Advanced Hybrid Structural Concepts for Care-Free Structures: Experimental Validation and Path Forward

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Dr. Markus Heinimann
R.J. Bucci, M. Kulak, F.A. Shoup, J. Hinrichsen
Alcoa Technical Center, Alcoa Center, PA, USA

G.H.J.J. Roebroeks, P.A. Hooijmeijer, GTM Advanced Structures, The Hague, The Netherlands

Outline

- Introduction to Advanced Hybrid Structures (AHS) Concepts
- Introduction to Idea of Care-Free Structures
- Experimental Data to Demonstrate Care-Free Promise of AHS Concepts
  - Crack Initiation and Small Crack Growth and Residual Strength
  - Large, Easily Detectable Crack Growth and Residual Strength
- Manufacturing and In-Service Inspection
- Remaining Technology Gaps

Alcoa Aerospace R&D - *the path forward*

To fulfill its vision of meeting demanding mission and affordability requirements of future aircraft, Alcoa has made a fundamental R&D shift from incremental alloy improvements to a long-term strategic initiative integrating materials, design, manufacturing, assembly and sustainment technologies.

Design trade studies, large panel testing and manufacturing demonstrators conducted to date strongly indicate that Advanced Hybrid Structural *<u>Assemblies</u>* combining cutting edge metallic and hybrid material/structural concepts offer potential quantum leap improvements in weight and cost savings along with extended inspection interval, high corrosion resistance and lower life cycle cost.

Introduction to Advanced Hybrid Structure Concepts

- **Combines advanced design with best characteristics of current aerospace materials – metals and composites, while avoiding the respective disadvantages**
  - ✓ Employs advanced metallic design placing more expensive fibrous materials only where necessary to improve properties
  - ✓ Allows tailoring of structural performance to simultaneously meet many of the dimensioning criteria by varying materials & form metal/fiber volume fractions/orientations, adhesive type, number of interfaces, etc.
  - ✓ Efficient design by maximizing buy-to-fly economics with minimal over-design to any single criteria (common uni-material limitation)

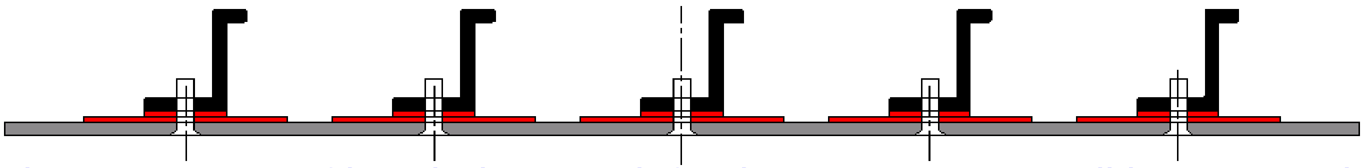
- **Two concepts currently under development at Alcoa:**
  - ✓ Selective Reinforcement (low hybridization)
  - ✓ Sandwich Reinforced Panels (higher hybridization)

Preliminary Definitions

Alcoa Advanced Hybrid Structure:

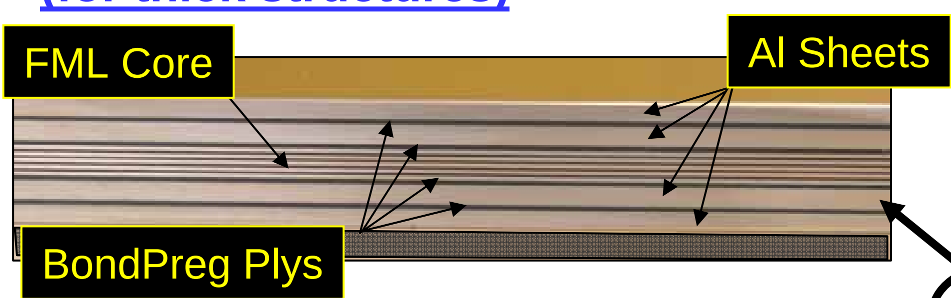
The structural marriage of advanced alloys in sheet, plate or extruded form with reinforcement provided by high-performing FML materials to achieve significant property improvements and exceptional damage tolerance

Selective Reinforcement: (for thin structures < 0.2”)

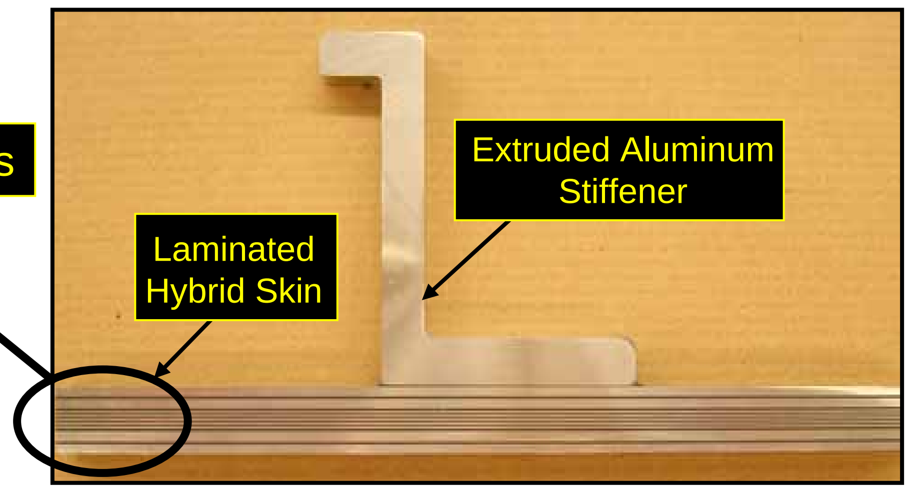


The selective placement of bonded FML reinforcing straps over traditional metallic structure

Advanced Hybrid Structure: (for thick structures)



Typ. CentrAl Skin Configuration



A reinforced assembly combining the concept of selective reinforcement and laminated metallic structure with embedded FML reinforcement

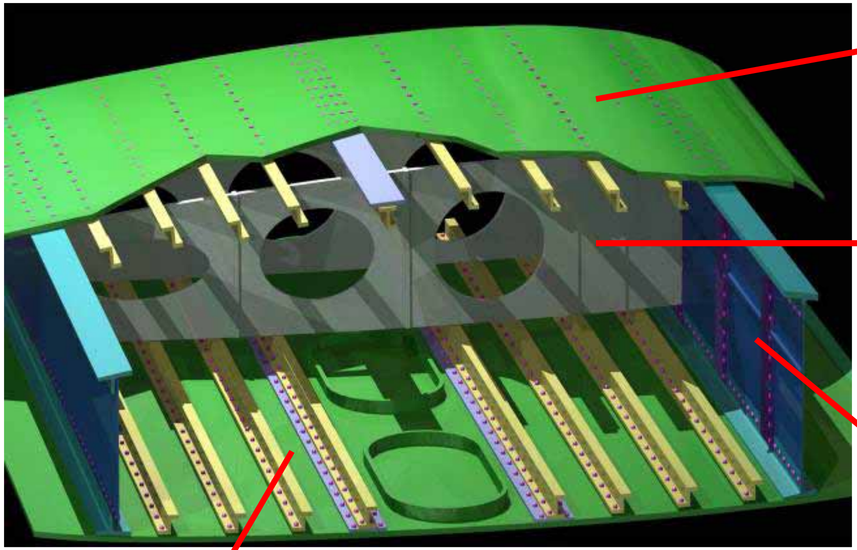
FML strong points are well-suited to the Hybrid Structure Concept

- **Combines best of two material systems**
  - ✓ **Metal: isotropy, plasticity, shear, bearing, impact, damage detection**
  - ✓ **Composite: fatigue, tensile strength**
- **Highly crack growth resistant – "fatigue insensitive material"**
- **Up to 40% higher directional strength and 10-15% lower density than conventional aluminum alloys**
- **Works like metal (machining, drilling, forming, joining, …)**
- **Metallic and composite inspection/repair methods apply**
- **Other:**
  - ✓ **Good corrosion, lightning strike and flame barrier properties**
  - ✓ **Metal layers protect fibers from traffic and moisture**
  - ✓ **Improved dent resistance**
  - ✓ **Splice joining concept makes ultra-large panels possible**
  - ✓ **Autoclave curable to produce complete structure (e.g., large curved panels with co-cured doublers and stiffening elements)**
  - ✓ **Improved vibration damping over aluminum sheet**

