Advanced Metallic & Hybrid Structural Concepts

… tailorable solutions to meet the demanding performance/ affordability requirements of tomorrow's aircraft

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Abstract

Alcoa has made a fundamental shift in its aerospace R&D program, broadening its scientific and engineering portfolio by creating an integrated, strategic, long-term initiative to revolutionize the future performance, cost and value of the metallic and hybrid aerostructure solution offerings the company feels necessary to meet demanding mission requirements of tomorrow’s aircraft.

Recent intense internal research programs on various structural options indicate that Hybrid Structural Components utilizing optimized combinations of advanced metallic forms, high performance fibers and fiber metal laminate (FML) materials offer the best opportunities to maximize structural performance and cost, especially when coupled with new alloys that have already resulted in dramatic strength, toughness, crack growth and corrosion resistance improvements. Even with higher operating stresses, Advanced Metallic and Hybrid design concepts show the potential for multi-fold increases in weight and cost saving surpassing that of today’s uni-material structures.

This presentation reviews several advanced structural concepts targeted for wing and fuselage applications. Large scale test article results supporting Alcoa’s optimism for Advanced Metallic and Hybrid Structures, and the potential for structural cost reduction will also be discussed. A key attribute of the concepts presented (hybrid materials and components, selective reinforcement, damage containment features, residual stress management, etc.) is that they all allow structural performance tailoring to meet application requirements. Highlighting this point establishes how next generation defense applications can directly benefit from the wealth of technology and know-how being developed for next generation civilian jetliners. Brief examples will show how choice of material and form, amount and type of selective reinforcement, etc, can be tailored to meet demanding mission and affordability requirements. The presentation will also address design approach changes needed to capture full advantage of promising metallic intensive approaches.

Outline

- Alcoa Advanced Aerostructure Vision
- Advanced Alloys
- Advanced Metallic & Hybrid Structural Concepts
- Large Panel Validation Testing
- Design Study Examples
- Summary Remarks

Premise - Alcoa Advanced Aerostructure Initiative

The marriage of advanced alloys with innovative design & mfg / assembly is capable of dramatic weight & cost saving improvements over current state-of-the-art.

- **Advanced Alloys & Product Forms**
  - ✓ New corrosion resistant alloys with improved strength, durability and damage tolerance
  - ✓ Low density, high toughness, fatigue resistant Al-Li alloys
  - ✓ New weldable alloys
  - ✓ High performance thick products
  - ✓ Integrally stiffened product forms
  - ✓ Fiber metal laminates (e.g., GLARE)
- **Innovative Design Concepts**
  - ✓ Monolithic and semi-monolithic structure
  - ✓ Selective reinforcement to improve damage tolerance
  - ✓ Tailoring of stiffeners & damage containment features
  - ✓ Sandwich reinforced hybrids (e.g., CentrAL) – tailorable to the structure requirement
- **Novel Manufacturing & Assembly Techniques**
  - ✓ Bonded metallic & hybrid structures capable of complex curvatures
  - ✓ Advanced joining methods – FSW, Laser Beam Welding, Bonding
  - ✓ Advanced forming
  - ✓ Age/creep forming
  - ✓ Automatable manufacturing and assembly processes

Vision and Goal of Alcoa Aerospace

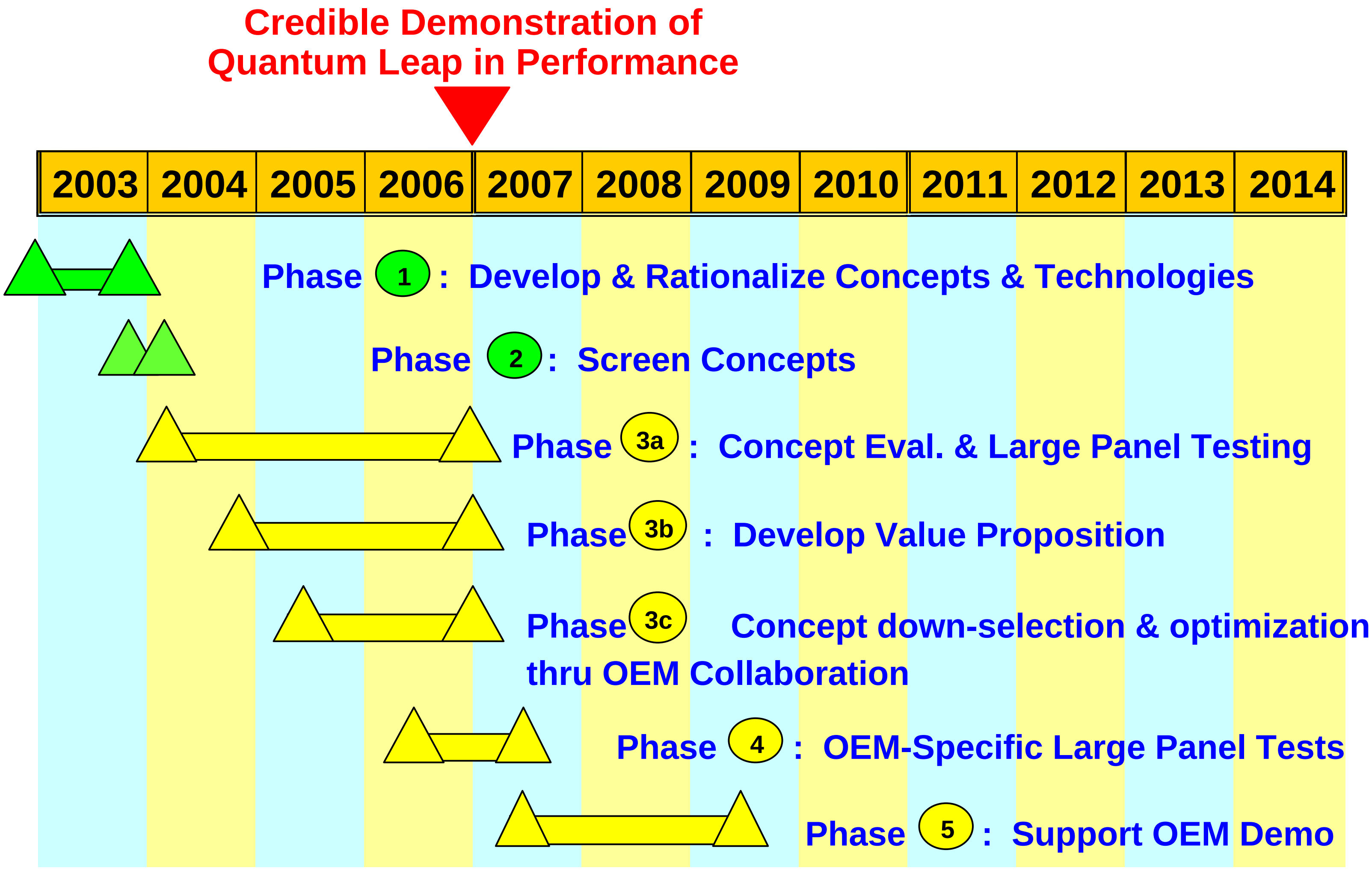
- **Fundamental shift in aerospace R&D from incremental alloy improvements to an integrated long-term strategic initiative to:**
  - **Re-define performance, cost & value of materials and components for tomorrow's aircraft**
  - **Offer solutions tailored to demanding mission & affordability requirements**
  - **Revolutionize evolution of new material, design, engineering and manufacturing/assembly technologies through internal and collaborative external programs**

- **Early studies & large panel test results indicate that Selective Reinforced and Advanced Hybrid Structural *Assemblies* offer multi-fold weight and cost saving opportunities over today's uni-material construction**

Advanced Design Concepts to Meet Aggressive Weight Saving Goals

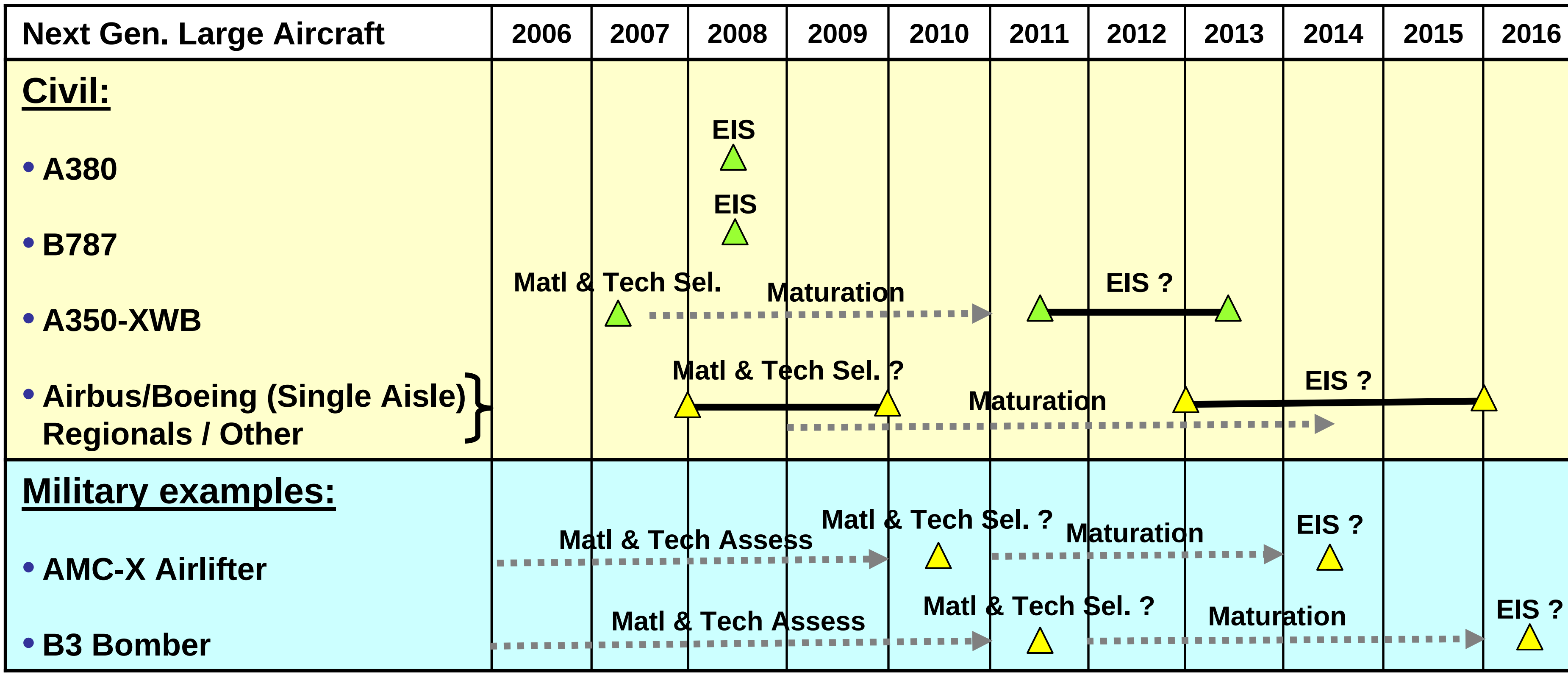
- **Metallic structures will need to operate at higher stresses to meet aggressive weight saving goals**
  - ✓ **Advanced alloys are capable of meeting the static load requirement to match or exceed composite weight/performance**
  - ✓ **New solutions are needed to address the metallic structure DADT deficit**
- **Concept technologies are being developed to achieve the required structural FCG and residual strength improvements**
  - ✓ **Selective Reinforcement**
  - ✓ **Stiffener & Damage Containment Feature tailoring**
  - ✓ **Advanced Hybrid Structural concepts**
  - ✓ **Structural Health Monitoring to achieve design approach changes and reduce inspection burden**
- **The ultimate solution is fatigue & DADT insensitive metallic structure**
  - ✓ **Paradigm shift to sizing driven purely by static strength requirement**
  - ✓ **Enabled by advanced alloy & design/mfg concept integration**
  - ✓ **Potential uses for new materials & forms optimized for new approaches**

