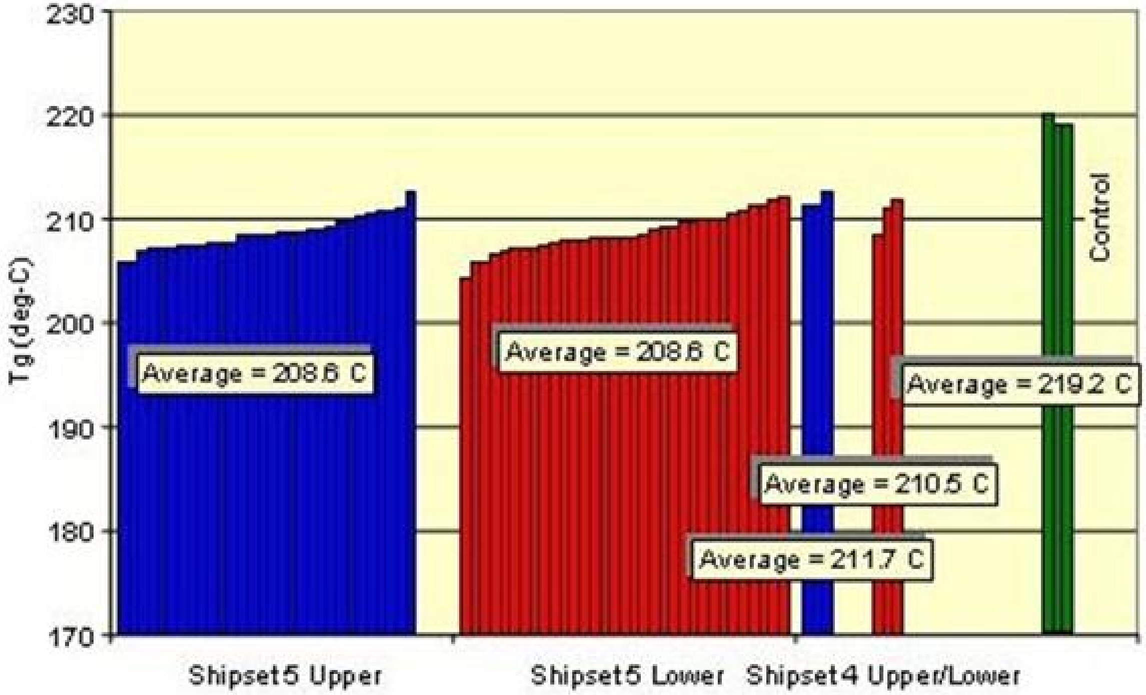


Today's Sensitivity

(scans show same structure but different sensitivity level)

Physical Test Results
(Tg)

