Aging of Composite Aircraft Structures

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May 19th, 2010

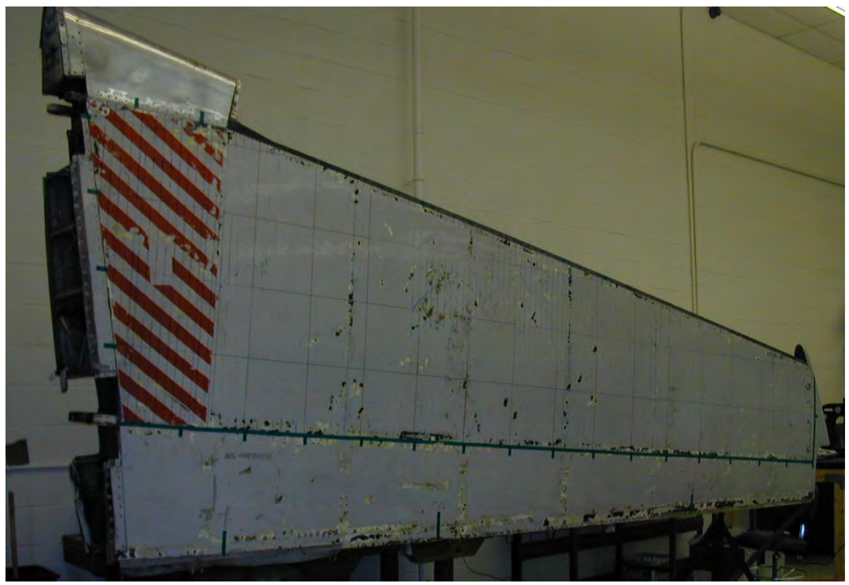
The Joint Advanced Materials and Structures Center of Excellence

B737-Stabilizer
FAA Sponsored Project Information

- Principal Investigators & Researchers
  - Dr. John Tomblin
  - Lamia Salah
- FAA Technical Monitor
  - Curtis Davies
- Other FAA Personnel Involved
  - Larry Ilcewiz
  - Peter Shyprykevich
- Industry Participation
  - Dr. Matthew Miller, The Boeing Company
  - Dan Hoffman, Jeff Kollgaard, Karl Nelson, The Boeing Company

Research Objective

- To evaluate the aging effects of a (RH) graphite-epoxy horizontal stabilizer after 18 years of service (48000 flights, 2/3 of DSO)

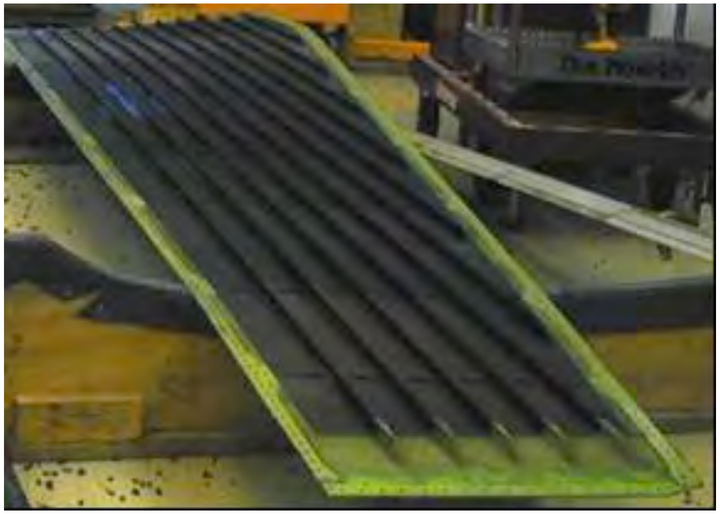


Boeing 737 Horizontal Stabilizer Fleet Status

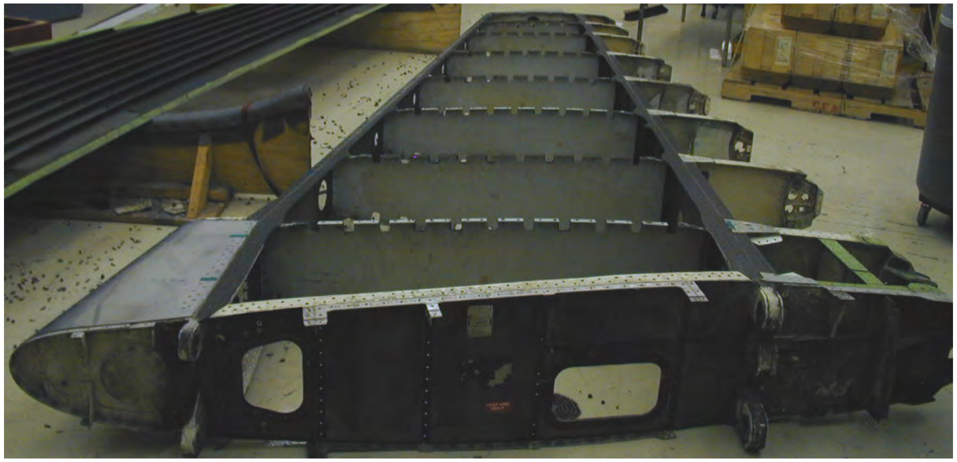
Shipset / Production Line #	Entry into Service	Airline	Status as of January 2009
1 / 1003	2 May 1984	A & F	In service (60000 hours, 45000 flights) sold to a foreign carrier
2 /1012	21 March 1984	A	Returned to lessor, currently being refurbished (62000 hours, 47000 flights)
3 / 1025	11 May 1984	B	Damaged 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

B737 Horizontal Stabilizer Teardown

Upper Skin (RH)



Lower Skin (RH)



Center Box (RH)

- Structure held very well
- No evidence of pitting or corrosion

  as would be observed in a metal

  structure with similar service history

B737 Horizontal Stabilizer Teardown

Front (Top) and Rear (Bottom) Spars after disassembly

Conclusions
Value of the Results

- Structure held extremely well after 18 years of service: no obvious signs of aging to the naked eye such as pitting and corrosion as would a metal structure with a similar service history exhibit
- Physical tests showed moisture levels in the structure after 18 years of service as predicted during the design phase (1.1 ± 0.1%)
- Thermal analysis results very consistent with those obtained for the left hand stabilizer
- Thermal analysis showed that the degree of cure of the spars is close to 100%, that additional curing may have occurred in the upper skin due to UV exposure (overall at least 95% cure was achieved in the structure)
- Significant improvements in composite manufacturing processes and NDI methods
- New material resin system thermal properties comparable to old material but strength is higher (fiber processing improvement)
- Teardown provides closure to a very successful NASA program and affirms the viability of composite materials for use in structural components
- From all data generated, the margins were sufficient to warrant a "no significant degradation" conclusion.