- ***Potential for significant weight & ownership cost reductions; lower maintenance and longer-lived structures***

Alcoa Wing Box Concept Opportunities

Utilizes best material and design concept to arrive at optimum wing box concept – overall can provide a 20% weight savings, at significantly extended inspection intervals, at lower cost than state-of-the-art metallic wing

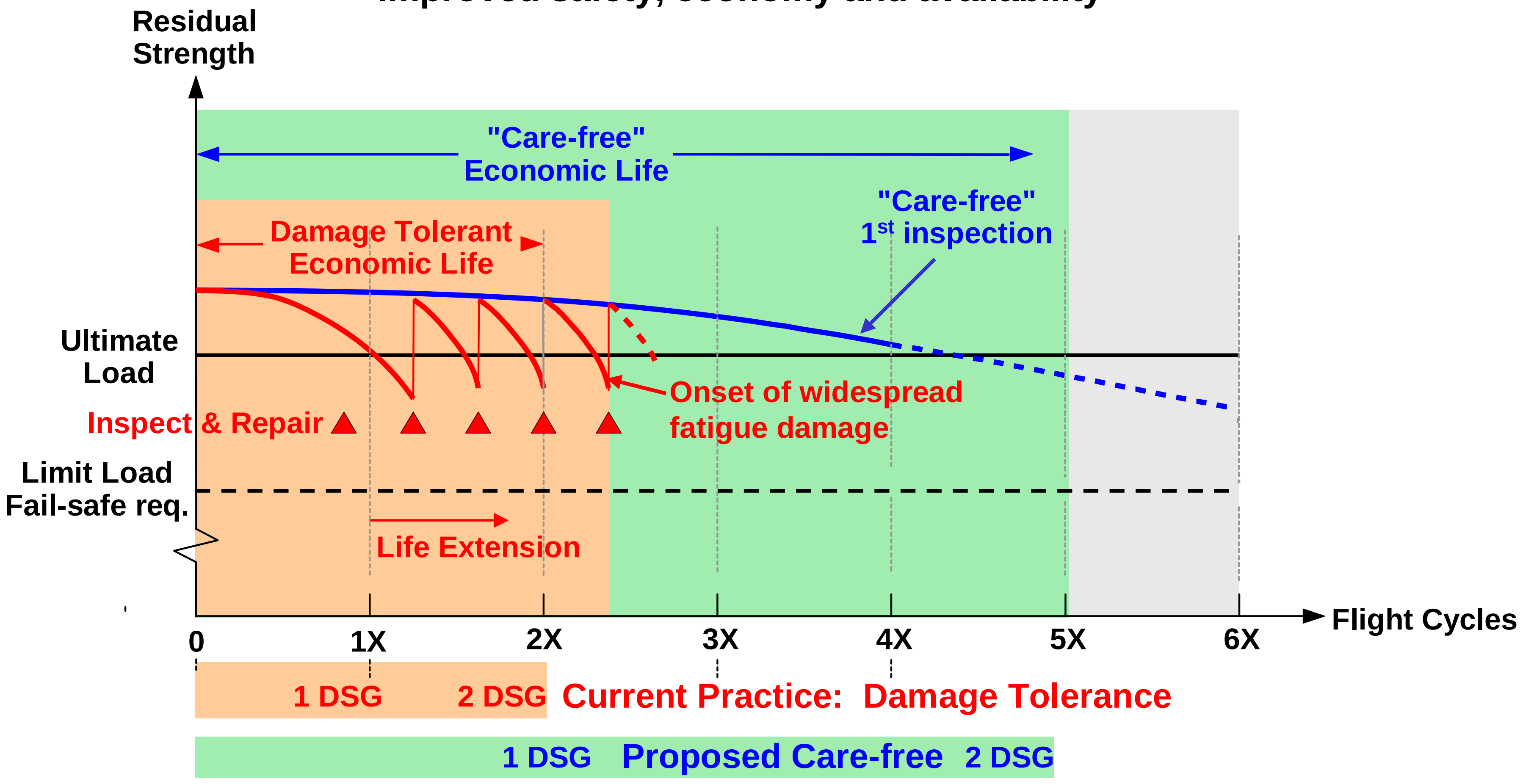


- **Upper Wing: Metallic design, built-up or integral with advanced alloys**
- **Ribs: Single piece machined rib from advanced alloy plate or integral extrusion**
- **Spars: Multi-piece spars**

- **Lower Wing – tension dominated, sized by damage tolerance:**
  Advanced hybrid sandwich structure lower cover with advanced alloy, fastened or bonded stringers, integrated man-hole surrounds

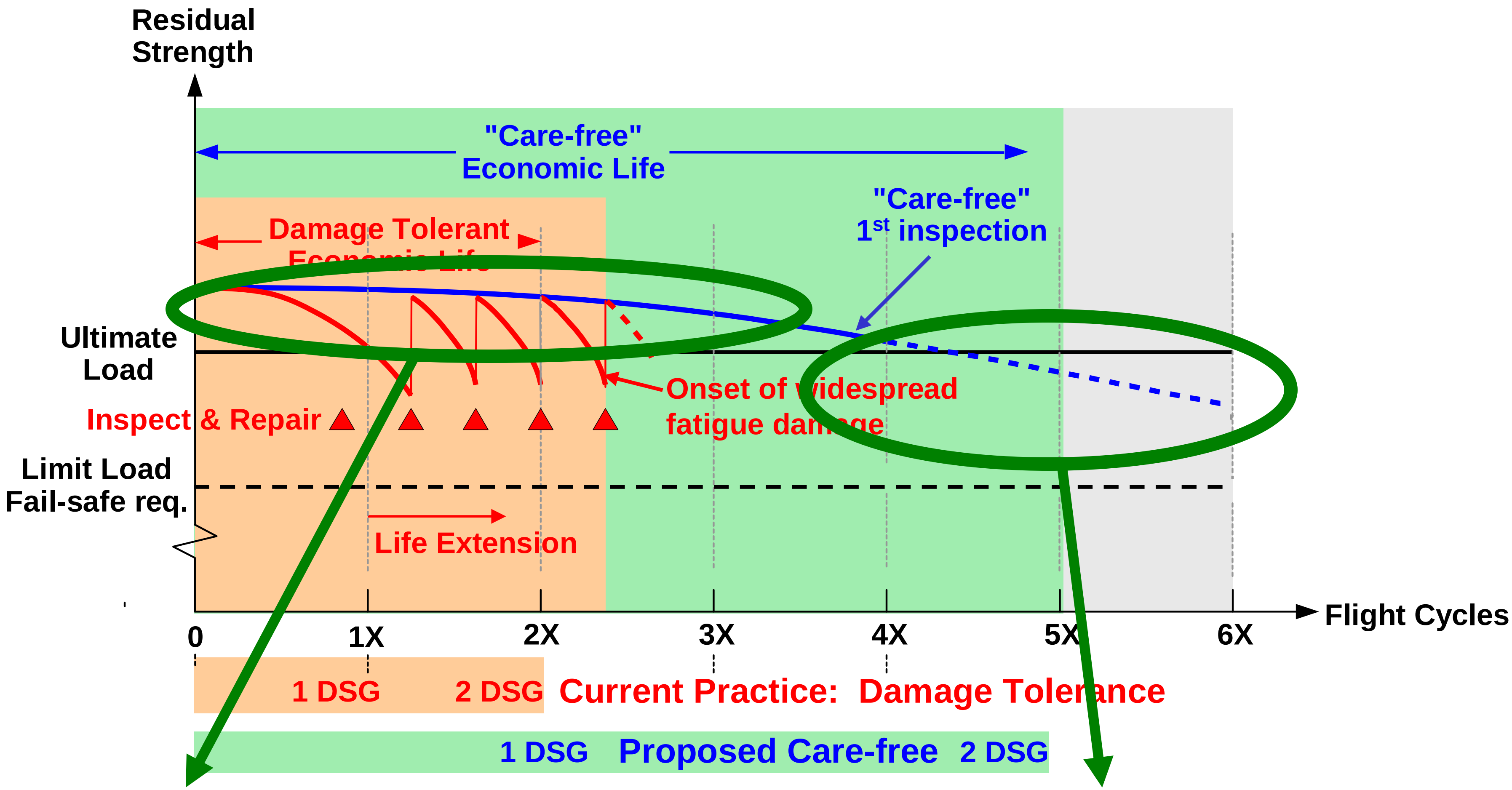
Introduction to Care-Free Structures Approach

- **Longer inspection intervals**
- **Much longer critical crack size, easier to find**
- **Improved safety, economy and availability**



Ref.: Fredell, “Carefree” Hybrid Wing Structures for Aging USAF Transports”, DTAS Conference, TU Delft, The Netherlands, Sept., 2007.