Alcoa Advanced Aerostructure Initiative Timetable

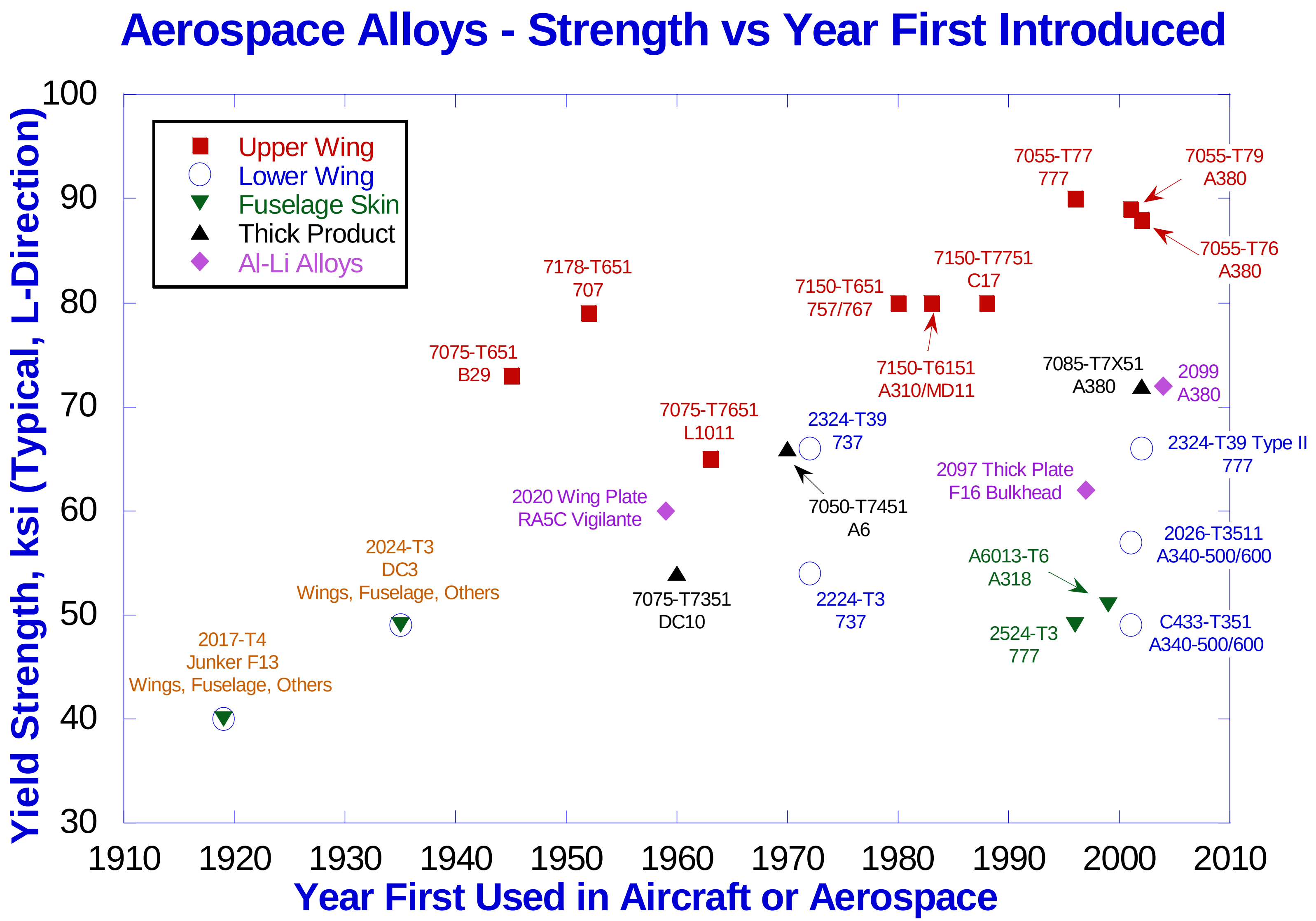


Estimated Milestone Timetable
Next Generation Transport-type Aircraft Programs

Military programs can leverage new technologies developed to serve the global civil transport market



Recent Trend: Multiple Alloy Tailoring for Local Design Drivers: e.g., Strength, Stiffness, DADT, Weld-joining …



Advanced Alloys Continue to Evolve

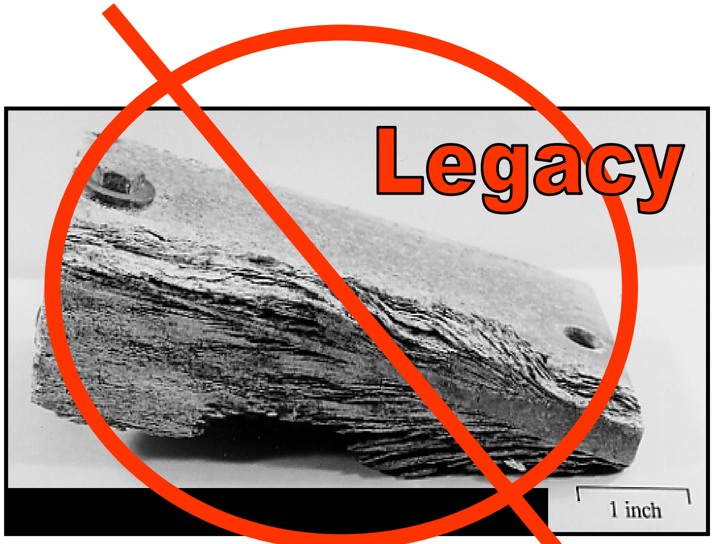
- **Recent additions to Alcoa's comprehensive alloy product portfolio:**
  - ✓ **On-the-shelf**
    - ➢ **3rd Generation low-density Al-Li alloys (viz., 2099, 2199)**
    - ➢ **New High Zn 7xxx high toughness alloys, including 7085 (thk. sections)**
  - ✓ **Near-Commercial**
    - ➢ **New 2xxx+Ag alloys with high static & residual strengths**
    - ➢ **New 2xxx Al-Li alloys with ultra-high static & residual strengths**
    - ➢ **New Al-Mg-Sc alloys for welding & low-cost creep forming**

- **New alloys are:**
  - ✓ **Much more corrosion resistant than incumbent alloys**
  - ✓ **Excellent in damage tolerance capability**
  - ✓ **Further optimizable to address specific design drivers**
  - ✓ **Tailorable to maximize benefit of Advanced Hybrid Structure concepts**

New Aluminum Alloys Offer Significantly Improved Corrosion Resistance

- **Newer Generation 7xxx Alloys (7x5x, 7085) offer significant corrosion improvement over legacy "aging aircraft" alloys (2024, 7075)**
- **New Era Al-Li Alloys (2x99-T8 Sheet & Extr.) offer further corrosion improvement over newer-generation 7xxx Alloys (7x5x, 7085)**

Al-Li 2099-type alloy w/ no coating exposed at seacoast for 14 yrs; *No exfoliation occurred*



Al Alloy 7075-T6 (bare) after 6 yr seacoast exposure

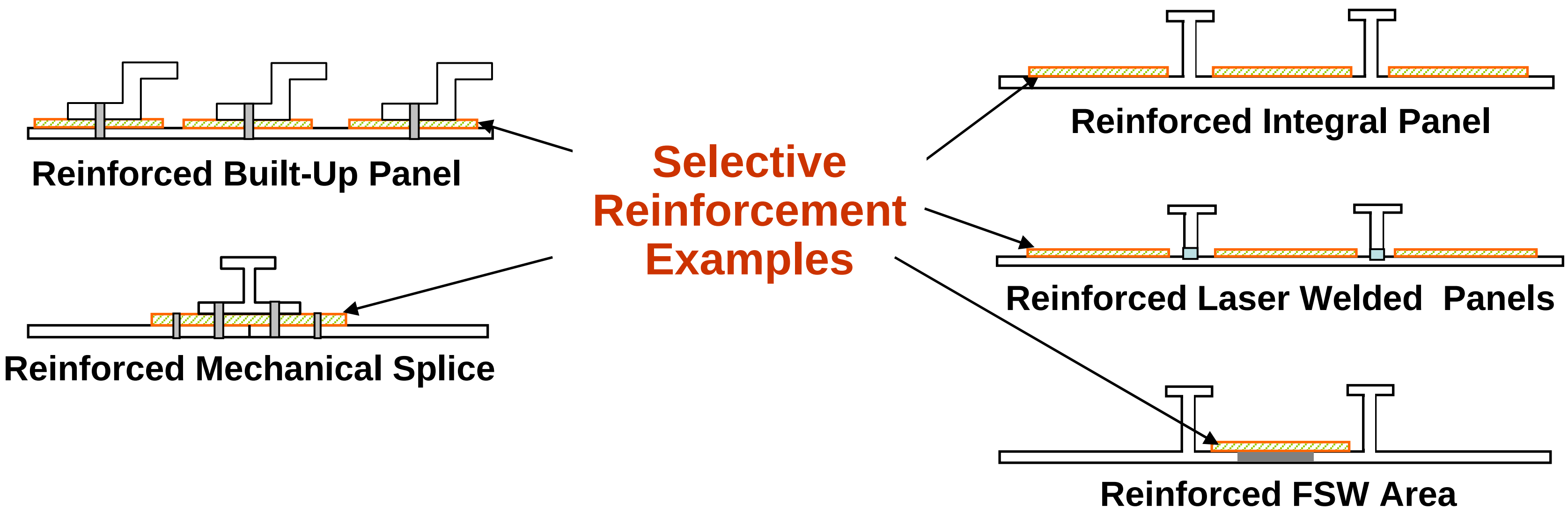
New Al alloys offer substantial reduction in cost burden associated with corrosion inspection & maintenance.