Project Complete, Final Report Submitted to Technical Monitor

Beechcraft Starship Aft Wing Teardown- FAA Sponsored Project Information

- Principal Investigators & Researchers
  - Dr. John Tomblin
  - Lamia Salah
- FAA Technical Monitor
  - Curtis Davies
- Other FAA Personnel Involved
  - Larry Ilcewicz
  - Peter Shyprykevich
- Industry Participation
  - Mike Mott

Research Objective

- To evaluate the aging effects of a Beechcraft starship (NC-8) main wing after 12 years
  of service
- To generate data substantiating aging of composite structures

Status of Tasks

➢ **Non-Destructive Inspection to identify flaws induced during manufacture/ service (delamination,
disbonds, impact damage, moisture ingression, etc…)** – **Complete**

➢ **Coupon level static and fatigue tests to investigate possible degradation in the mechanical
properties of the material (comparison with OEM tests) – In progress**

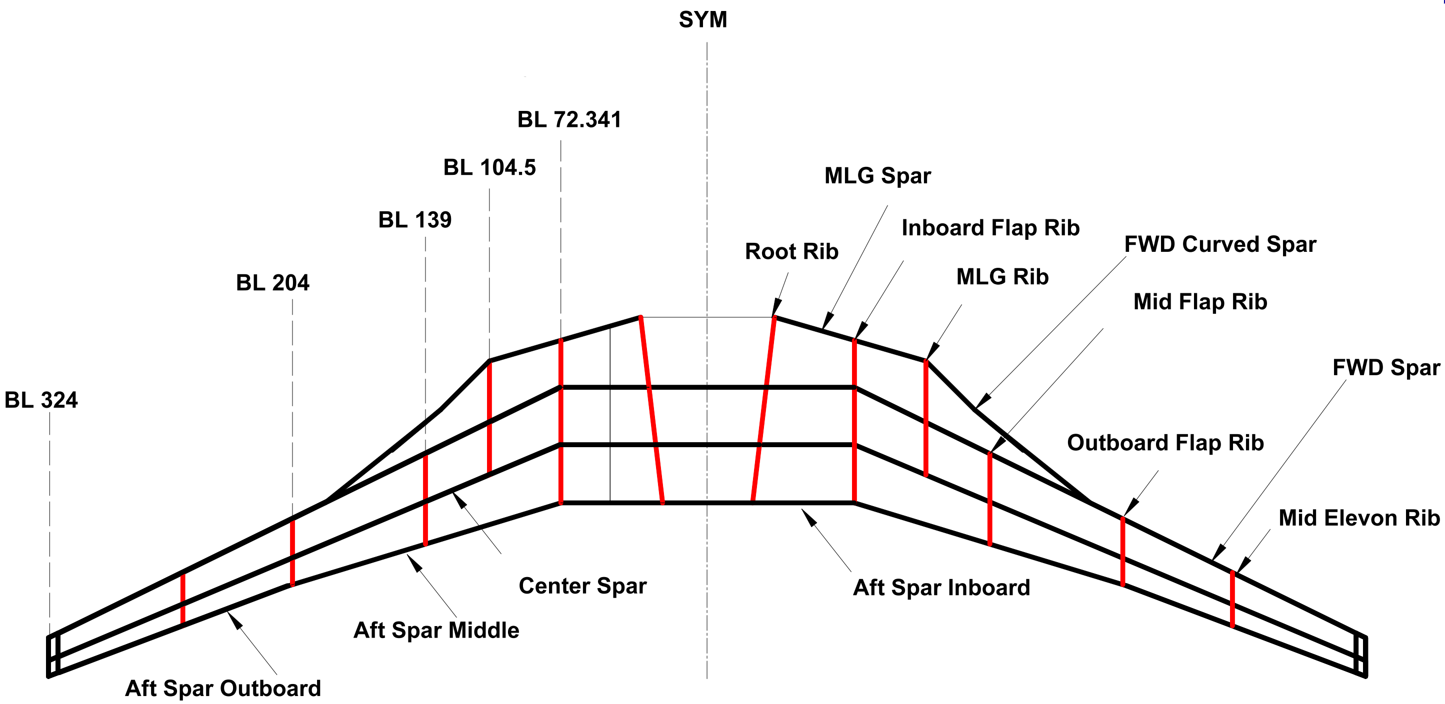
➢ **Physical and thermal tests to validate design properties, identify possible changes in the
chemical/ physical/ thermal properties of the mate**

➢ **Full scale static, durability tests to evaluate
the structural integrity of the main wing 19 years
since manufacture (12 years in service)**

Initial NDI inspection – Complete
Limit Load test followed by 1 fatigue lifetime – Com
NDI inspection after 1 fatigue lifetime – Complete
Residual Strength after fatigue (Limit Load) – Complete

Test Article Description (Main Wing)

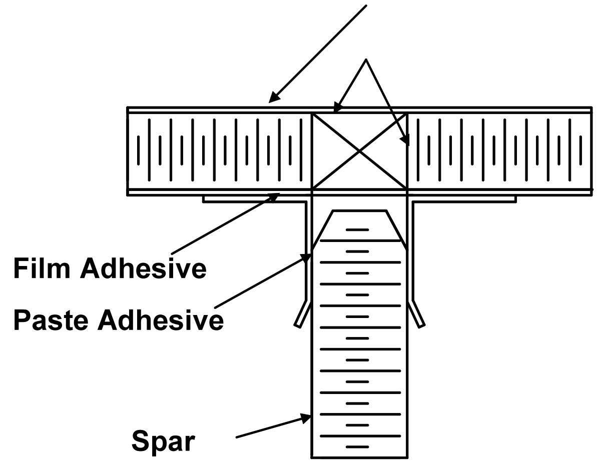
- Monocoque sandwich structure with three spars and five full-chord ribs symmetric about the aircraft centerline
- The wing skins are cured in one piece 54 feet tip to tip
- The wing skins are secondarily bonded to the spars and ribs using paste adhesive (EC3448 at 250°-270°F)
- Materials are AS4/E7K8 12K tape and AS4 E7K8 PW and 5HS with AF163 adhesive (Cured a
300°