Demonstrating that AHS Can Be Care-Free



Requires:

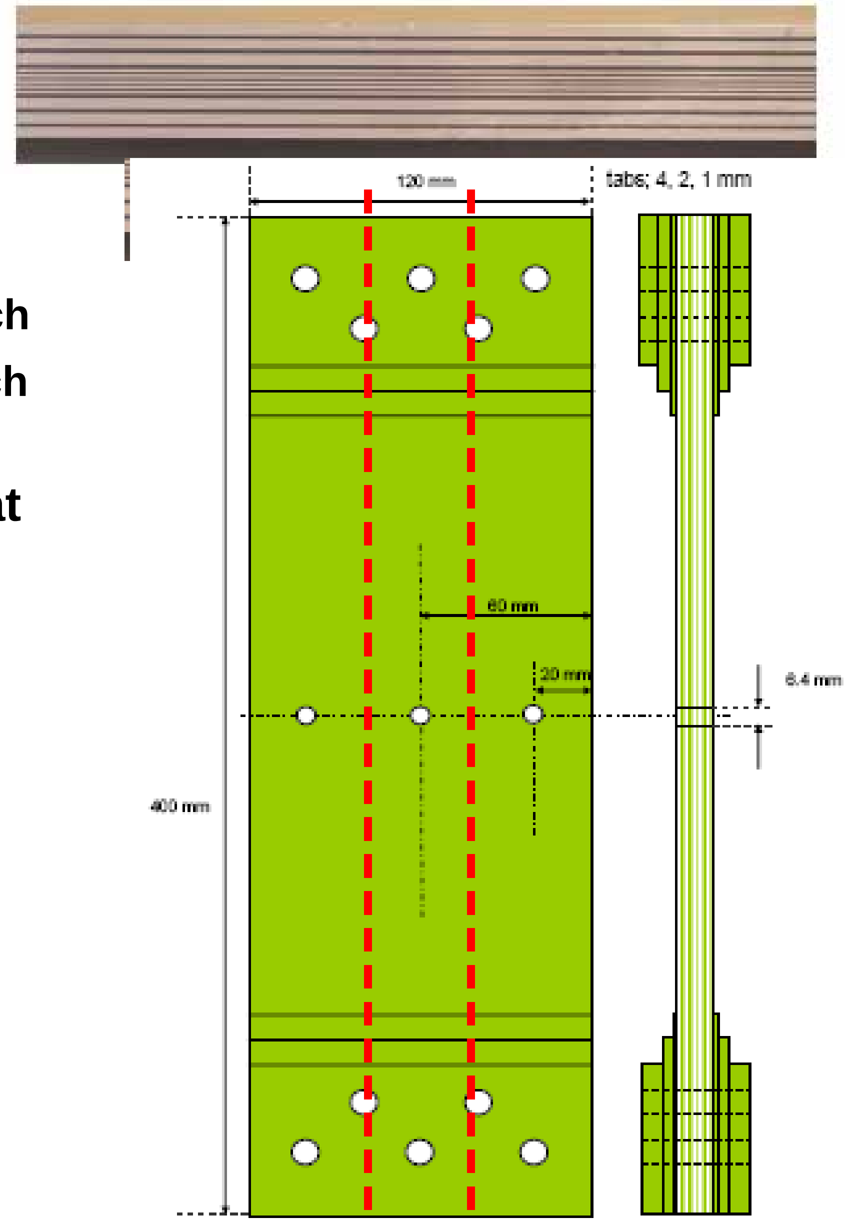
- Slow crack initiation from details
- Slow crack growth while maintaining high residual strength
- Good corrosion resistance

Requires:

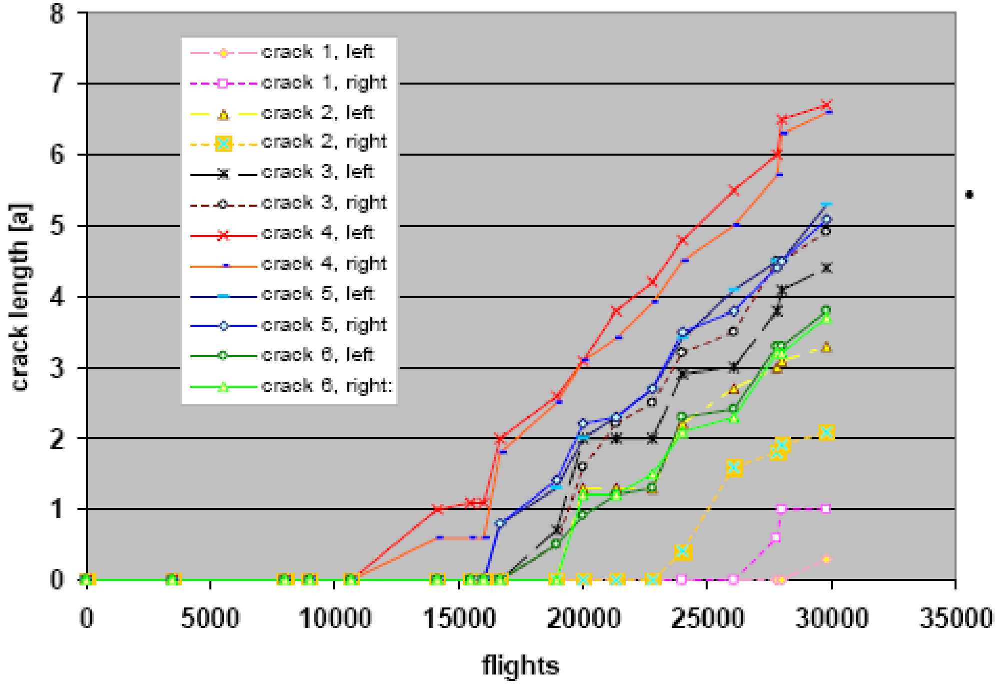
- Slow crack growth from large, easily detectable damage
- High residual strength with large damage

Crack Initiation and Growth from Open and Filled Holes

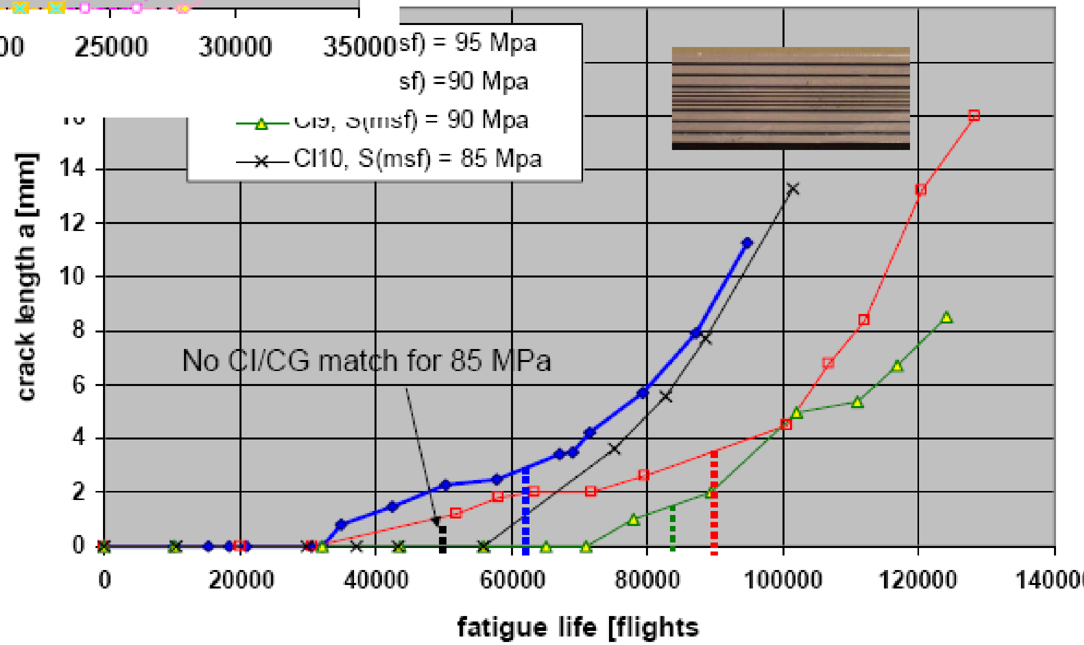
- **AHS Concept – CentrAl with Glare2 FML and three layers of 1.4 mm thick 2024-T3 sheets on either side.**
- **Two Specimen Types**
  - **Three 0.25” open holes at 1.57” pitch**
  - **Three 0.37” filled holes at 1.57” pitch with 0.002” interference fit Ti bolts**
- **Tested under Mini-TWIST spectrum at 5 mean stress levels between 12 ksi and 15 ksi.**
- **Monitor:**
  - **Fatigue crack initiation**
  - **Crack growth**
  - **Crack length distribution**
  - **Residual strength after fatigue**
- **Residual strength testing performed after fatigue testing**