Advanced Structural Concepts

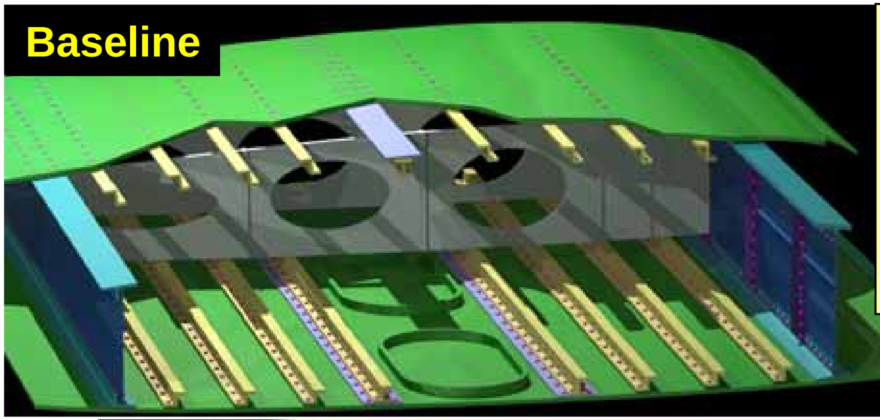
- **Selective Reinforcement *(low hybridization)***
- **Unitized Structure; Damage Containment Features**
- **Sandwich Reinforced Panels *(higher hybridization)***

Selective Reinforcement

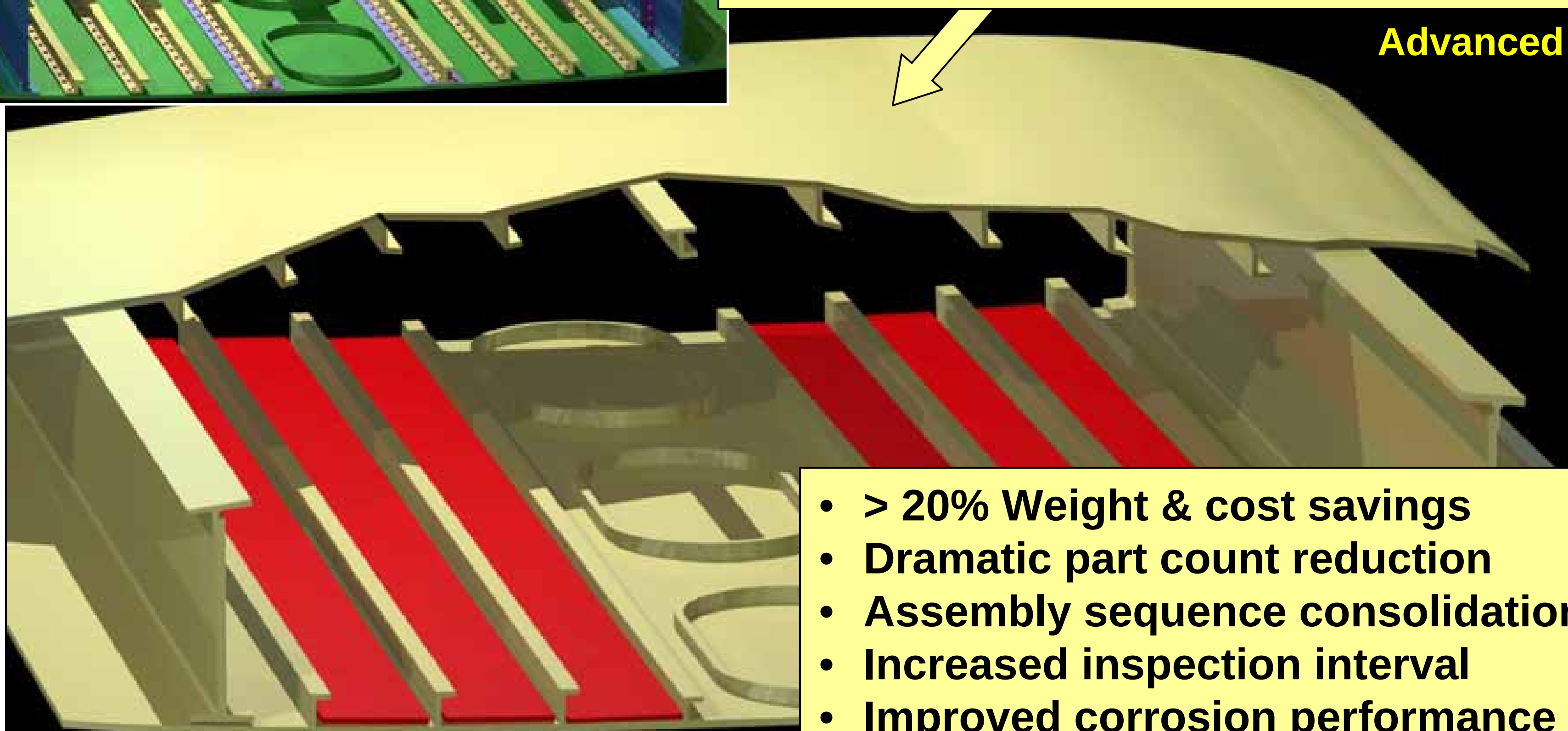
- Bonding of crack resistant straps – Fiber Metal Laminates (e.g., GLARE)
- Applied only to "problem" areas to improve structure performance
  - Improves residual strength, especially of integral stiffened structures
  - Improves FCG resistance through fiber bridging
- Under development: high modulus strap material to offload skin & stiffeners



Advanced Wing Design and Fabrication

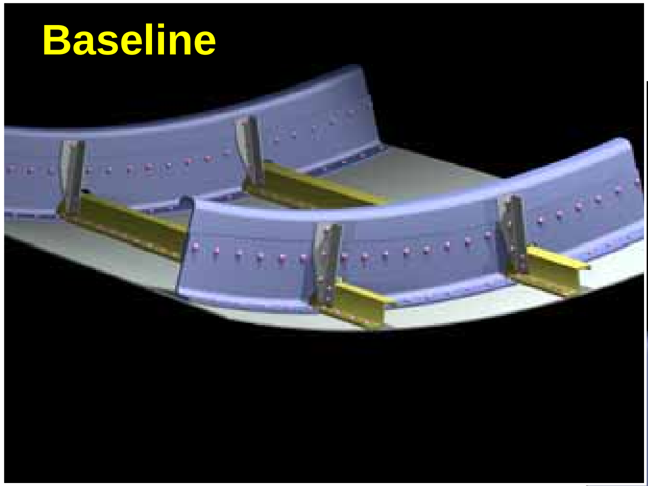


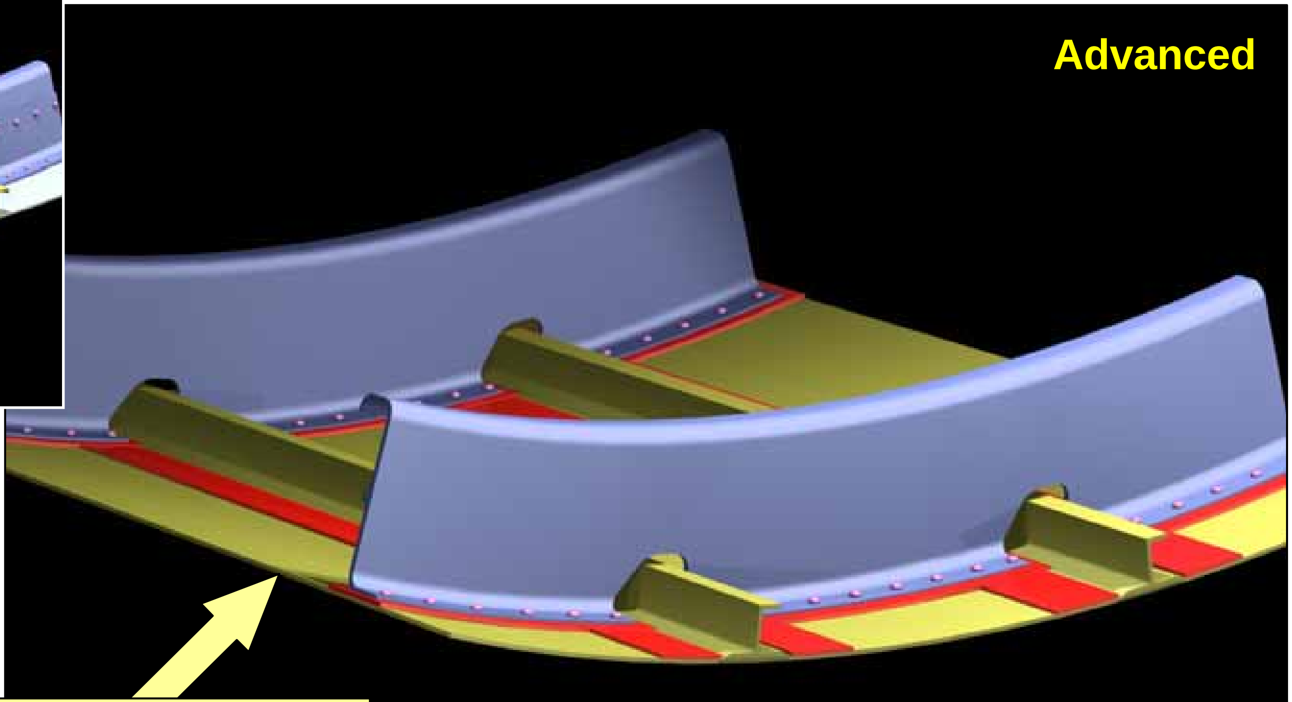
- Integral Skin, Stringer & Spars
- Machined Extrusion or Plate ISP
- Friction Stir & Electron Beam Welding
- Hybrid Lower Cover, Age Forming, Selective Reinforcement



- > 20% Weight & cost savings
- Dramatic part count reduction
- Assembly sequence consolidation
- Increased inspection interval
- Improved corrosion performance

Advanced Fuselage Design and Fabrication

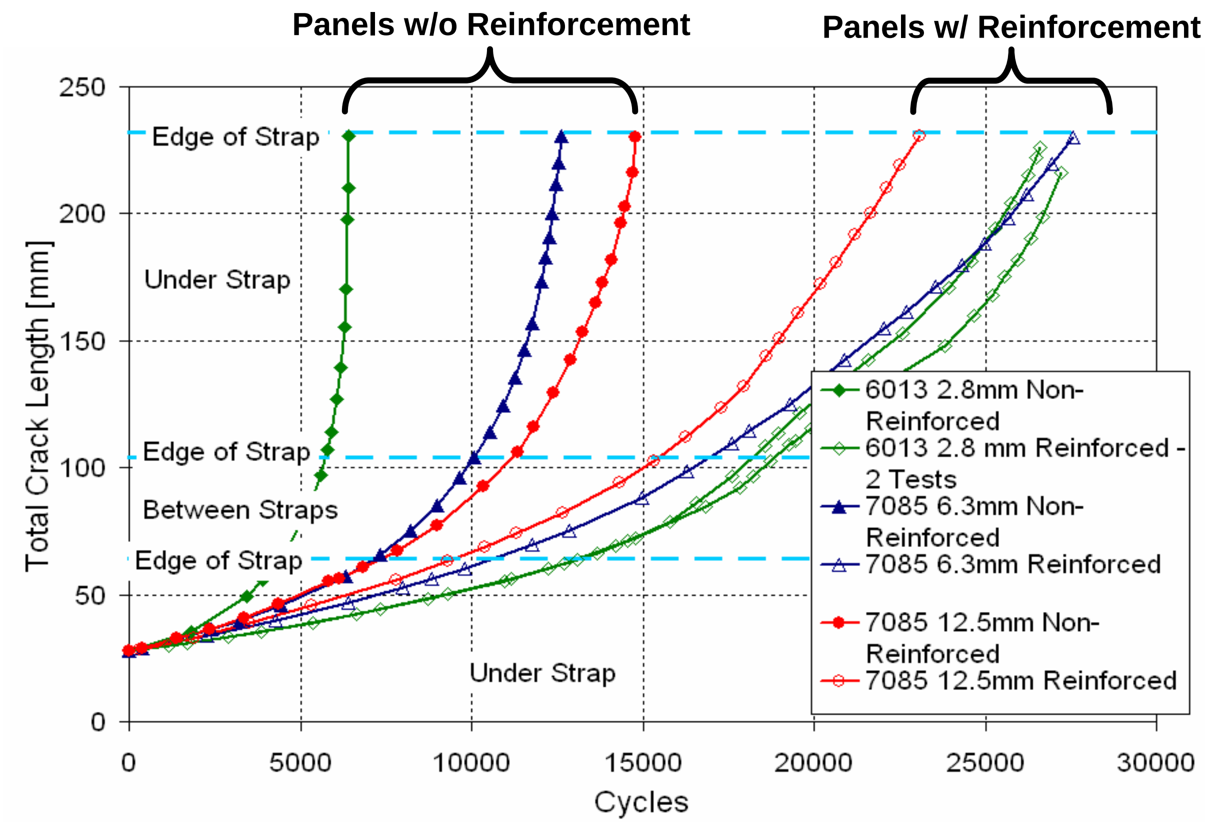




- Integral Skin, Stringer, & Frames
- Ultra-wide Extruded ISP
- Friction Stir Welding of Skins
- Laser Welding of Stringers
- Creep Forming of Skin-Stringer Panel
- Selective Reinforcement