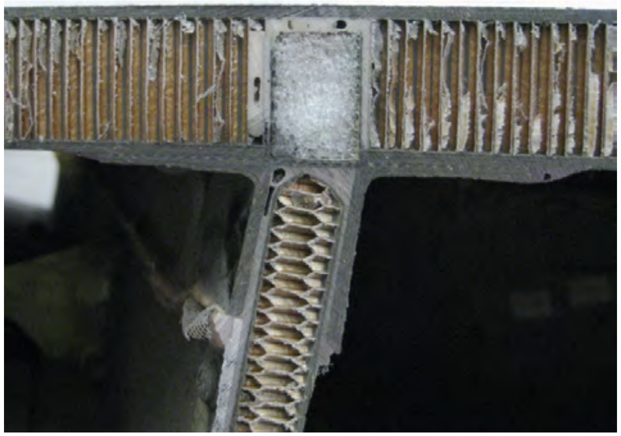


Test Article Description (Main Wing)

- H-Joint: used to join the upper and lower skins
  to the spars
- A cutout is first routed in the skin prior to bonding the joint to the skin.
- The joint is then secondarily bonded to the skin
  using paste and film adhesive (EC3448 and AF163)
- The spars are finally bonded to the assembly
  using paste adhesive

- Lightning Protection: Aluminum interwoven
  wires in the outer ply of all exterior surfaces



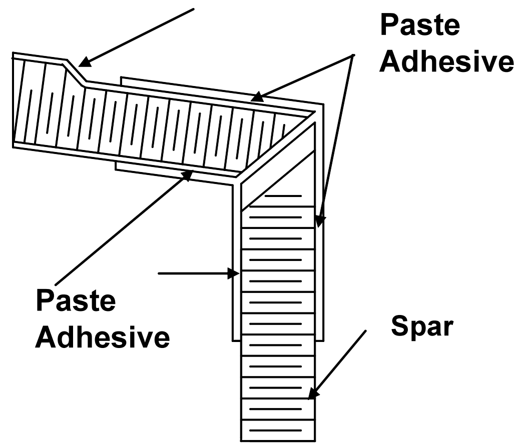


Test Article Description (Main Wing)

- V-Joint: used to bond the upper and lower wing
  skins to sections of the forward and aft spars

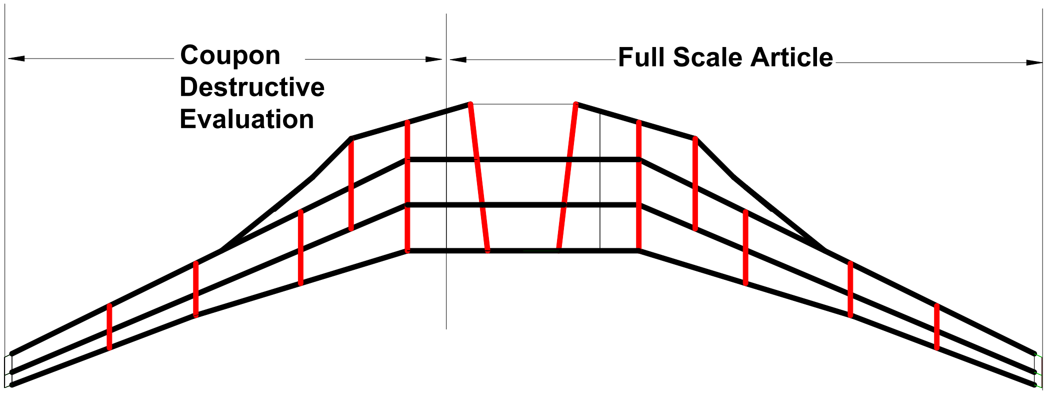
- The pre-cured graphite epoxy joint is secondarily
  bonded to the wing skin first using paste adhesive

- After this process is completed, the assembly is
  subsequently joined to the spars using paste
  adhesive