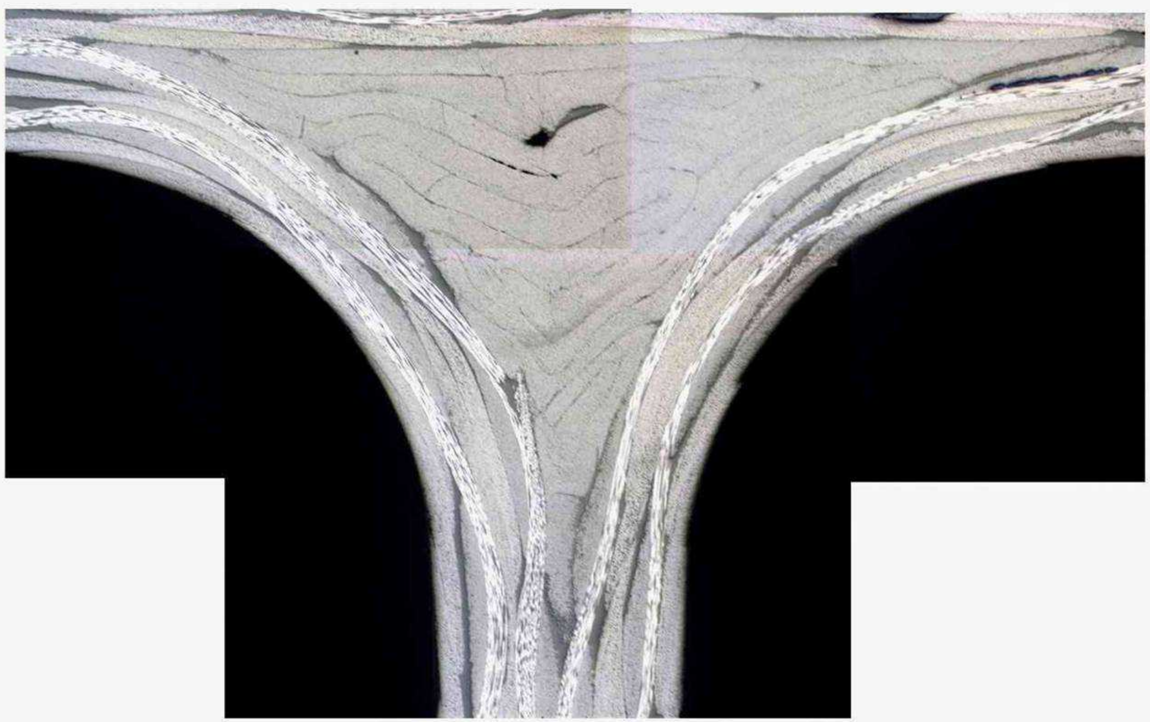
- **Tg values consistent but lower than limited "Quasi-Control" obtained from secondarily bonded spar**
- **NIAR results similar to slightly lower**
- **Tg remains significantly above service temperature**



Physical Test Results

(Microscopy)

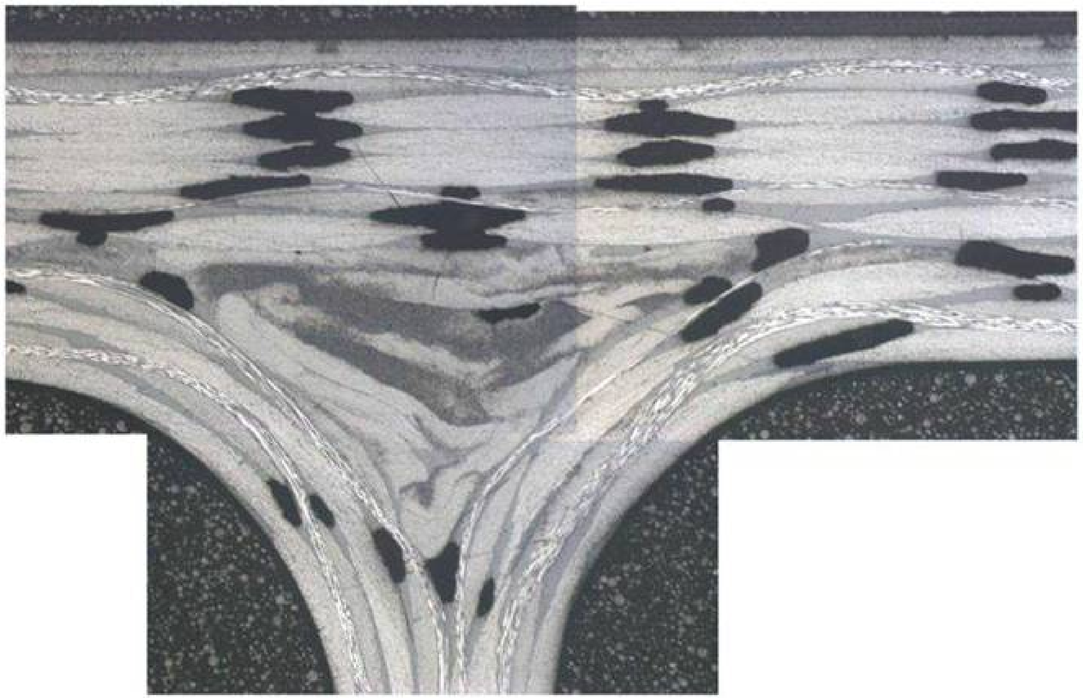
- **Upper skin stringer showing noodle region**
- **Good compaction / low porosity**
- **Some microcracking evident; microcracks concentrated in resin rich & resin starved areas**