- > 20% Weight and Cost Savings
- Increased Inspection Interval
- Dramatic Part Count Reduction
- Assembly Sequence Consolidation
- Improved Corrosion Performance

Alcoa Flat Panel Selective Reinforcement Concept Validation Test Program

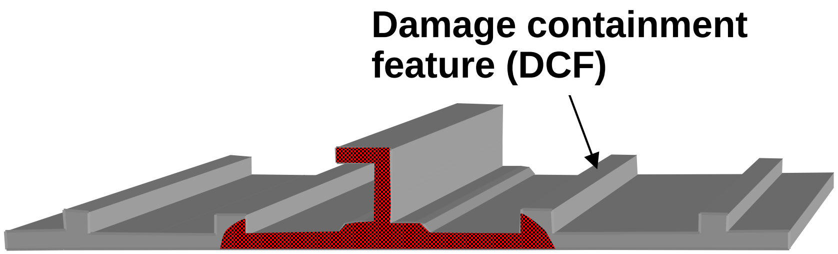


Sel. Reinf. Test Panel Broken Half

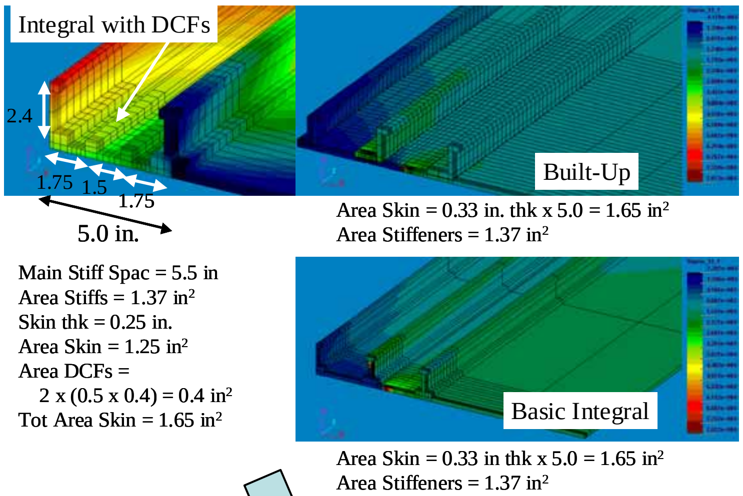
Results:

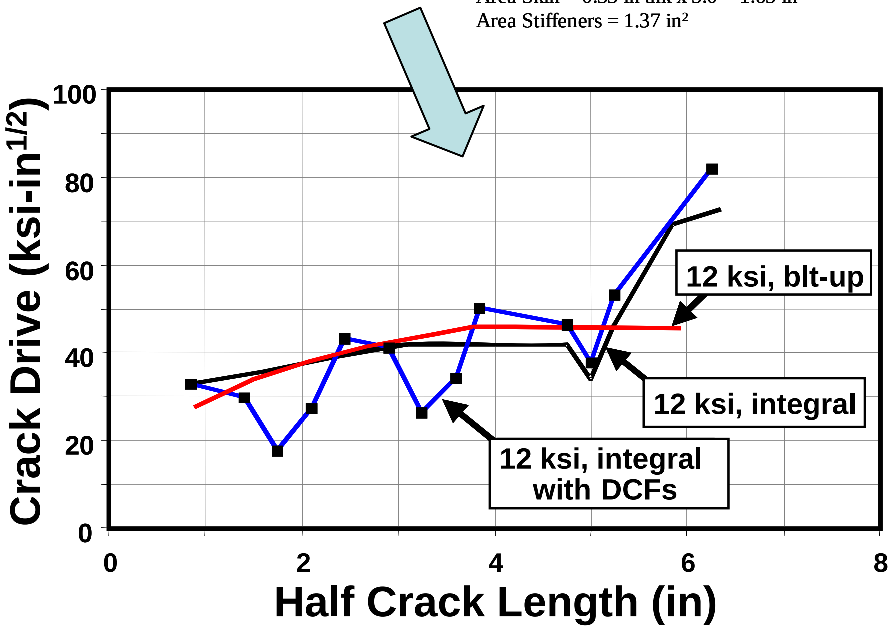
- **FCG stress allowable increase 10% - 45%**
- **Residual strength increase 25% - 40%**
- **Benefit can be tailored based on required improvements**
- **~30% Potential weight savings in DADT critical applications (e.g., Lower Wing)**

Concept Technologies:
Damage Containment Features (DCF’s)



Crack slows through each feature



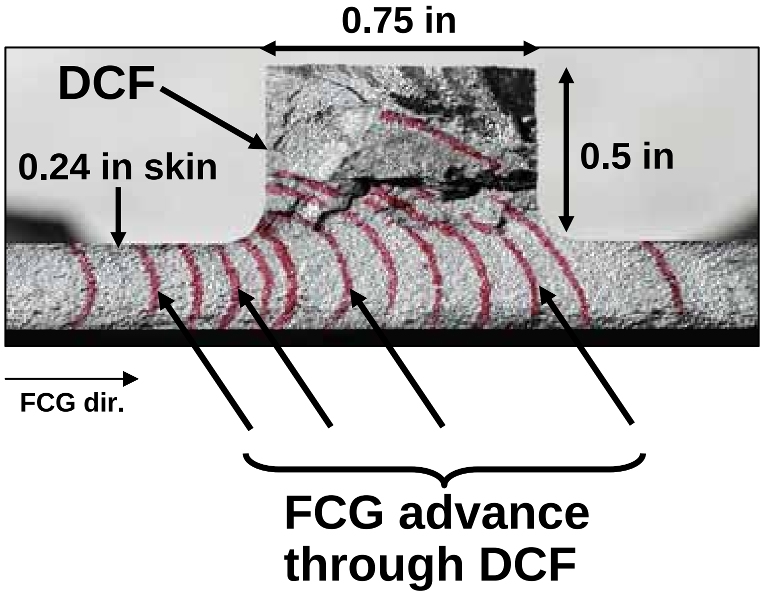


Damage Containment Features

- Energy consumed in FCG transition from thru to corner crack
  - Cyclic life benefit of the initial K-drop outweighs K-increase when feature fails
  - Substantial life improvement potential owing to log da/dN-ΔK relationship
- Features can be placed where needed
  - Additive benefit; e.g., can be combined with selective reinforcements
  - Potential means to overcome the unitized structure DADT deficit
- Modern design tools facilitate the DCF tailoring process

DCF Panel Test Result

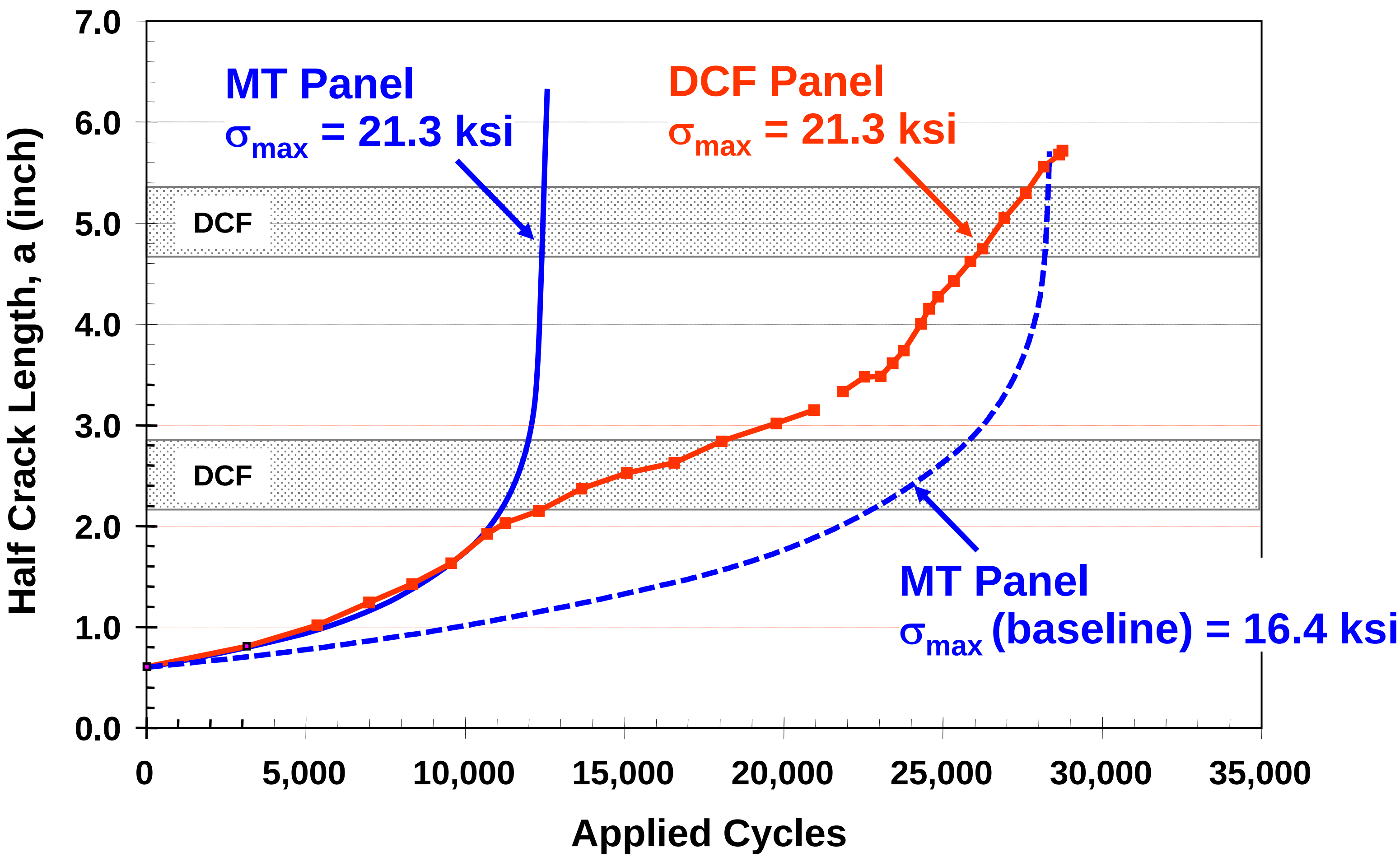
- Retarded FCG thru DCF
- Thru-to-partial thk. crack transition
- Achieves significant stress improvement for same life