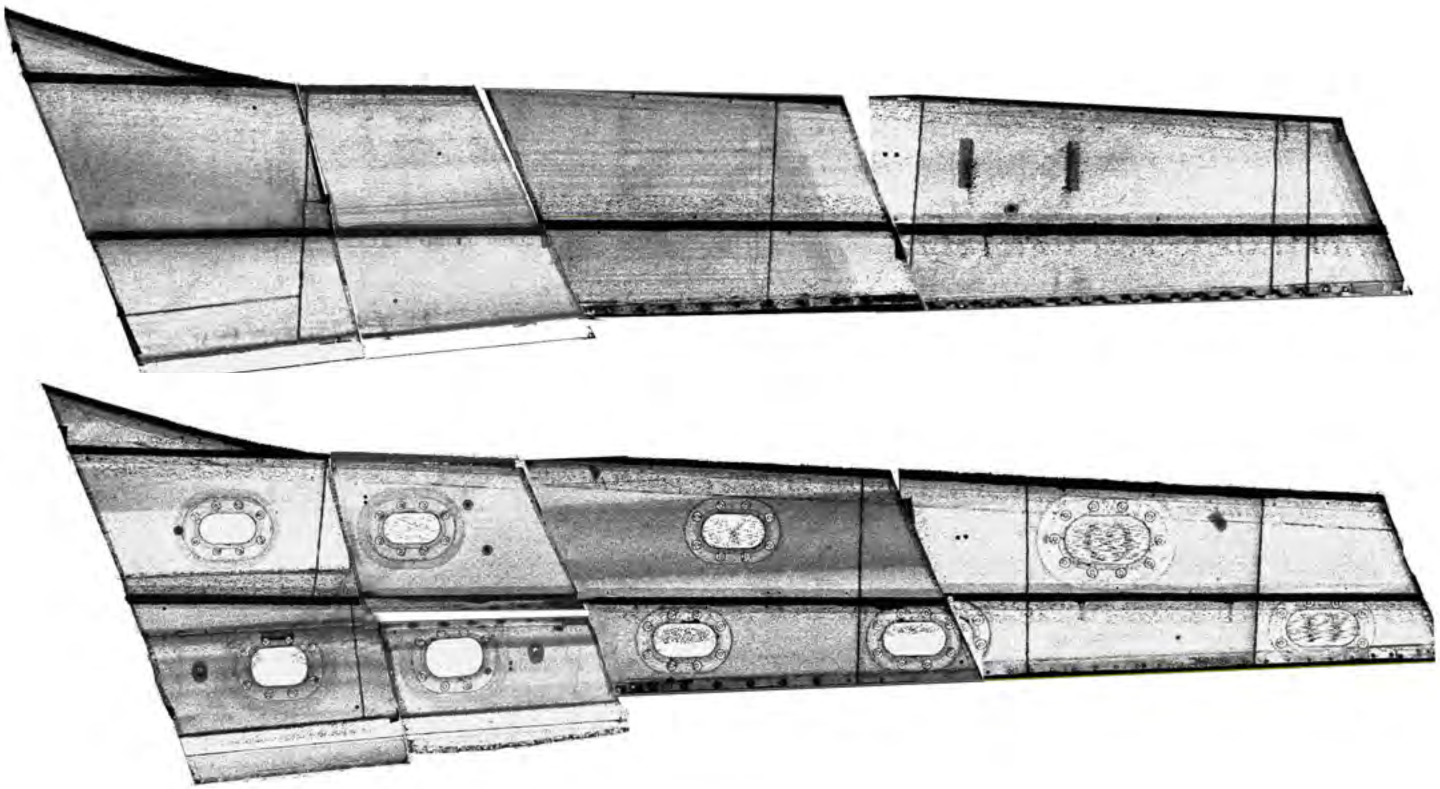
Teardown

- Main components disassembled (fuselage, forward wing, main wing, nacelles, fuel tanks)
- Main wing cut in two pieces for ease of transportation



NDI-LH Main Wing (Skins)

TTU Non-Destructive inspection showed no major flaws induced during manufacture or service in the skins. Maximum porosity levels found were less than 2.3%.



Thermal Analysis
Physical Test Results

- Tg results from coupons extracted from upper and lower skins are very consistent (300°F cure)

  US Results ~ 313°F (average storage modulus) -351°F (average peak tanδ)

  LS Results ~ 307°F (average storage modulus) -348°F (average peak tanδ)

- DSC Results on both upper and lower skins yielded small heat of reaction values -> fully cured

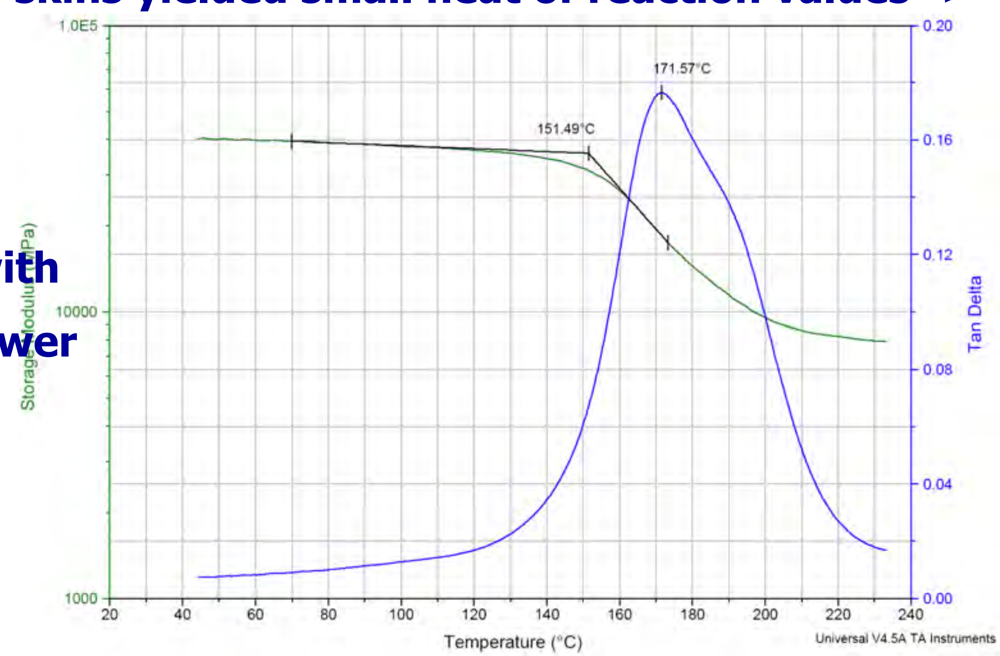
  skins

- Physical test results showed porosity

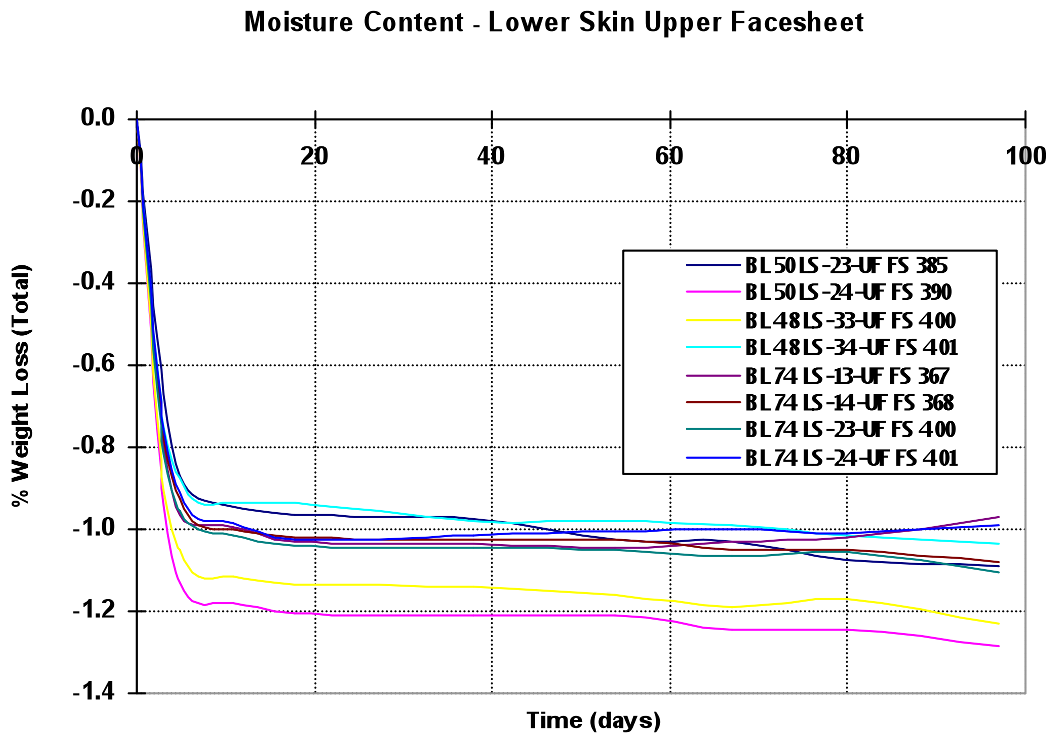
  levels lower than 2.3% (correlates with