Physical Test Results
(Microscopy)

- **Upper skin/stringer region taken in area of high attenuation**

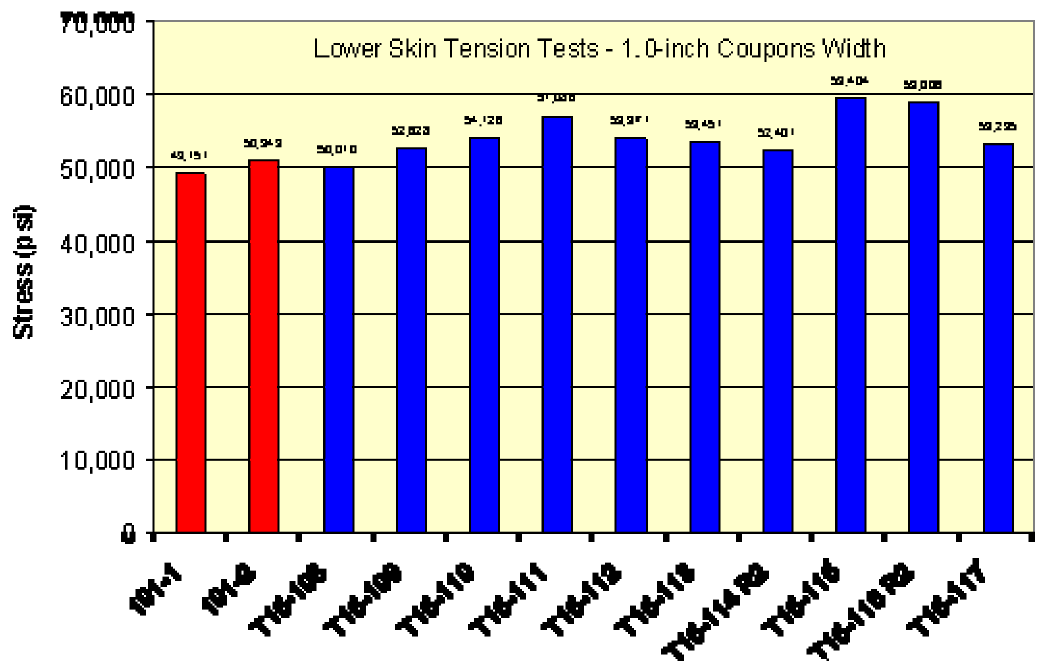
- **Up to 5+% porosity noted in Boeing teardown; similar results reported from NIAR teardown**



Ramifications?

Mechanical Test Results
(Tension)