DCF Panel in Test Frame

DCF Panel Fatigue Crack Growth Test Result

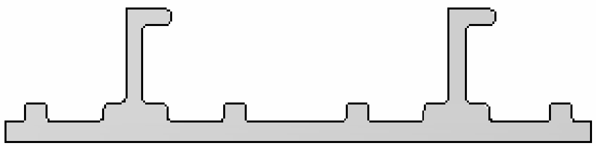
Al-Li 2099 DCF panel tested at 30% greater stress matched the crack growth life of a flat MT panel of same cross-section area



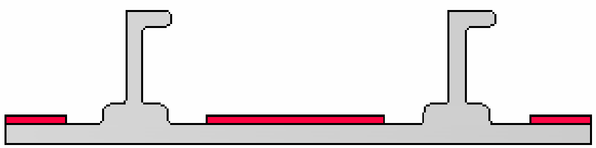
Benefits of Adv. Alloys, Damage Containment Features & Selective Reinforcement are **Additive**

Integral Lower Cover

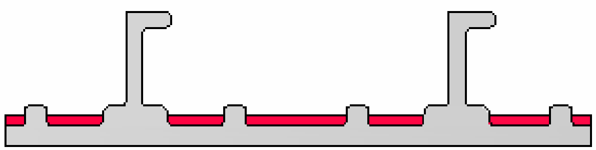
Baseline



DCF – 10% - 15% FCG Improvement



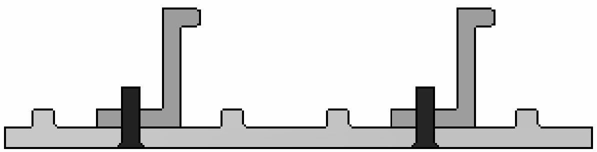
Sel. Reinf. – 15% FCG & 15% Residual Strength Improvement



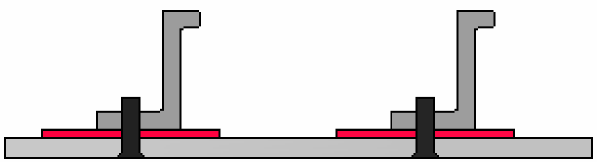
Sel. Reinf. & DCF – 25% FCG & 15% Residual Strength Improvement

Built-Up Lower Cover

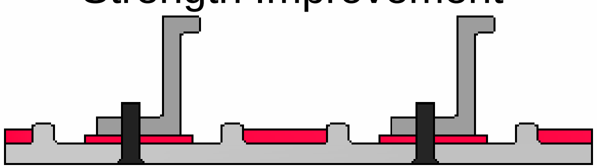
Baseline



DCF – 10% - 15% FCG Improvement



Sel. Reinf. – 15% FCG & 15% Residual Strength Improvement



Sel. Reinf. & DCF – 25% FCG & 15% Residual Strength Improvement

Advanced Hybrid Aerostructures - Definition

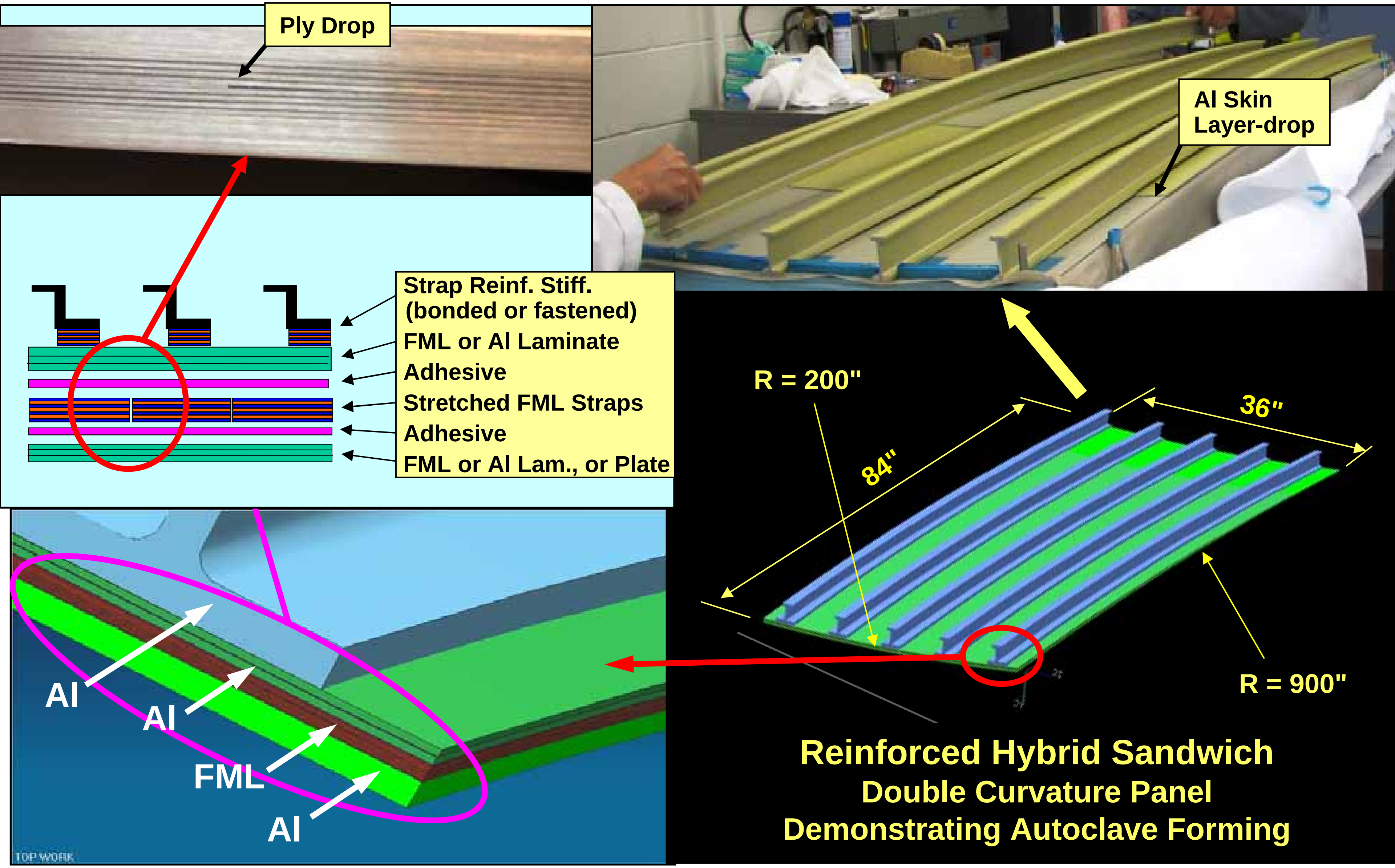
- **Aluminum products (e.g., sheet, plate, extrusion) and high performing fibers are the fundamental basis of Advanced Hybrid Structure**

- **Involves strategic placement of tailored Fiber Metal Laminates (FML) *only where necessary* to:**
  - **Enhance performance**
    - ✓ Static strength
    - ✓ Crack growth behavior (extend inspection intervals)
    - ✓ Residual strength (safety) with large damage present
    - ✓ Fatigue durability (minimal impact of local & wide-spread fatigue damage states on ability to carry load)
    - ✓ Permits use of different aluminum alloys & FMLs to further optimize performance (and cost)
    - ✓ Dent and impact resistant with good post-impact property retention
    - ✓ Barrier protection to resist corrosion and lightning strike penetration
  - **Streamline mfg. / reduce cost by use of laminate technologies**
    - ✓ Significantly reduced buy-to-fly
    - ✓ Potential to eliminate complex forming operations
    - ✓ Use of layer drop-offs to reduce or eliminate machining

- **Advanced Hybrid Structures are at early stages of development and offer significant further improvement opportunity over selective reinforcement**

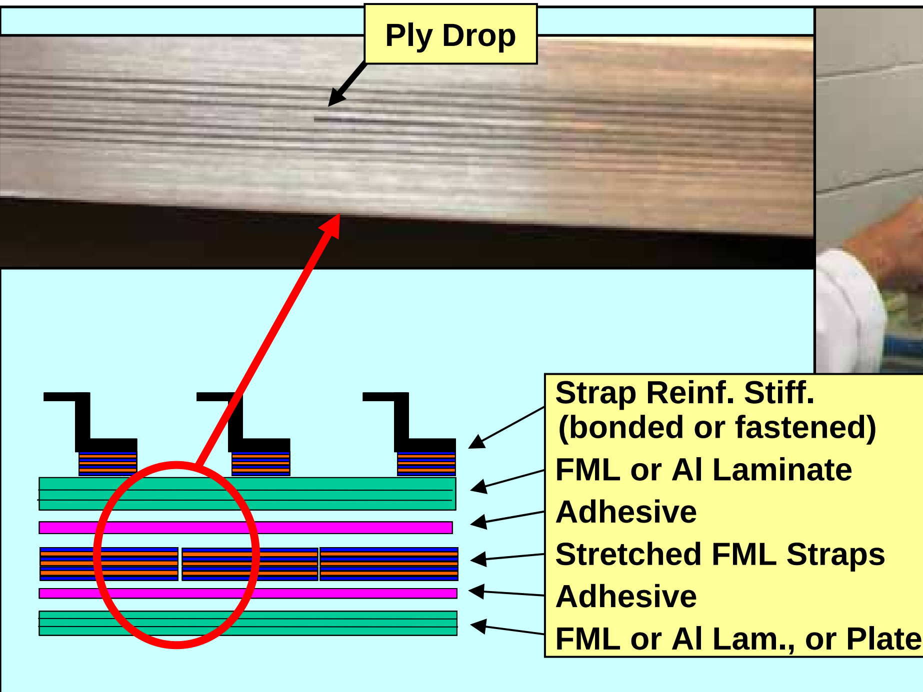
Further Opportunities - Advanced Hybrid Structure