  OEM NDI data) for both upper and lower

  skins



Physical Test Results
Moisture Content



Specimens extracted from both upper and lower sandwich skins (upper and lower facesheets)

Facesheets dried per ASTM D5229

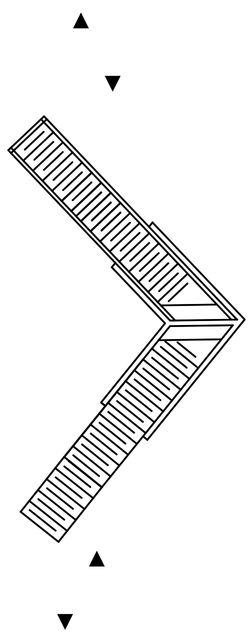
Maximum Moisture content ~1.065% for US and ~1.286% for LS

NASA Report Moisture Analysis

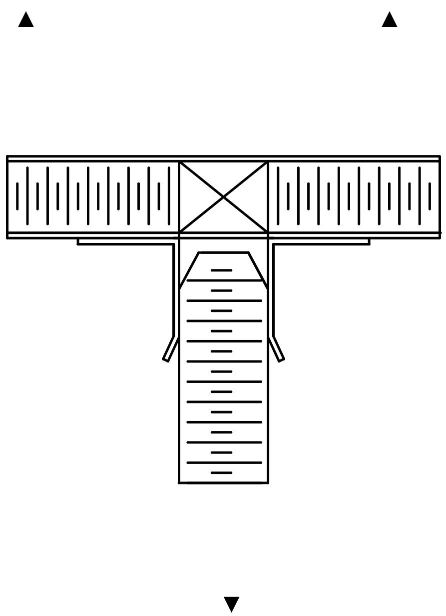
1.1±0.1% total weight gain expected in the structure in service

Investigative Plan – Planned Mechanical Tests

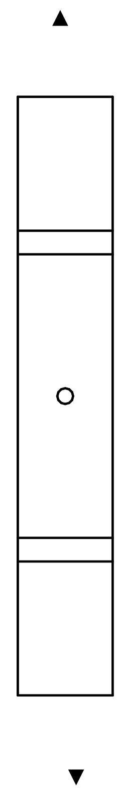
- **Mechanical Testing: V/H Joint Mechanical Testing, CAI testing (to compare with OEM data)**



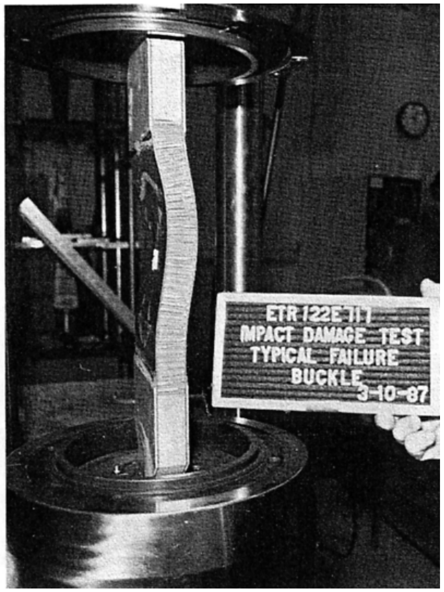
V-joint Static/ Cyclic Tension/ Compression



H-joint Static/ Cyclic Tension



FHT



Compression after Impact

Full Scale Structural Test

Purpose:

- unique opportunity to use a production model with service history to validate the component's (Starship aft wing) structural integrity
- to test the same structure with the same team that conducted the full scale tests during certification (minimize operator variability)
- to be able to assess aging effects and estimate the "residual" life of the component using a production article with service history

Methodology

- A baseline Non-Destructive Inspection was conducted according to OEM specifications prior to subjecting the structure to limit load (NDI grid has been drawn on the structure for ease of inspection and flaw growth monitoring)
- Visual inspection, TTU and tap testing were used for the inspection
- A few areas in both the upper and lower skins have been identified as disbonds by the inspectors ->identified as potted areas-> areas repaired per OEM prior to limit load test

Full Scale Structural Test - Summary

Baseline NDI Inspection after 1800 hours of service

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Limit Load Test – Max Upbending Case
- Strain and Deflection Surveys
- Comparison with Certification Data

↓

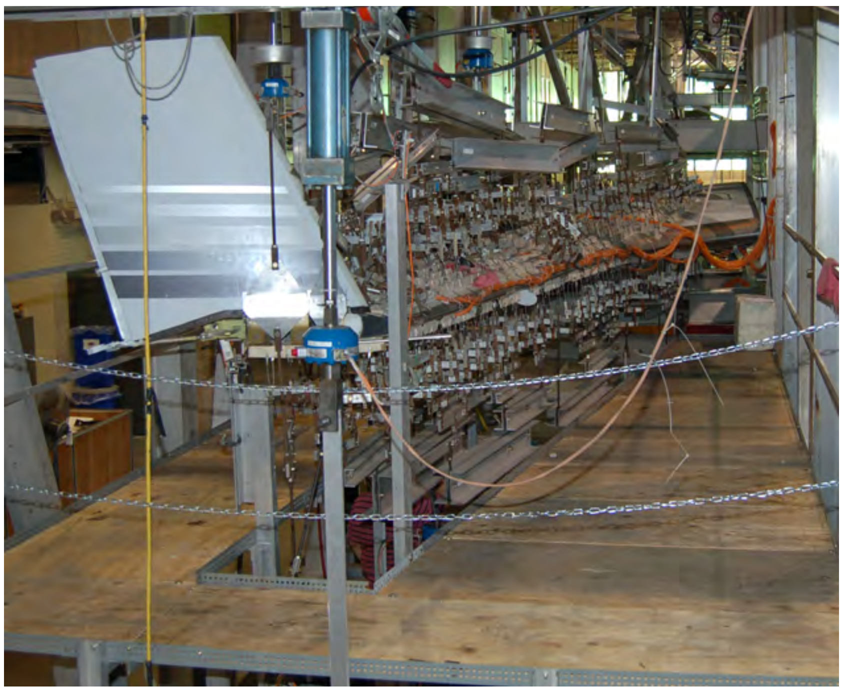
Durability Test at original spectrum levels with 15% LEF
-NDI inspection after 10000 hours
-NDI inspection after durability test