Crack Initiation Test Results



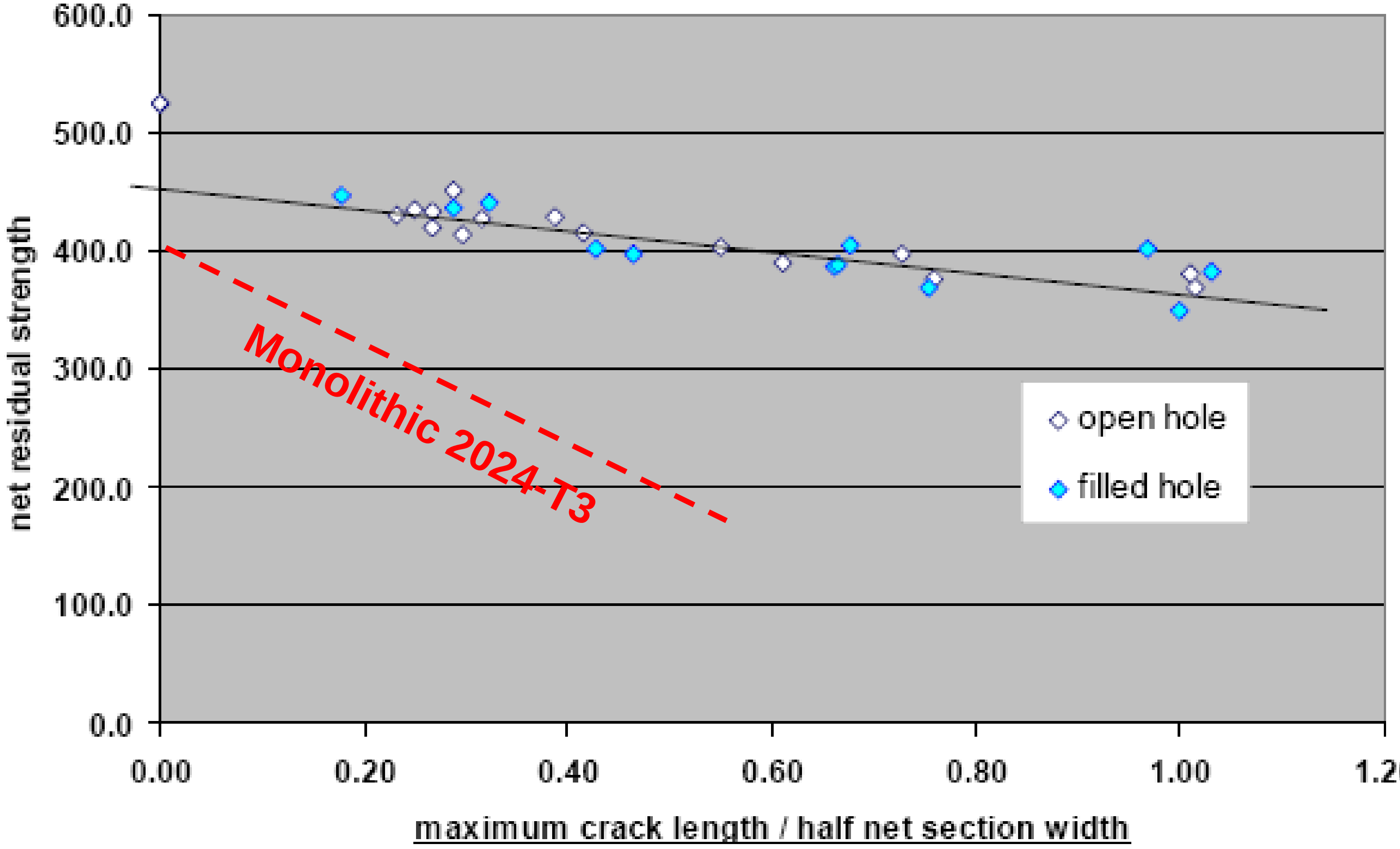
- Sample open hole crack initiation and growth results



- Sample filled hole crack initiation and growth results
- **Filled hole specimens have slower crack initiation and growth than open hole specimens**

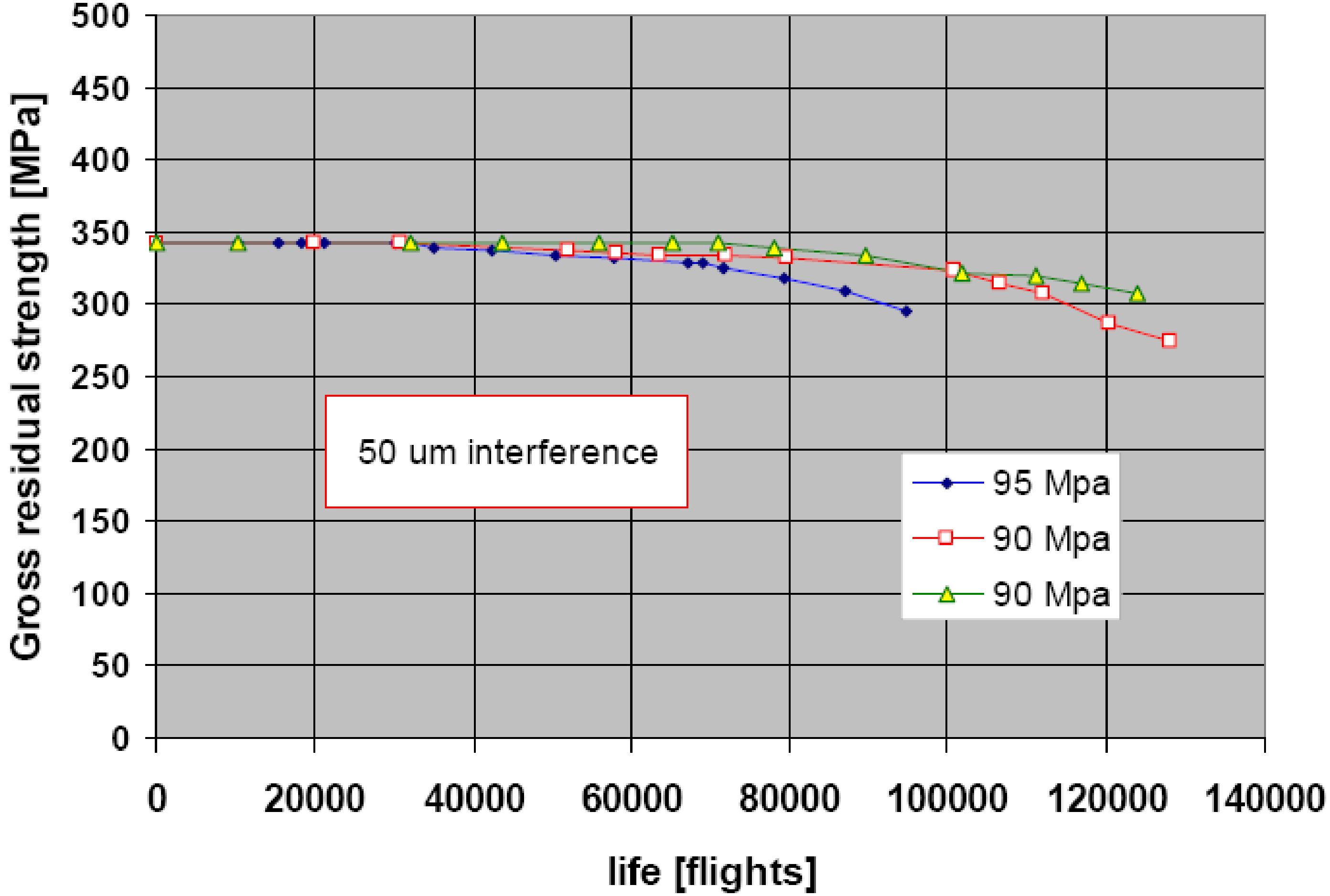
Residual Strength of Filled and Open Hole Specimens