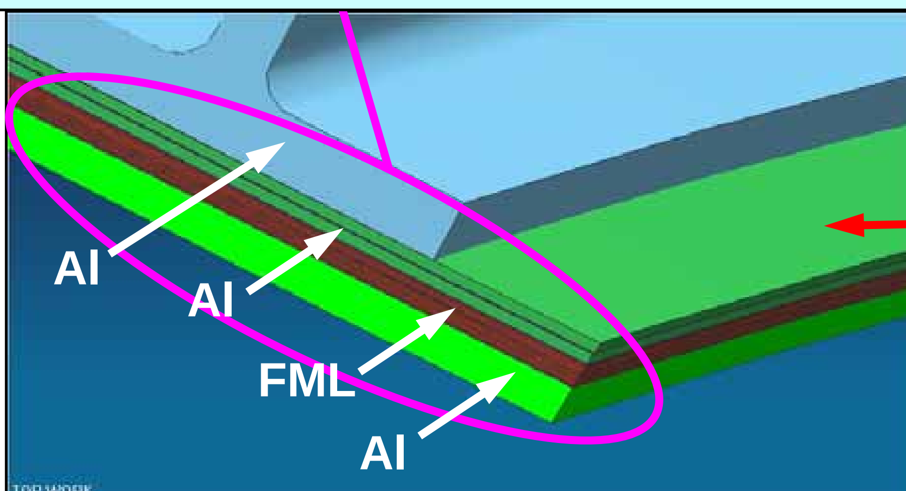
Manufacturing Demonstrator - Sandwich Reinforced Panel



Further Opportunities - Advanced Hybrid Structure

Manufacturing Demonstrator - Sandwich Reinforced Panel





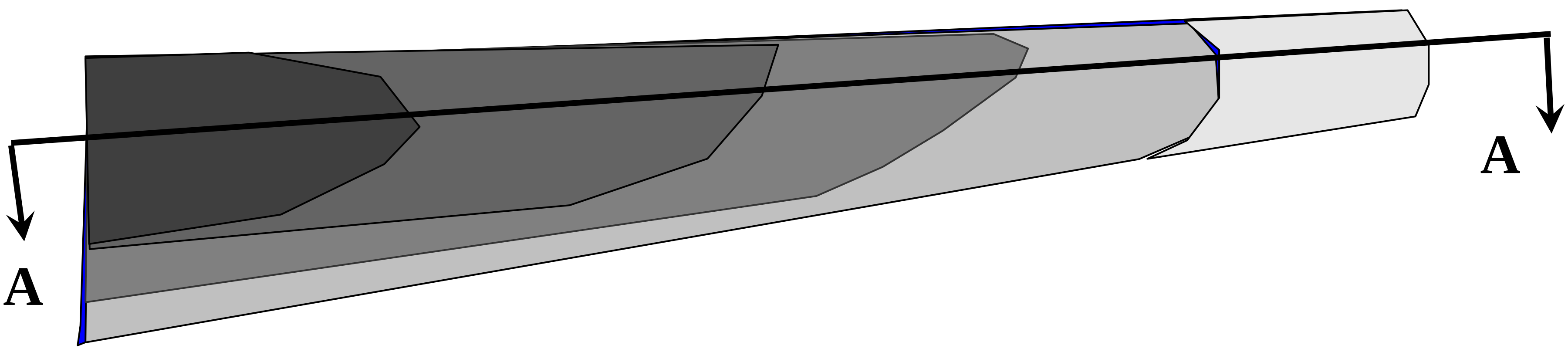
Concept Attributes:

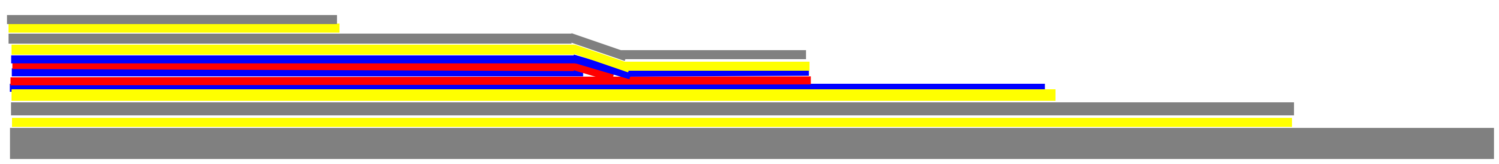
- Low buy-to-fly
- Tapered skin & double curvature capable
- Simplified mfg flow path:
  - ✓ layer drop-offs to reduce machining
  - ✓ autoclave forming to eliminate complex forming steps
- Low cost process
  - ✓ minimal sheet & prepreg waste
  - ✓ Pre-made FML straps
- Directly connectable to other monolithic, built-up, welded component forms
- Bonded Al stringer to reduce part count; minimize faster holes
- Maximum flexibility for design & mixed material compatibility (e.g., coeff. of thermal expansion, modulus, galvanic corrosion)

Hybrid Wing Skins Can Be Tapered Along Length & Width

Adv. Hybrid Properties (strength, D/DT, Stiffness, density) can be tailored

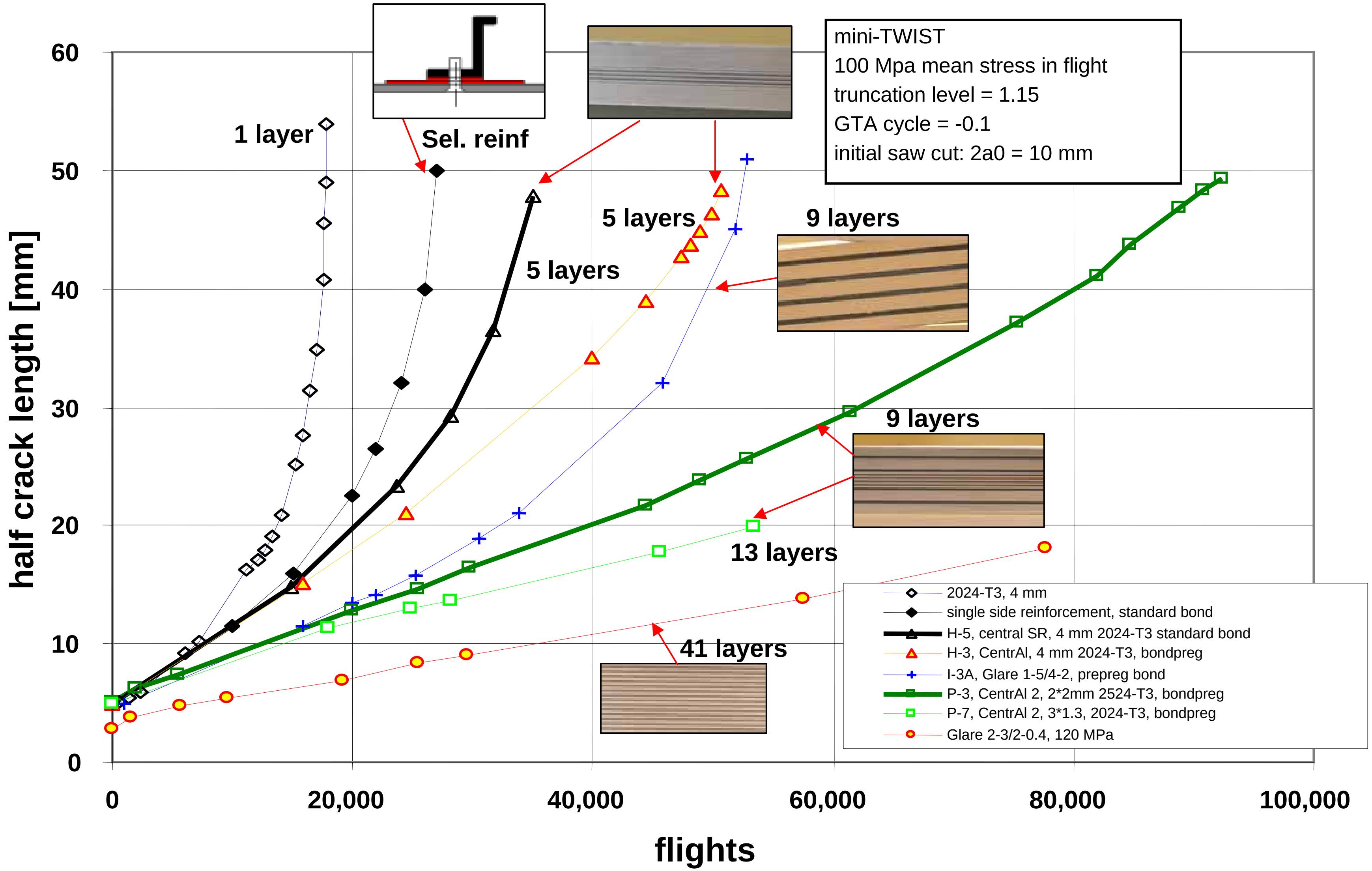
- **Metal to FML Volume Fraction**
- **Al Sheet Alloy, Temper, and Thicknesses**
- **Type of Prepreg, Bonding Adhesive**





Section A-A

Center Crack Panel Test Results Showing Concept Flexibility to Alter the Cost-Performance Trade



Alcoa Large Panel Concept Validation Program

Goal

- Validate performance & weight reductions for several adv. design concepts by **designing, building, & testing** structural articles

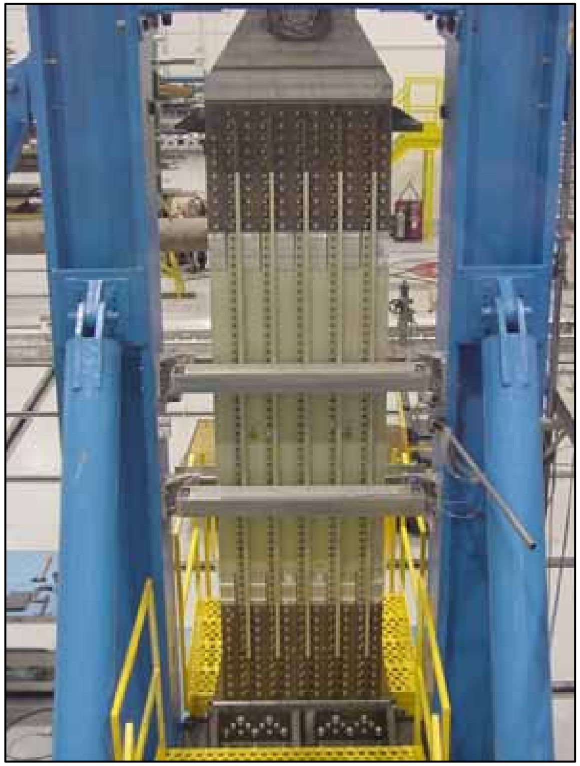
Description

- Lower Wing the initial focus
  - ✓ High acreage application
  - ✓ Area where conventional aluminum design most challenged by composite
- Evaluate adv. concepts for improved damage tolerance, crack growth & residual strength
  - ➢ Conditions Evaluated
    - ✓ Baseline vs Advanced Alloys
    - ✓ Built-up vs Integral
    - ✓ Selective Reinforcement
    - ✓ Damage Containment Features
    - ✓ Reinforced Sandwich Hybrid
  - ➢ Load Conditions
    - ✓ Constant Amplitude vs Spectrum
    - ✓ Baseline vs 25% Stress Increase