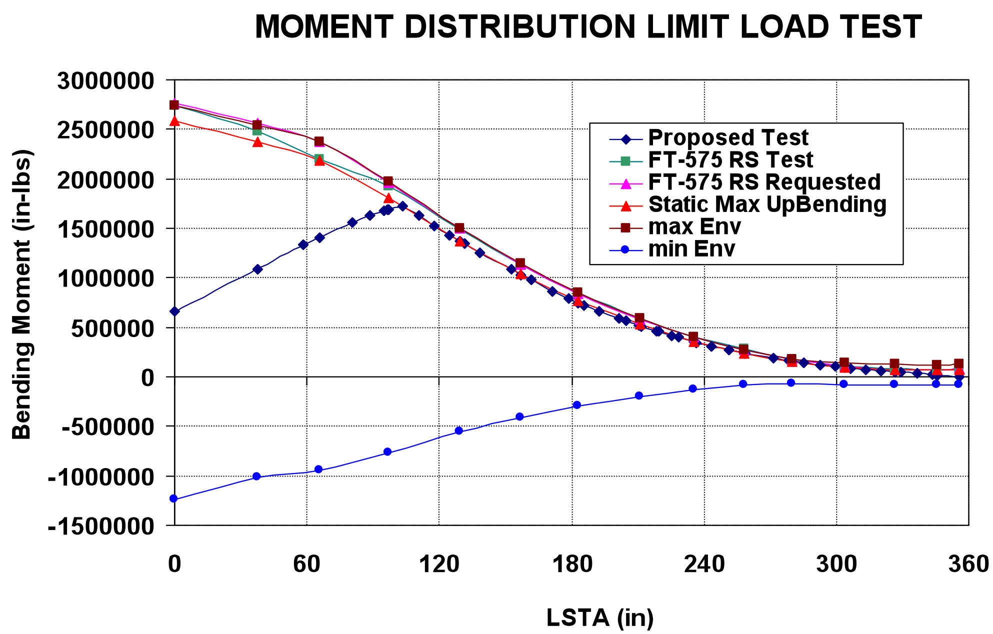
↓

Residual Strength Test (Limit)
-Strain and Deflection Surveys
- Comparison with Certification Data

Limit Load Test-
Upbending Case Cond 4A

- **Limit Load Condition 4A- (Max Positive Moment) – most severe**
- **Shear/ moment/ torque introduced were very close to the static 4A (upbending case) values from RBL 100 to RBL 360**





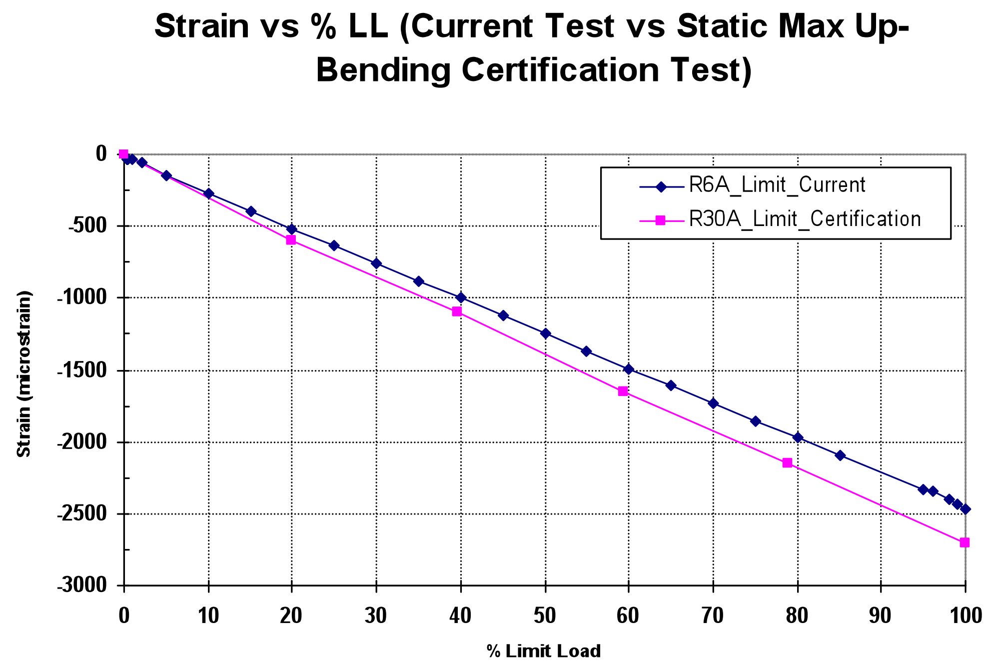
Limit Load Test

- **R-H Wing sustained 100% Up-bending Limit Load Test**

Limit Load Test (LL)-Results

- Strain and Deflection vs % LL comparison between current test and wing max upbending
  certification limit test (Cond 4A)
- No major change in compliance, certification data correlates very well with aged structure
  limit load test results (data linear to limit load)

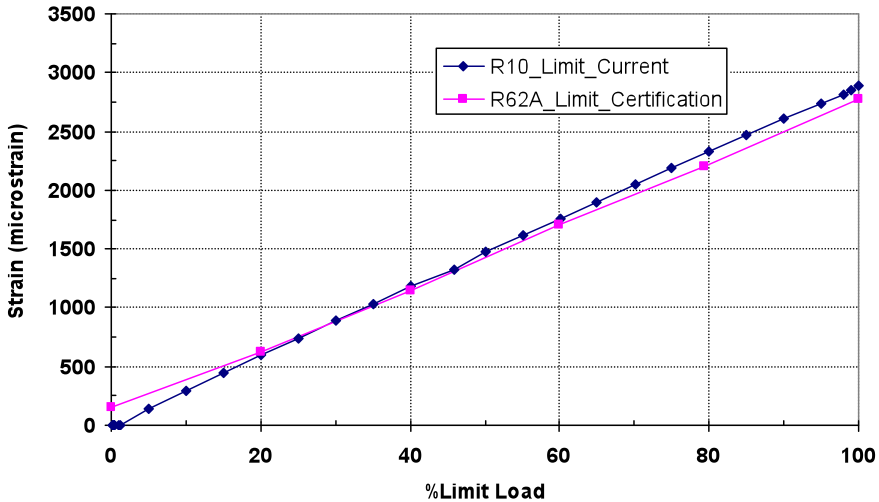
Strain Gage R6 on test article
Located on Upper Skin
RBL 174 FS 424.5
Same Location as R30
(Certification Test)