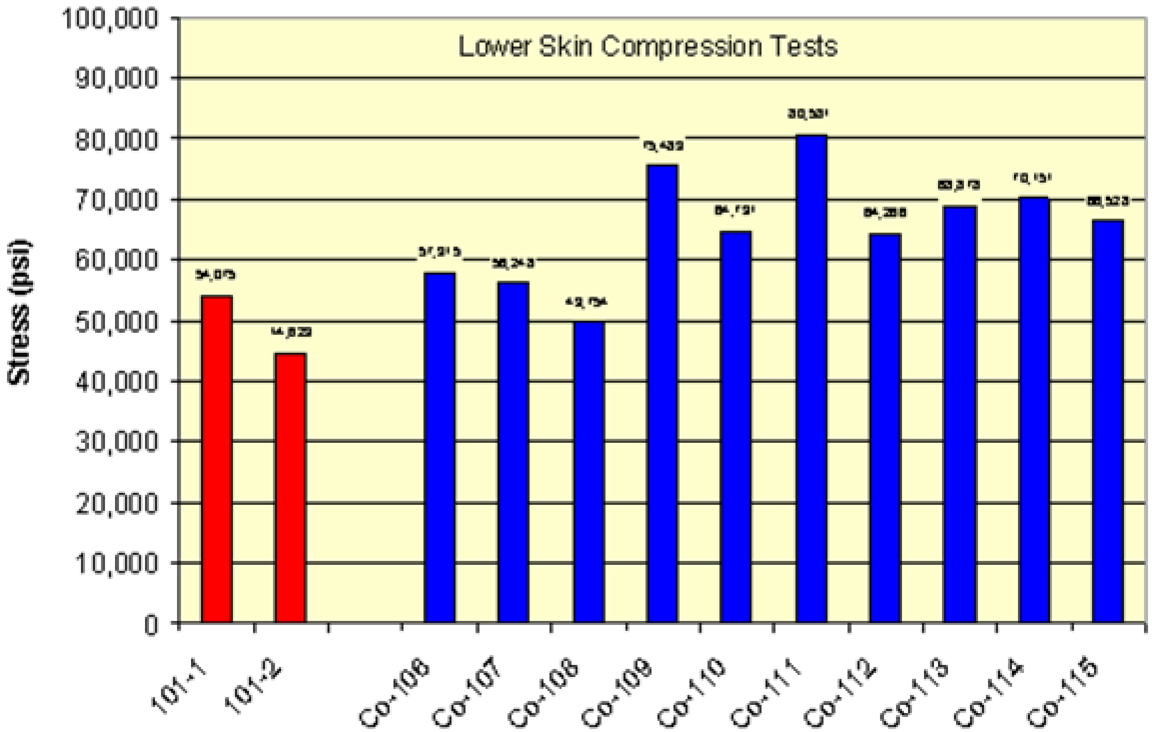
- **70 specimens from upper and lower skins of two stabilizer articles**
- **No significant degradation**
- **Shipset 4 equivalent to shipset 5**
- **Specimen curvature had little effect**



Mechanical Test Results

(Compression)

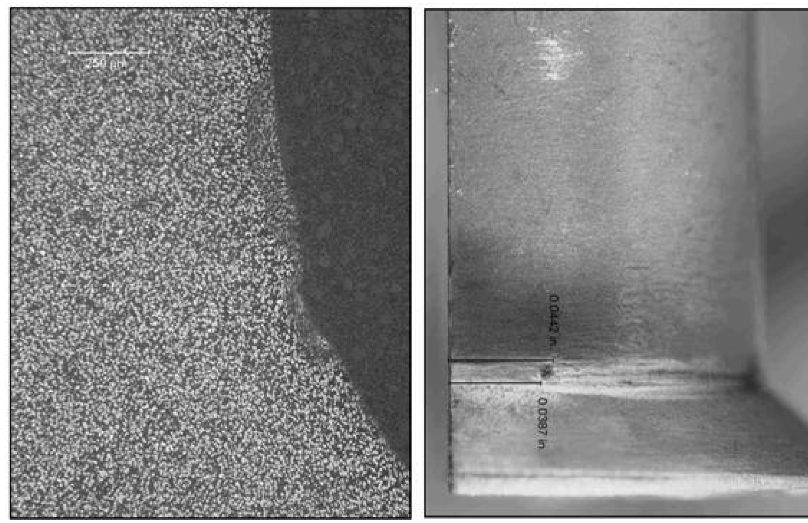
- **70 specimens from upper and lower skins of two stabilizer articles**
- **High scatter but no significant degradation / residuals higher than baseline for all regions / Shipset 4 equivalent to Shipset 5**
- **Scatter believed related to level of porosity**



Corrosion & Lightning Strike Evaluation

- **No evidence of lightning induced fastener pitting even though the teardown article leading edge & tip showed evidence of having been struck**