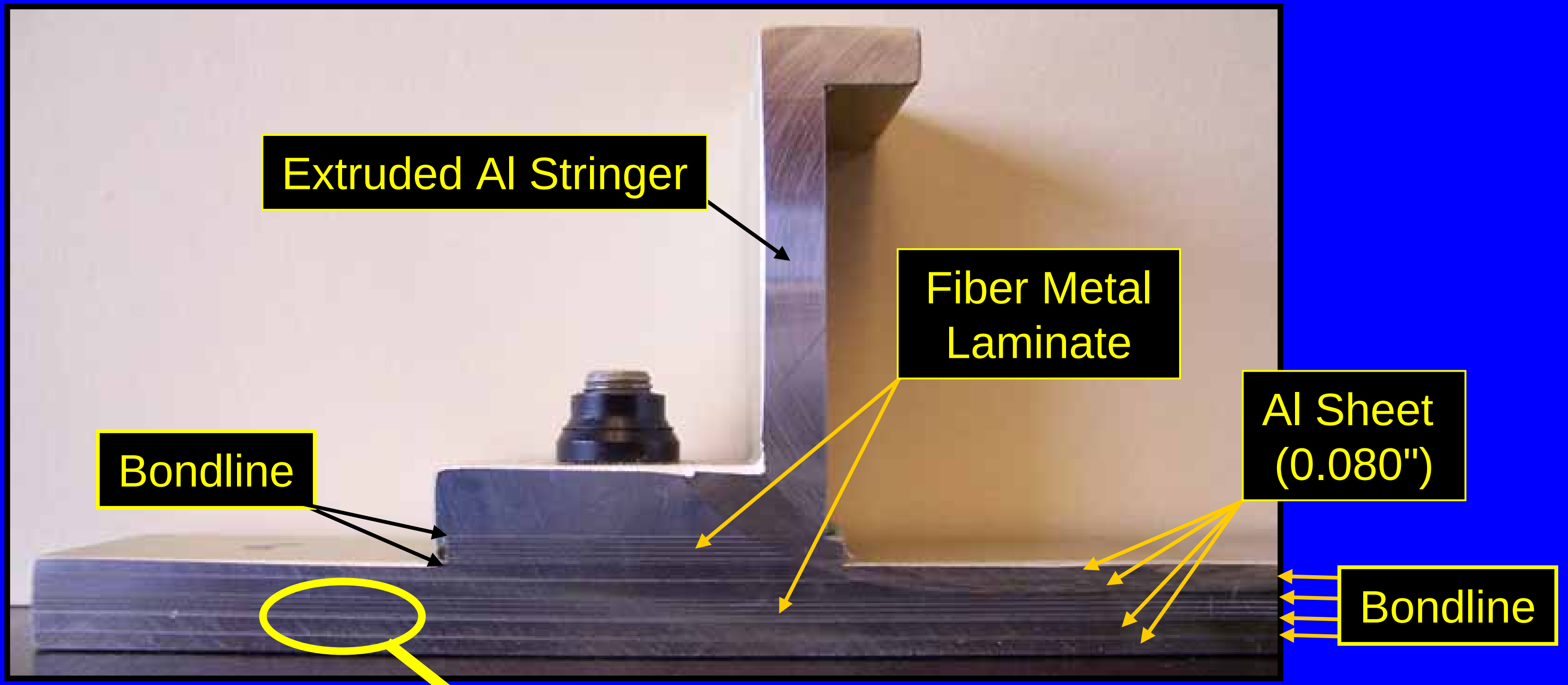
Lower wing simulation test article

Alcoa Lower Wing Panel Validation Test Program

- Testing performed at Vought in Dallas, TX
- All panels measure 30 in x 90 in with 5-stiffeners (5.5 in spacing)
  - 2a initial = 2.0 in with severed central stiffener
  - Fatigue cycled at baseline & target 25% improvement stress
- Test matrix consists of 28 stiffened panels representing 13 different concepts
  - Panels tested under both constant amplitude and Mini-TWIST wing spectra
  - Panels also tested for residual strength



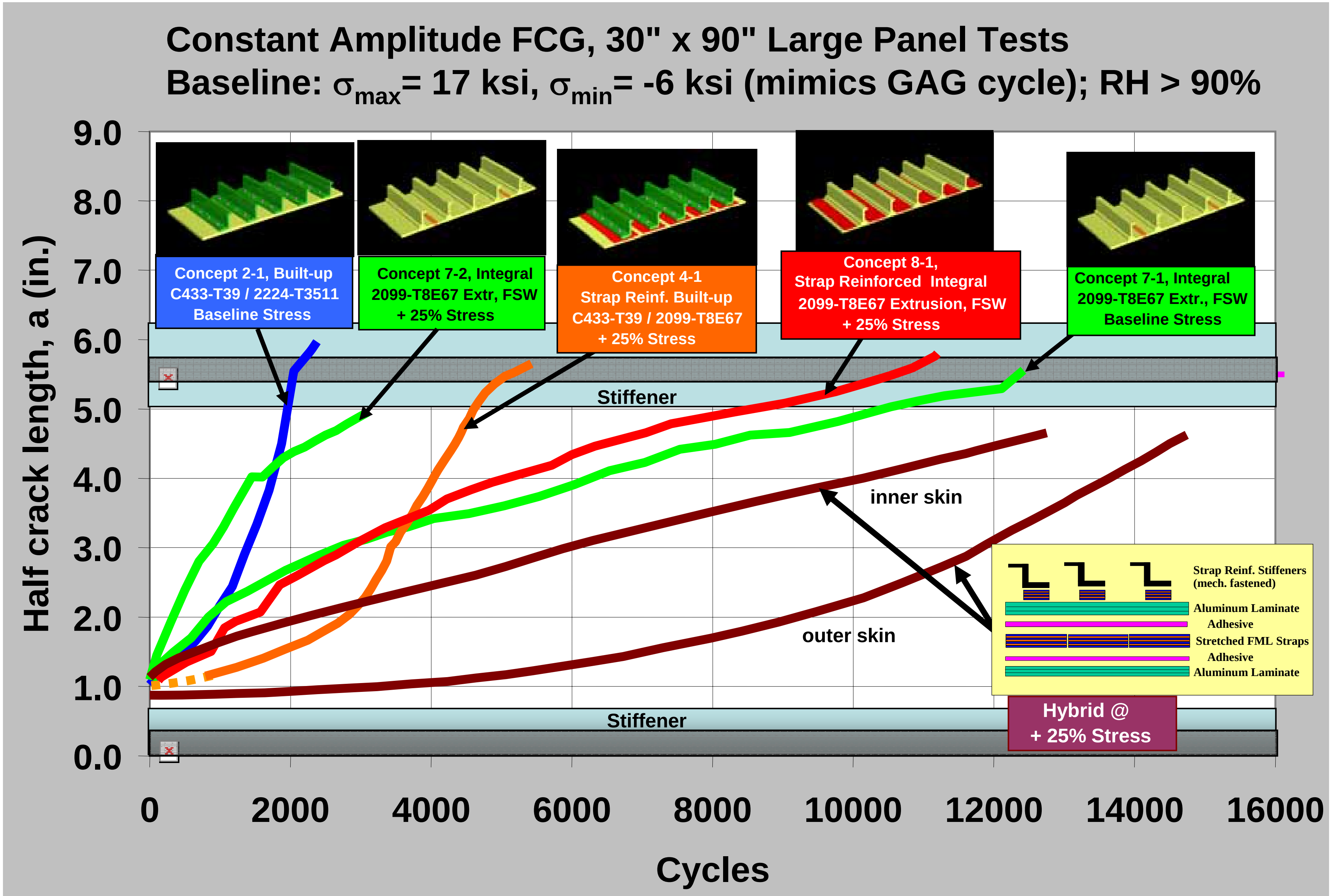
Adv. Hybrid Properties can be Tailored by Changing Metal to FML Vol. Fraction, Alloy, Temper, Sheet Thk., & Adhesive Type



Fiber Metal Laminate Detail

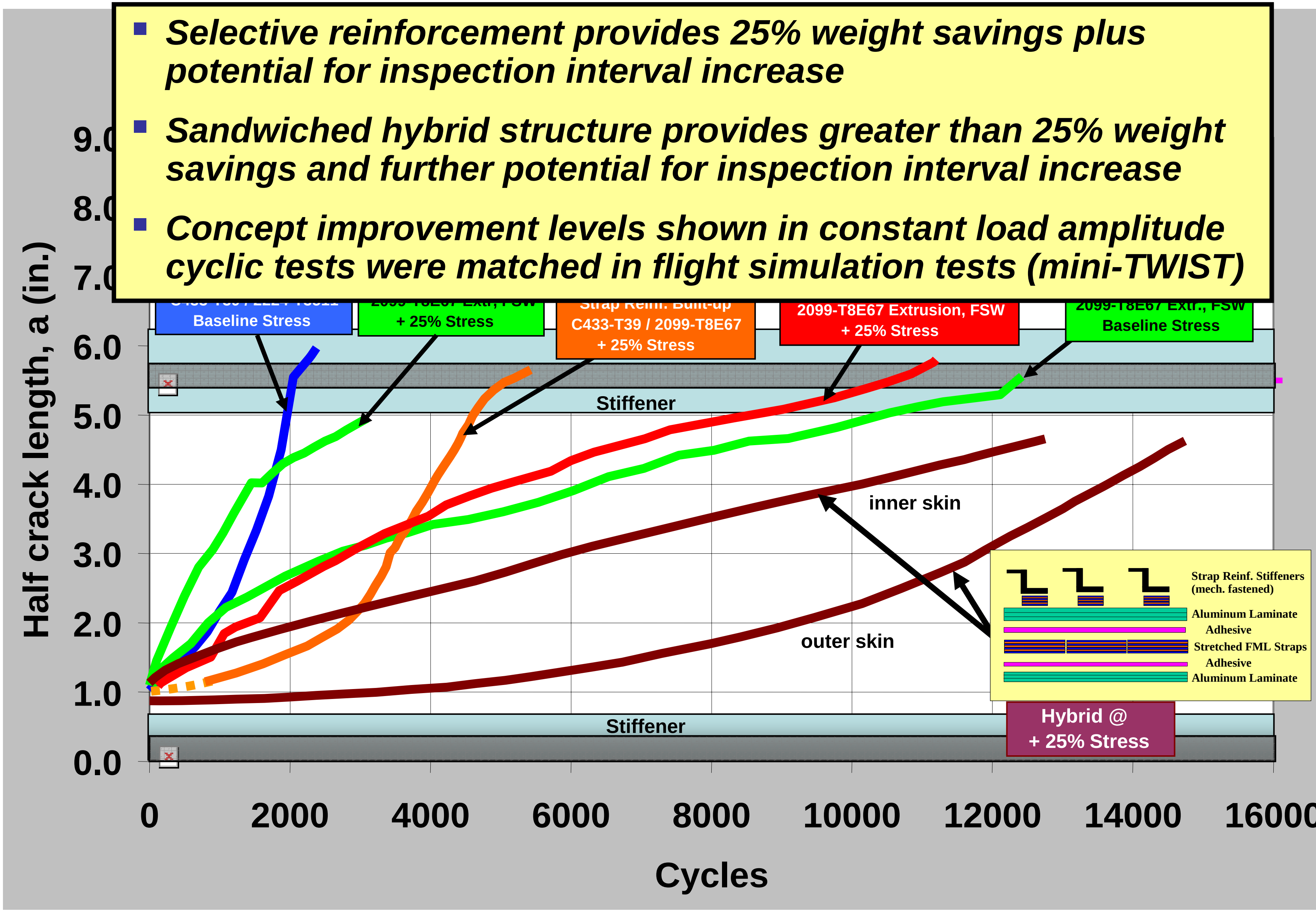
Adv. Hybrid Concept - Large Wing Panel Test Panel