- **AHS specimens maintain much higher residual strength than monolithic Al specimens, especially as cracks grow larger**



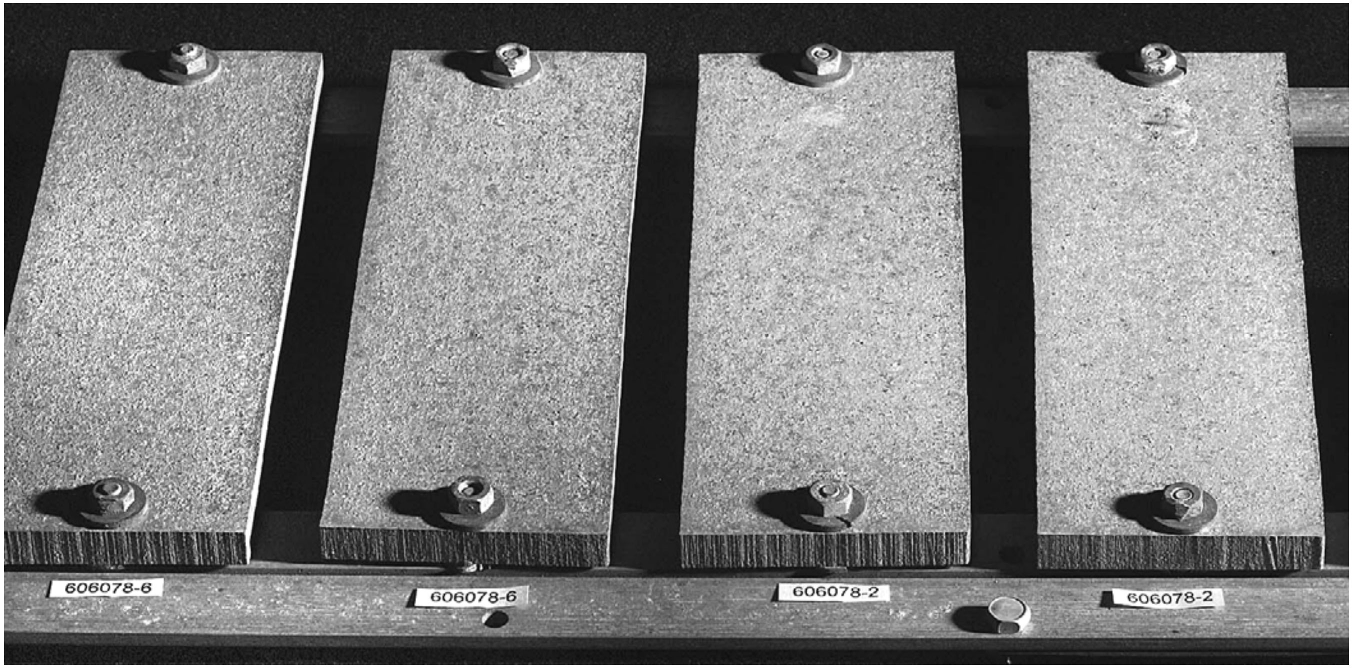
Residual Strength Diagram for AHS

- **Based on combination of crack initiation, crack growth and residual strength results of filled hole specimens**
- **Data based on AHS concepts with 2024-T3, higher residual strength achievable with higher strength alloys**



Improved Corrosion Resistance

- **New alloys offer dramatically improved corrosion resistance**



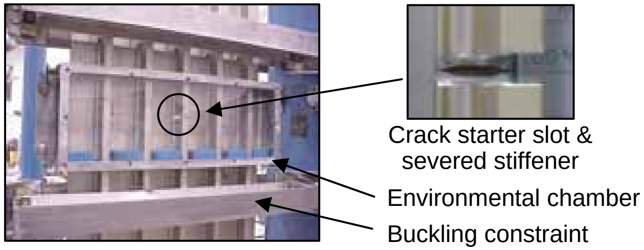
Example: Al-Li 2X99-type specimens with no coating exposed at seacoast for 14 years. No exfoliation occurred.

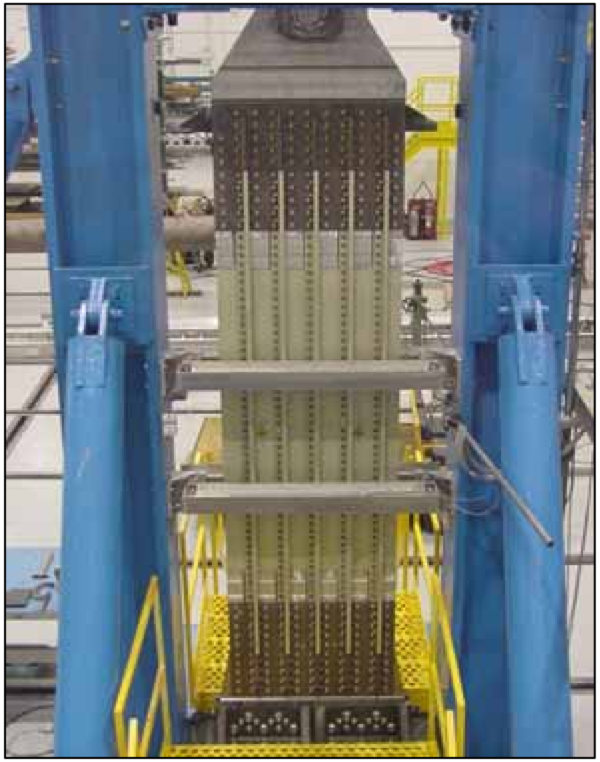
- **AHS offer additional improved corrosion resistance through barrier properties from laminate construction.**

Crack Growth and Residual Strength with Large Damage

Demonstrated as part ot Alcoa's large panel test program

- Testing performed at Vought Aircraft Inc., Dallas, TX, USA
- Scenario evaluated is large skin crack under broken central stiffener
- Starting total crack length (2a) after precracking was 2 in (50.8 mm)
- Cracks grown to total two-bay crack length, 2a = 11 in (280 mm), and tested for residual strength (save for single interrupted test for teardown evaluation)
- Tested two baseline panels representing best lower wing materials as used on Boeing 777 and Airbus A380
- Comparable panels of various advanced materials and design concepts were tested and compared to baseline performance