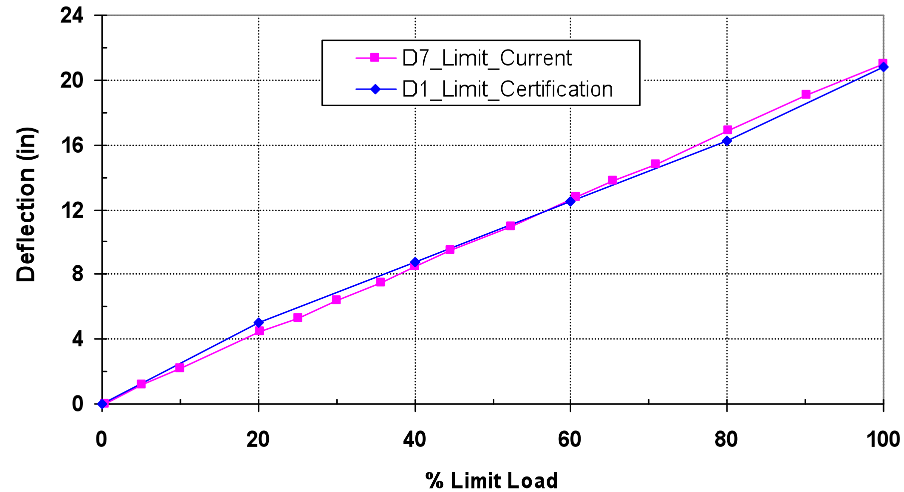
Limit Load Test (LL)-Results

➢ **Certification test article data correlates very well with aged structure limit load test data**
(data linear to limit load)

Strain vs % LL (Current Test vs Static Max Up-Bending Certification Test)



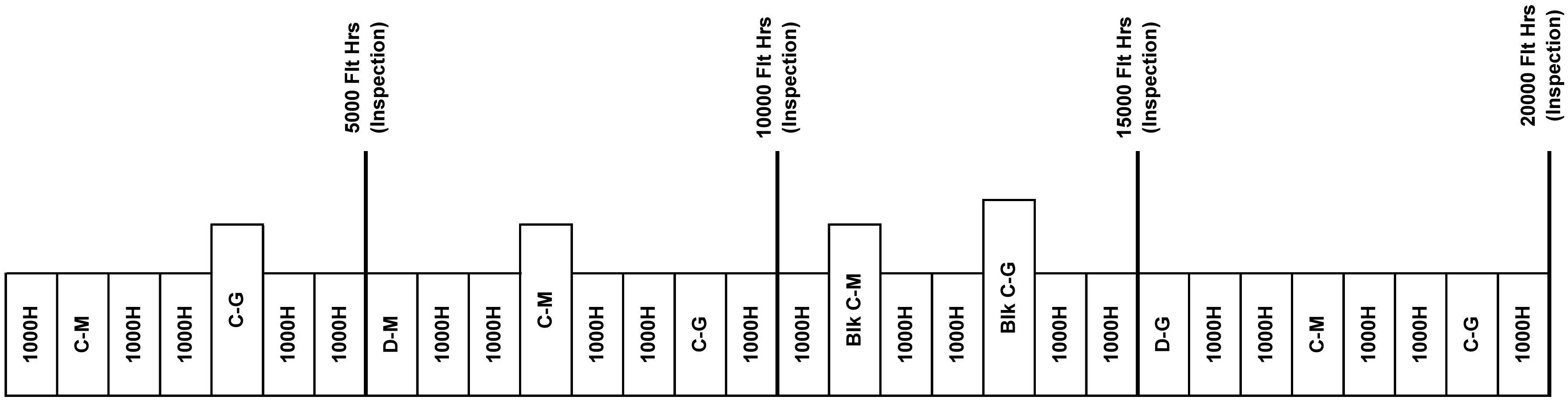
Deflection vs % LL (Current Test vs Static Max Up-Bending Certification Test)



Strain Gage R10 on test article
Located on Lower Skin Outer Facesheet
RBL 208 FS 439.5
Same Location as R62 (Certification Test)

Deflection Transducer D7 on test article
Located on Lower Skin Outer Facesheet
RBL 319.4 FS 479.7
Same Location as D1 (Certification Test)

Durability Test – Spectrum Loading Sequence



1 test lifetime = 20000 hours consists of 219395 total cycles

1 Lifetime (20000 hour) spectrum:

- **12 load blocks (115335 gust cycles, 66060 Maneuver cycles, 19000 Landing cycles 19000 takeoff cycles)**
- **A=100 Hour Block, B=1000 Hour Block, C=5000 Hour Block, D=20000 Hour Block**
- **T= Takeoff, G= Gust, M=Maneuver, L=Landing**
- **100 hour block (A-T, A-M, A-G, A-L)**
- **1000 hour block (100H, B-T, B-M, B-G, B-L, 100H)**