Lab Test specimen following simulated lightning strike



Mechanically induced fastener pit found on teardown article fastener – no evidence of lightning induced damage

Conclusions

- The teardown articles held up well in service
  - -- CFRP -- Fasteners -- Moldable Plastic Shim
- Almost all residual strengths above developmental baselines
  - (Postcure / physical aging?)
- Evidence of no creep
- The results also illustrate the dramatic improvements that have taken place in the last 25 years with CFRP materials and our ability to produce and inspect them
  - -- Production level NDI quality is moving into in-service environment
  - -- Newer, non-ultrasonic techniques are demonstrating great potential
- The results validated Boeing's design, analysis, certification, inspection, maintenance, and repair philosophies:
  - -- Damage occurred in service, inspections found the damage, & all damage was repairable

Some Other Le$$ons Along the Way

- **Some thermoplastic resin systems are Skydrol ® sensitive**
- **Kevlar® “wicks” moisture**
- **Damage to composite structure often more extensive than visible to the naked eye**
- **Even state of the art NDI will <u>not</u> necessarily find all defects**

CMH-17 Chapter 13 Outline

13.0 Defects, Damage & Inspection (NEW)

- **13.1 Defects and Damage**
  - **13.1.1 Defect Types**
    - **13.1.1.1 Porosity**
    - **13.1.1.2 Local Resin-Content Variations**
    - **13.1.1.3 Ply Misorientation**
    - **13.1.1.4 Ply Overlaps and Gaps**
    - **13.1.1.5 Fiber Distortion**
    - **13.1.1.6 Embedded Foreign Objects**
    - **13.1.1.7 Poor Bonds**
    - **13.1.1.8 Improper Curing**
    - **13.1.1.9 Warpage**
    - **13.1.1.10 Improper Fastener Installation**

Chapter 13 Outline (cont)

13.1.2 Damage Types

- **13.1.2.1 Fiber Breakage**
- **13.1.2.2 Matrix Imperfections**
- **13.1.2.3 Delaminations and Debonds**
- **13.1.2.4 Combined Damages**
- **13.1.2.5 Flawed Fastener Holes**
- **13.1.2.6 Nicks, Scratches and Gouges**
- **13.1.2.7 Dents**
- **13.1.2.8 Puncture**
- **13.1.2.9 Erosion**
- **13.1.2.10 Heat Damage**
- **13.1.2.11 Lightning Strike Damage**
- **13.1.2.12 Damage From Fluid Ingression into Sandwich Panels**

Chapter 13 Outline (cont)

- 13.1.3 Defect and Damage Sources
  - 13.1.3.1 Manufacturing
  - 13.1.3.2 Service
- 13.2 Inspection Methods
  - 13.2.1 Non-Destructive Inspection
    - 13.2.1.1 Visual
    - 13.2.1.2 Tap Testing / Lamb Wave
    - 13.2.1.3 Ultrasonics
    - 13.2.1.4 Radiography
    - 13.2.1.5 Shearography
    - 13.2.2.6 Themography
    - 13.2.2.7 Moisture Meters
    - 13.2.2.8 Bond Testers
    - 13.2.2.9 Eddy Current

Chapter 13 Outline (conc)

13.2.2 Destructive Inspection

- 13.2.2.1 Cross-sectioning / Photomicrographs
- 13.2.2.2 Deply
- 13.2.2.2 (Level-of-Cure Techniques)
- 13.2.2.3 Other ???

- **Status**

  Chapter 13 Draft well under way; ready for local review

  Outline sections in black font have been populated with material from:

  -- FAA Technical Document by Ilcewicz & Chang

  -- Sections 2.6, 3.4, 6.3, 12.4 & 14.3 of current CMH-17

  -- Lessons from service experience & teardown projects

  Chapter 14 rewrite just getting underway

  Welcome any additional inputs for either chapter

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