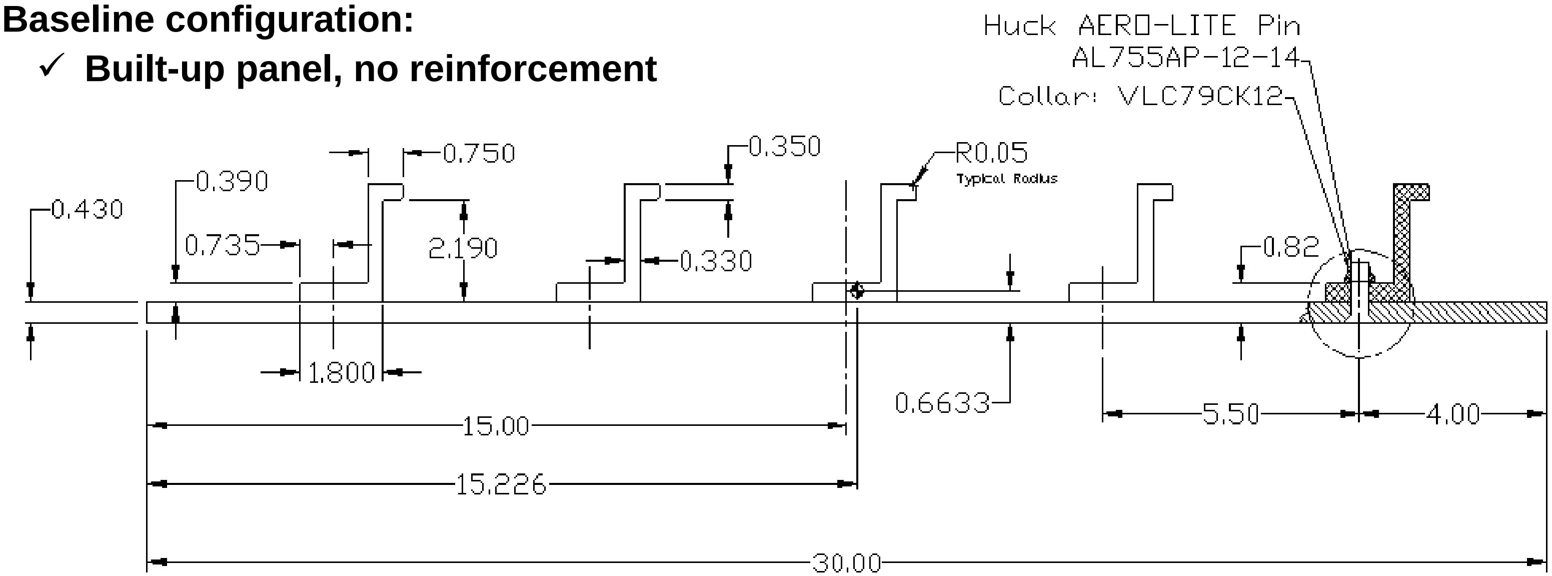




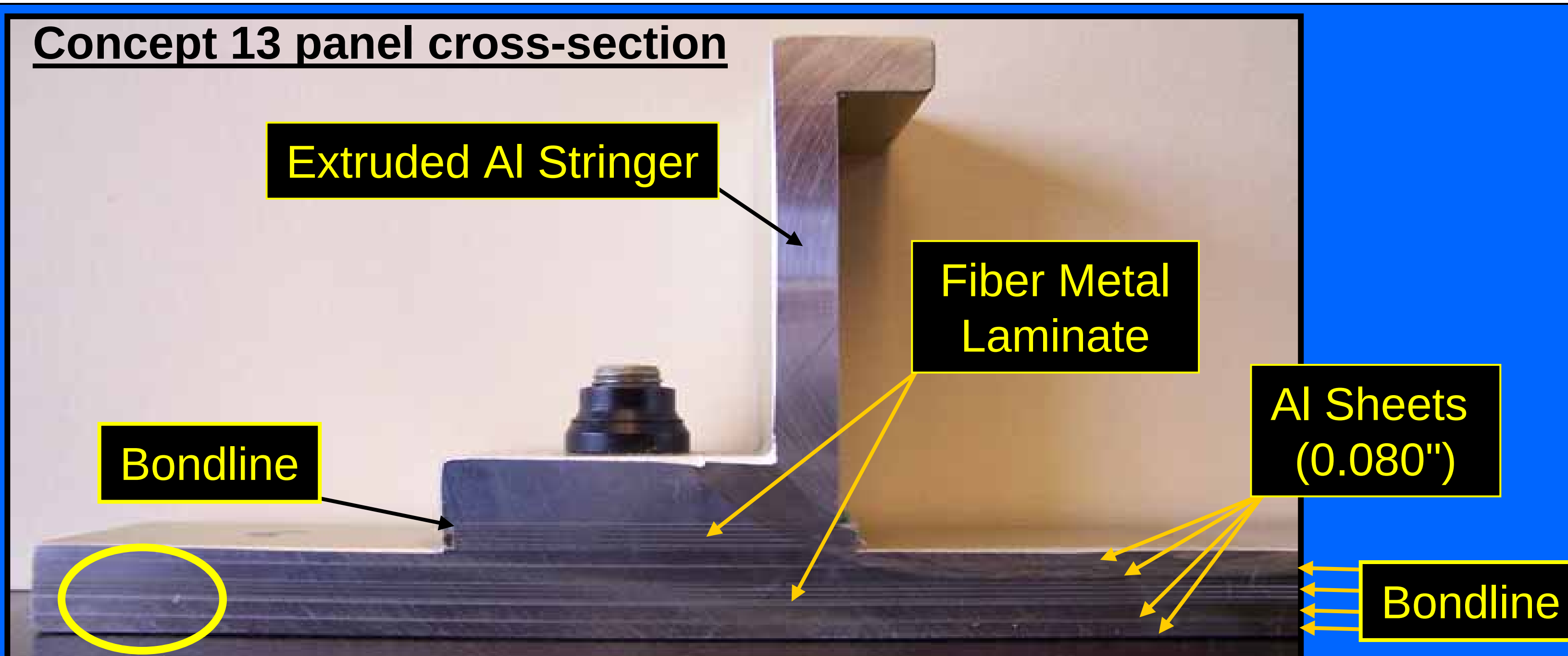
Lower Wing Panel & Test Set-up
Vought Aircraft Inc., Dallas, TX, USA

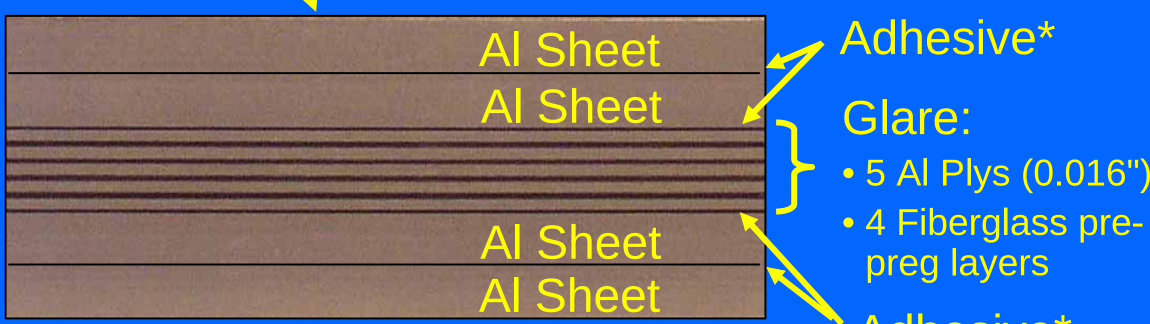
Lower Wing Concept Validation Program

- Designed to validate various concepts and materials for lower wing covers – testing for crack growth and residual strength
- Tested 25 large 5-stringer stiffened panels, 30 in x 90 in (760 mm x 2280 mm), representing 13 different concepts.
- Fatigue cycled at baseline and target 25% improvement stress:
  - ✓ Constant amplitude GAG cycle (R = - 0.35)
    - ✓ Baseline: s_{max} = 17 ksi
    - ✓ Advanced: s_{max} = 21.3 ksi
  - ✓ Mini-Twist Spectrum Level III Truncation with ground cycle
    - ✓ Baseline: $s_{min-flt}$ = 12 ksi ; $s_{max-flt}$ = 27.6 ksi ; s_{gnd} = - 6 ksi
    - ✓ Advanced: $s_{min-flt}$ = 15 ksi ; $s_{max-flt}$ = 34.5 ksi ; s_{gnd} = - 7.5 ksi
  - ✓ Humidity controlled environment: RH > 90%
  - ✓ Baseline configuration:
    - ✓ Built-up panel, no reinforcement