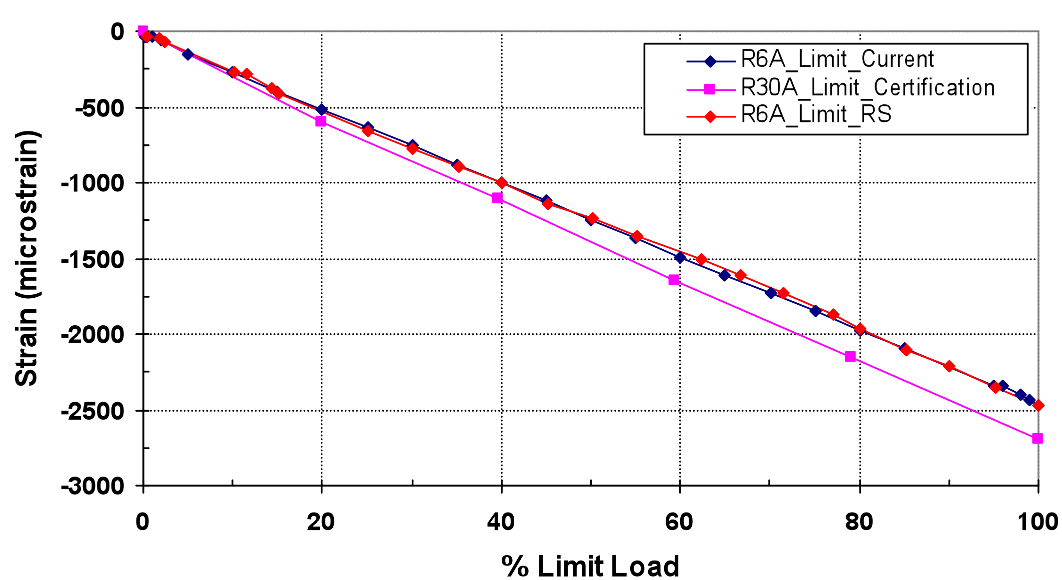
Durability Test

- full scale durability test to investigate the durability of the aged aft wing
- Fatigue loads include gust, maneuver, landing and taxi
- fatigue loads applied with 15% LEF
- landing loads not included (no landing gear or engines in the structure) (blocks A-L, B-L)
- Test frequency 0.25 hz
- Relieving loads were added to the landing gear and engine mount fittings in order to reduce
  the bending moment at the root of the wing (wing box)
- Negative loads (upper skin tension loads) truncated
- Wing subjected to 200395 cycles of fatigue, 1 lifetime equivalent to 20000 service hours
  (19000 takeoff cycles truncated)
- Durability test complete

Residual Strength Test to Limit Load-Results

- Strain and Deflection vs % LL comparison between current test and wing max upbending certification limit test (Cond 4A)
- No major change in compliance, certification data correlates very well with aged structure limit load test results (data linear to limit load)

Strain vs % LL (Current Test vs Static Max Up-Bending Certification Test)



Strain Gage R6 on test article
Located on Upper Skin
RBL 174 FS 424.5
Same Location as R30
(Certification Test)

Residual Strength Test to Limit-Results

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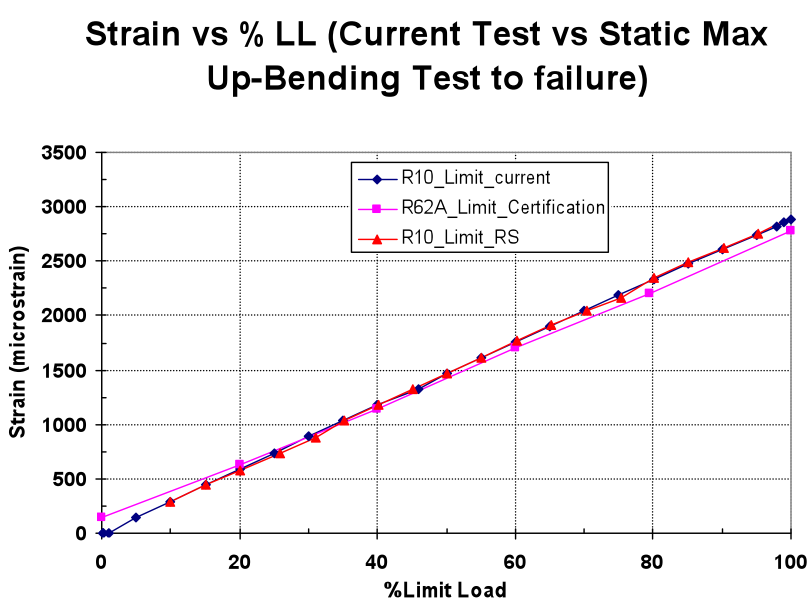
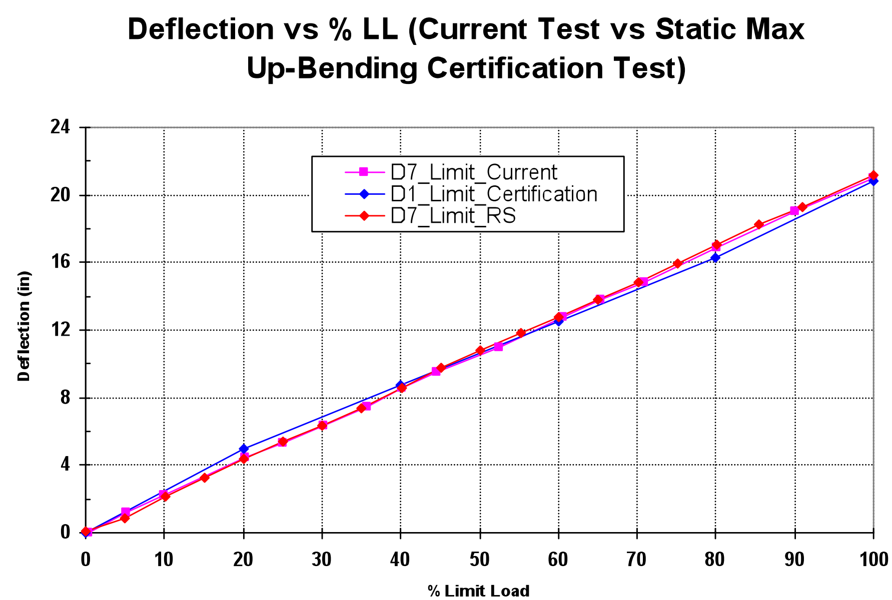
➢ **Certification test article data correlates very well with aged structure limit and residual strength (to limit) test data (data linear to limit load)**





Strain Gage R10 on test article
Located on Lower Skin Outer Facesheet
RBL 208 FS 439.5
Same Location as R62 (Certification Test)

Deflection Transducer D7 on test article
Located on Lower Skin Outer Facesheet
RBL 319.4 FS 479.7
Same Location as D1 (Certification Test)

Conclusions

- Structure held extremely well after 12 years of service: no obvious signs of aging/ degradation to the naked eye as would a metal structure with a similar service history exhibit
- Thermal analysis results show no degradation in thermal properties of the material and that the skins are fully cured/ cross-linked
- Physical Tests showed moisture levels indicative of a structure that has reached moisture equilibrium (consistent with other long term service exposure)
- Physical test results showed porosity levels higher than 2% which correlate with OEM production information
- LH NDI showed no major defects/ damage in the skins introduced during manufacture or service
- NDI response subject to operator interpretation (full scale test article inspection)
- Full scale test results of the "aged wing" correlated very well with the results obtained for the certification article

A Look Forward
Benefits to Aviation

- Understand the aging of composite structures (current aging studies focused on metal structures)

Producibility large co-cured assemblies reduce part and assembly cost, however other costs should be taken into account, for example, when disposing of non-conforming assemblies

Supportability needs to be addressed in design. Composite structures must be designed to be inspectable, maintainable and repairable

- most damage to composite structures occurs during assembly or routine aircraft maintenance
- SRM's are essential to operating with composite structures, engineering information needed for in-service maintenance and repair