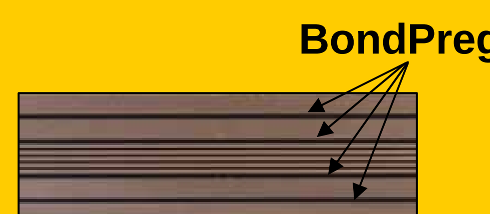
Adv. Hybrid Concept Panels 13 & 16





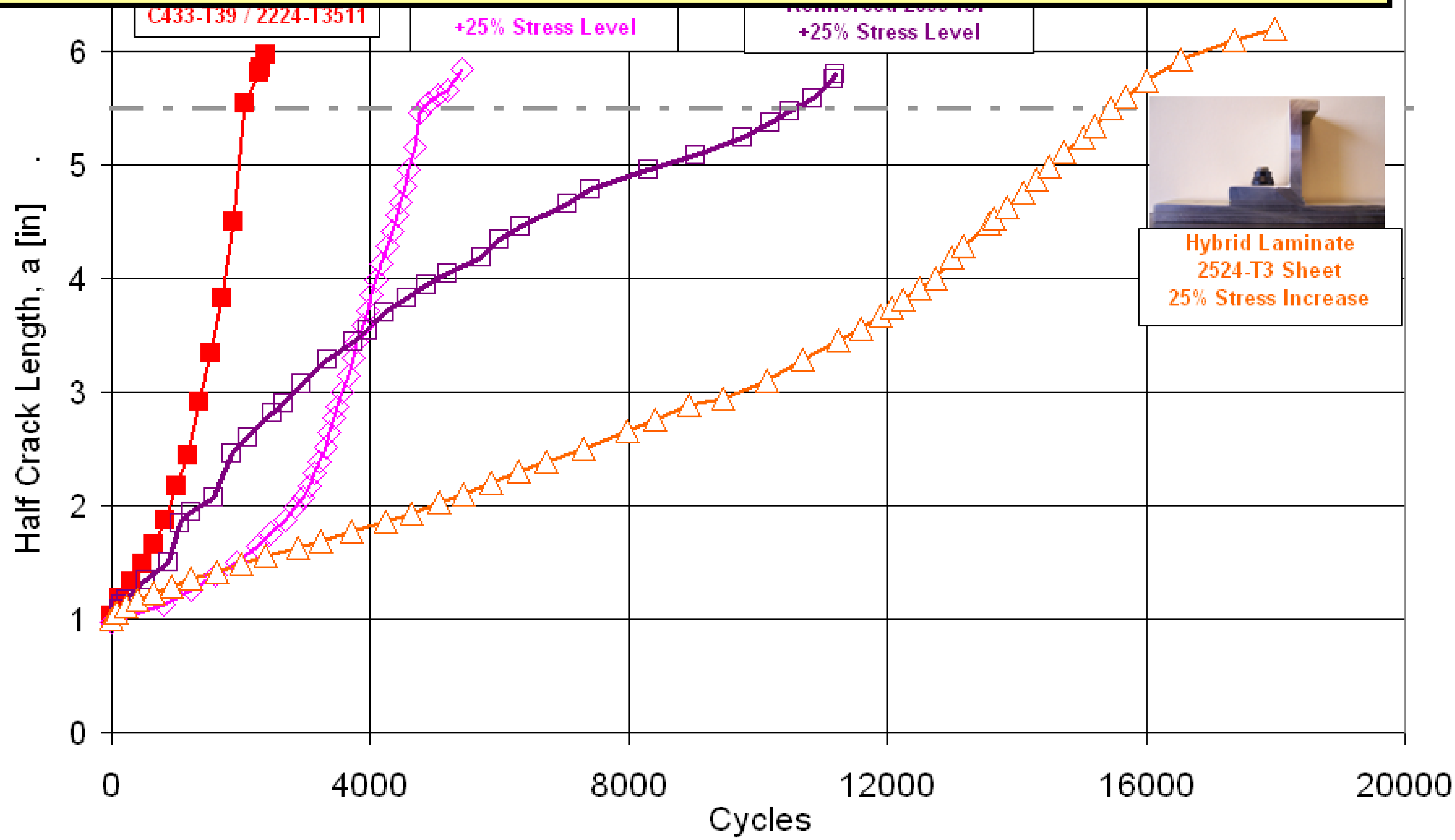
Concept 13 Panel Detail

*** Concept 16 pnl similar to Concept 13 (left) save for BondPreg layers**



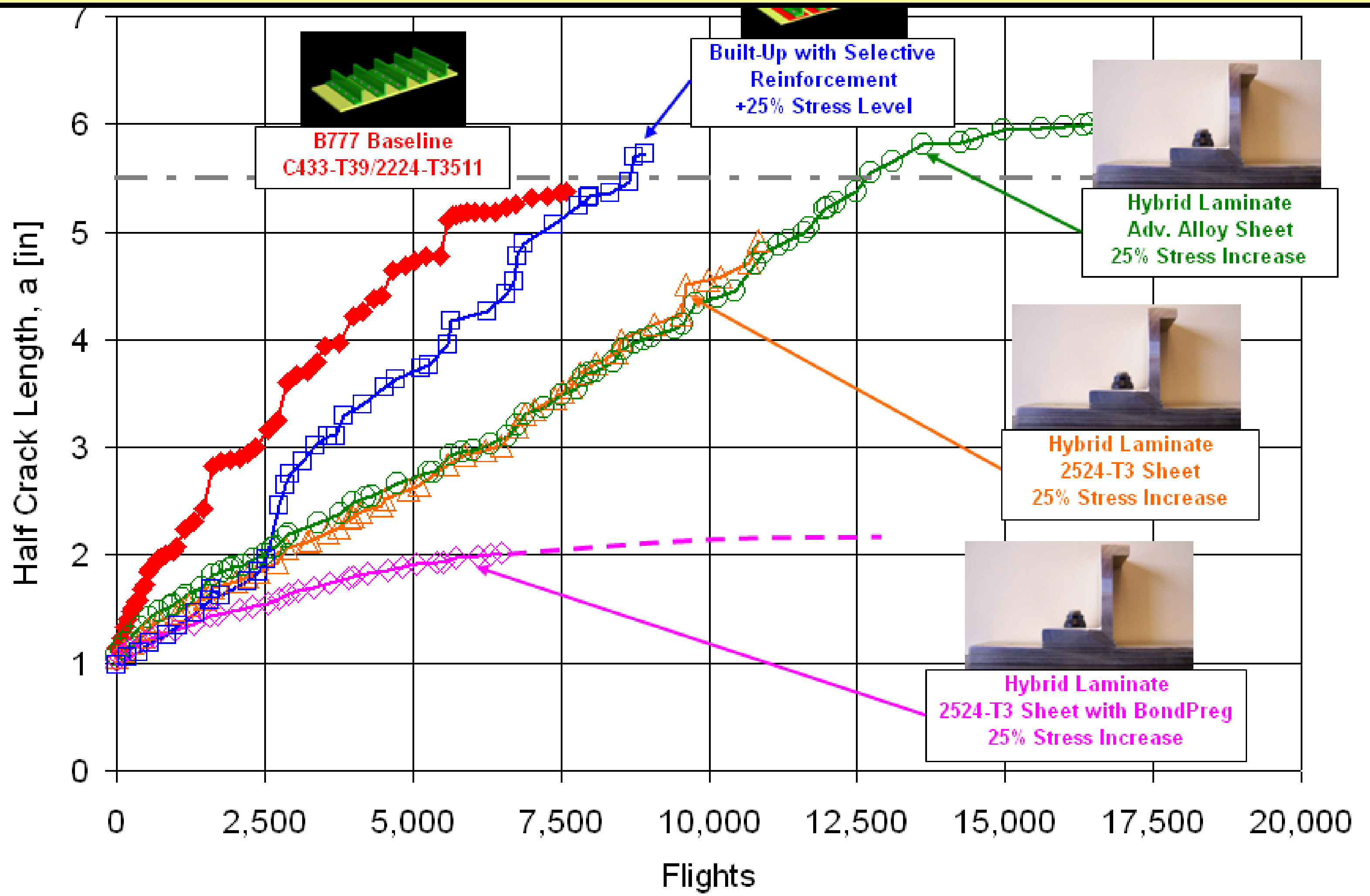
Alcoa Adv. Lower Wing Concept FCG Test Program

- ***Selective reinforcement provides 25% weight savings plus potential for inspection interval increase***
- ***Sandwiched hybrid structure provides greater than 25% weight savings and potential for <u>dramatic</u> inspection interval increases***

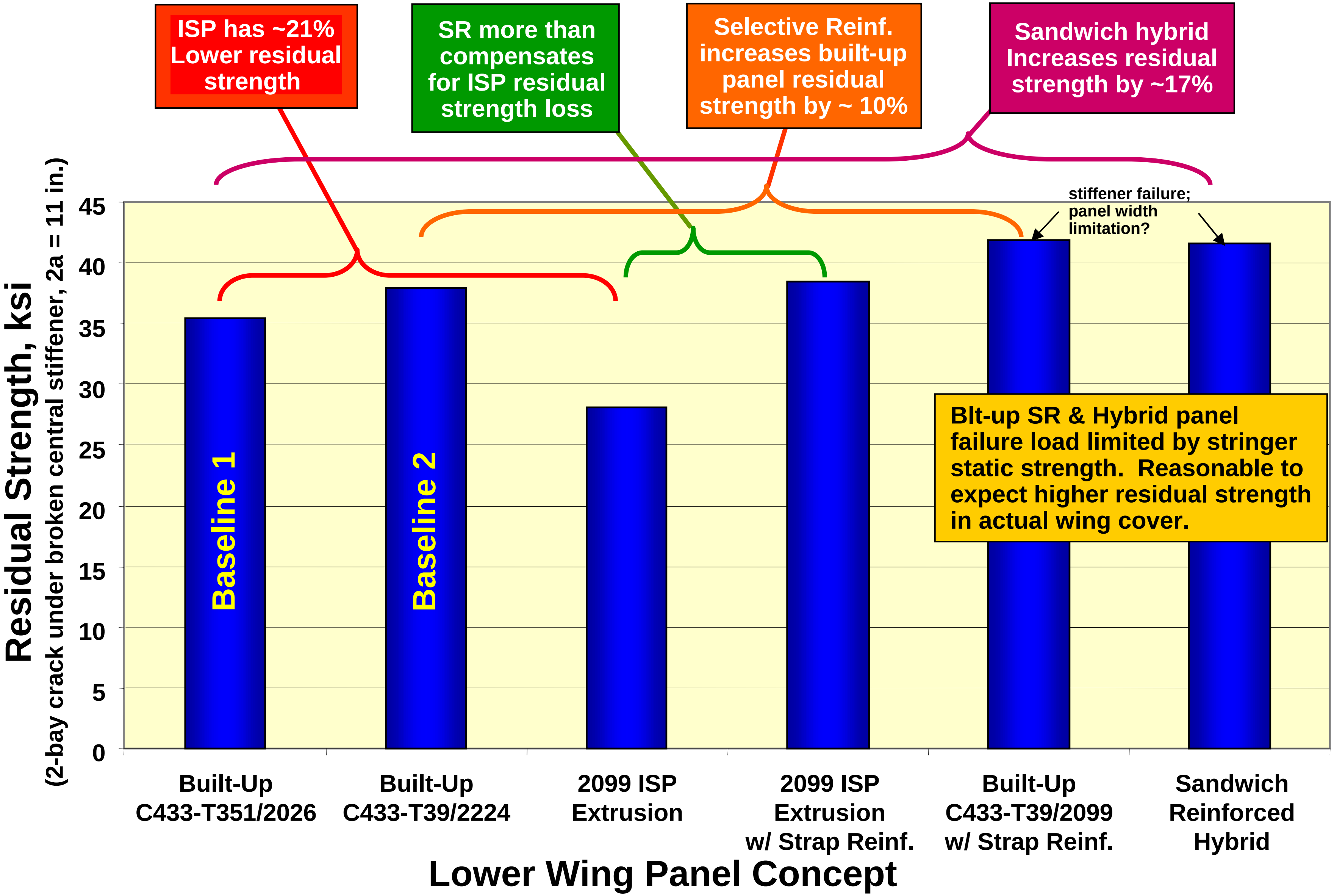


Spectrum FCG Results - 30"x 90" Stiffened Wing Panel Test

- **Selective reinforcement & sandwiched hybrid structure provide greater than 25% weight savings plus potential for inspection interval increase**
- **Use of Bondpreg further improves crack growth performance**

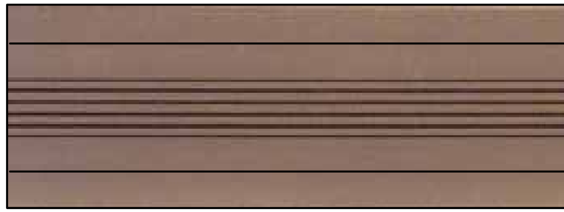


Large Wing Panel Residual Strength Test Results

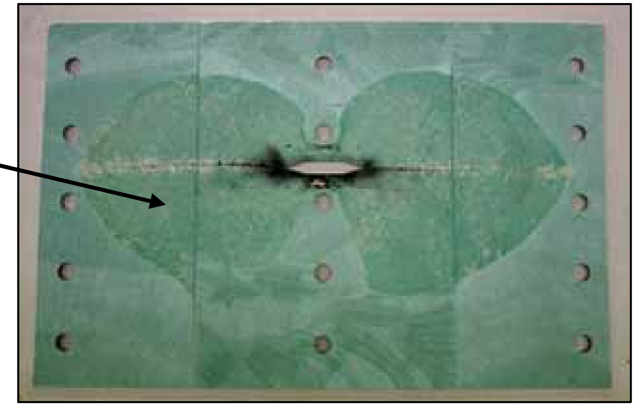


Both C-Scan & Ultrasonic Pencil Probe Detect Maximum Delamination Size

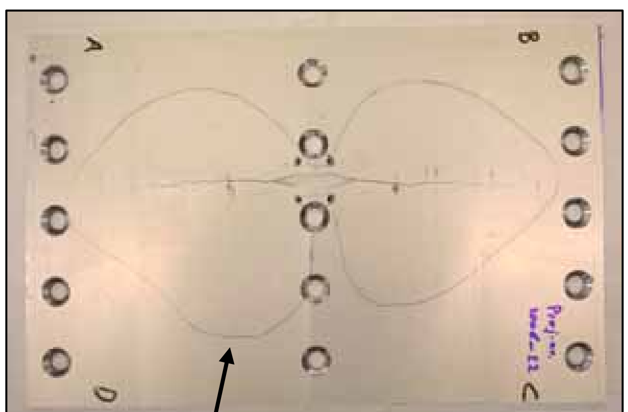
Concept
13-2 Panel



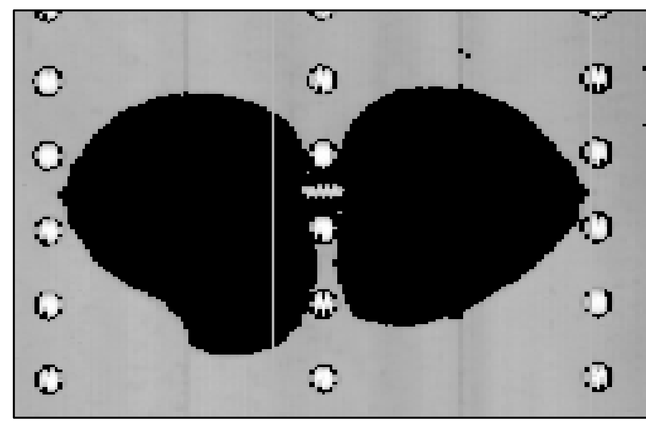
Con. 13 Skin cross-sect.



Largest Delam in Panel
(Bond btwn thk Al & 1st GLARE Al sht)



NDI trace during testing
(Ultrasonic Pencil Probe)



Ultrasonic C-scan image

Additional Strong Points - Advanced Hybrid Structure (AHS)

- **Compression Strength After Impact** – AHS are not sensitive to impact loads, since compression loads are carried by metallic elements. Impact resistance will be superior to graphite composite and even conventional metallic structures (leading edges of commercial transports are being designed in Glare to improve bird strike performance).
- **Extended Maintenance interval –** because cracks arrest or grow very slowly; highly damage tolerant.
- **Inspection / Reparability** – Most metallic and composite inspection and repair techniques can also be applied to AHS.
- **Crashworthiness** – AHS high metal content preserves the deformation and energy absorption attributes of conventional metallic structures.
- **Ballistics** – AHS are expected to have similar ballistic penetration performance as metallic and FML structures.

Remaining Technology Gaps

- **Certification approach for AHS**
  - **Requires more than simple material substitution**
  - **Involves treating AHS as structure**
- **Process for establishing design guidelines**
  - **Design allowable for AHS variants**
  - **Detail design guidelines for joints, thickness steps, etc.**
- **Demonstration of:**
  - **Long term environmental durability**
  - **Production and In-service inspectability**
  - **In-service repairability – depot and field level**
  - **Ballistic performance of AHS wing boxes**
- **The good news is:**
  - **Much of the above has already been done for Glare**
  - **The Five Tasks of ASIP are applicable to hybrid concept**

Summary

- **Advanced metallic & hybrid structural concepts are capable of achieving dramatic reduction in inspection / maintenance burden over current state-of-the-art with substantial weight & cost saving improvements at a low risk**
  - **Concepts based on proven (qualified) materials and processes**
  - **Concepts are well understood based on findings from coupon and large panel test results and structural component simulations**
  - **AHS have demonstrated that care-free structures are achievable**
  - **Path forward builds on the established Five Tasks of ASIP and building on FML development and certification experiences**

- **Next recommended steps:**
  - **Program to develop design and certification guidelines for AHS for USAF applications**
  - **Large or full-scale demonstration program of advanced wing box using AHS concepts**

Questions