Constant Amplitude Test Results - 30"x 90" Stiff. Wing Panel

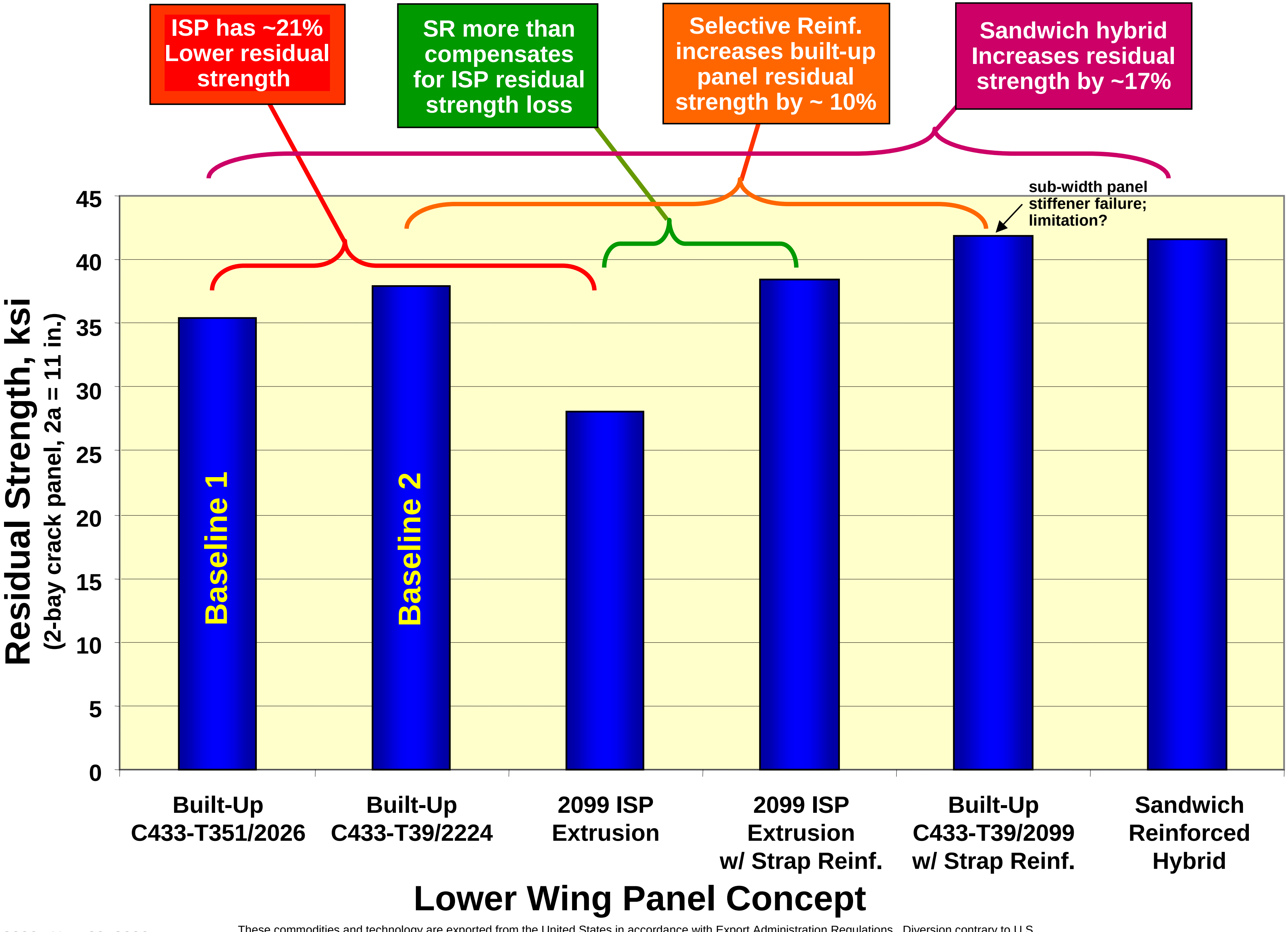


Constant Amplitude Test Results - 30"x 90" Stiff. Wing Panel

- ***Selective reinforcement provides 25% weight savings plus potential for inspection interval increase***
- ***Sandwiched hybrid structure provides greater than 25% weight savings and further potential for inspection interval increase***
- ***Concept improvement levels shown in constant load amplitude cyclic tests were matched in flight simulation tests (mini-TWIST)***

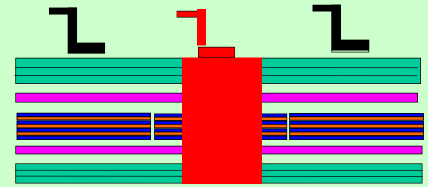


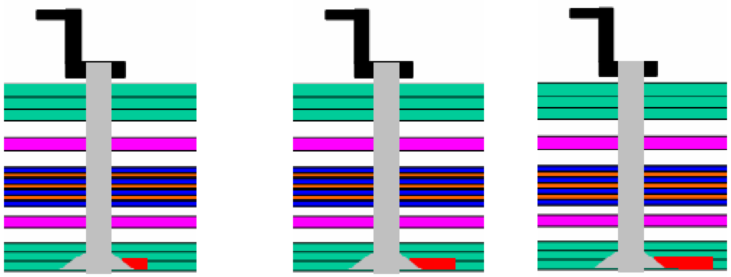
Large Wing Panel Residual Strength Test Results



New design/certification approaches are key to achieving advanced concept full benefit potential

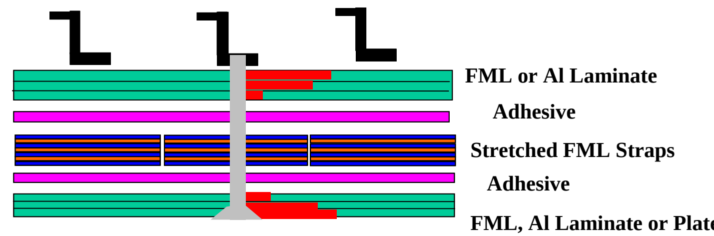
The tested thru crack starting damage for repeat inspections is ultra-conservative





S/N Fatigue/Initial Inspections

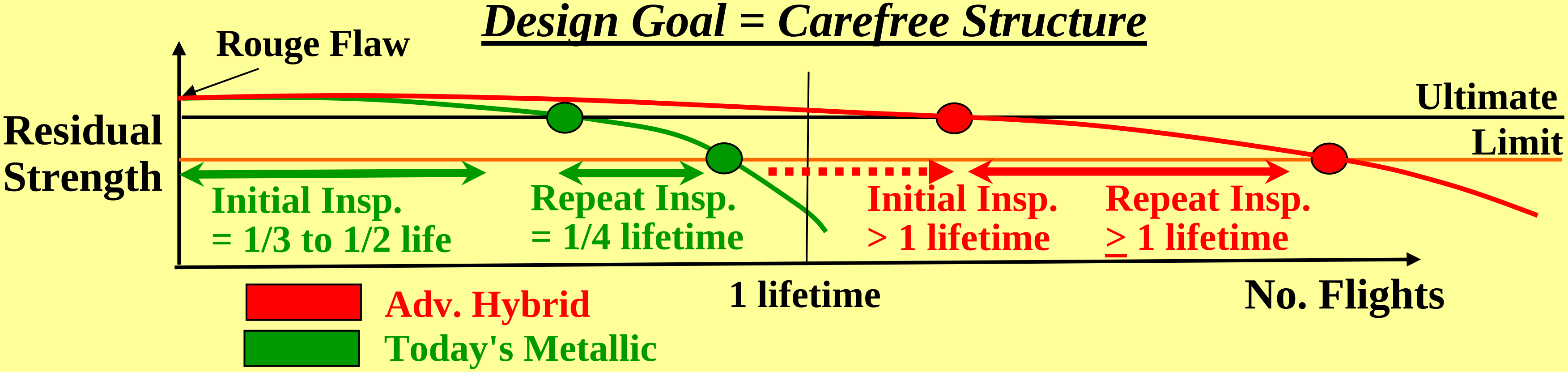
Early fatigue damage in thick GLARE skin contained within Al Layers and "bridged" by fiber containing layers



Repeat Inspections Inspections

Fatigue damage in thick GLARE skin contained within Al layers and "bridged" by Fiber containing layers. The stretched fatigue insensitive core stays intact

Design Goal = Carefree Structure



Alcoa Large Fuselage Panel Validation Tests

- **Structurally representative tests to confirm benefit of promising fuselage cover panel concepts defined from design studies**

- **Testing being executed at Purdue University Bowen Large Scale Test Laboratory**
  - ✓ 27 ft tall test frame; 220 kip actuator
  - ✓ Controlled environment (temp & RH in local crack plane)

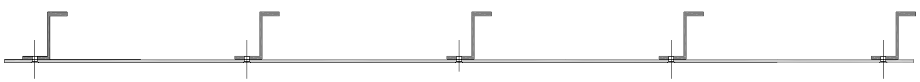
- **Test Program**
  - ✓ **7 stringer crown concepts; 30 in x 80 in panels**
  - ✓ **2 frame concepts; 30 in x 80 in MT panels**
  - ✓ **Testing of adv. alloy, design and mfg. concepts, including LBW**
  - ✓ **FCG (constant amplitude, crown & frame spectra) and residual strength testing**

Fuselage crown stringer panel test set-up

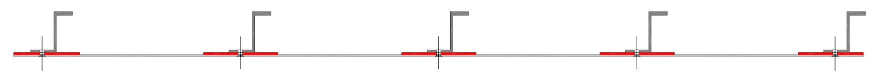
Fuselage Crown Stringer Panel Test Matrix

Baseline

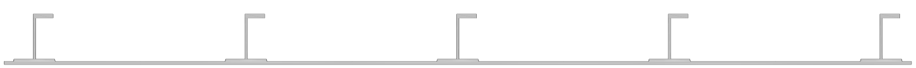
Concept	Skin	Stringer	Configuration	# Panels	Spectrum
Proto	2524-T3	7075-T76511	Built-up	1	Const Ampl
1	2524-T3	7150-T77	Built-up	2/3	Const Ampl + Spectrum
2	6013-T6	6xxx	Laser Beam Welded	2/4	Const Ampl + Spectrum
3	2199-T8	2099-T8 (+HS Variant)	Built-up	2/3	Const Ampl + Spectrum
4	2199-T8	2099-T8 (+HS Variant)	Laser Beam Welded	2/4	Const Ampl + Spectrum
5	2199-T8	2099-T8	Built-up with FML	2/3	Const Ampl + Spectrum
6	2199-T8	2099-T8 (+HS Variant)	LBW with FML	2/4	Const Ampl + Spectrum
9	2xxx Variant	2099-T8	Built-Up	2/3	Const Ampl + Spectrum



Built-up panel



Built-up panel w/ reinforcement



Laser beam welded panel

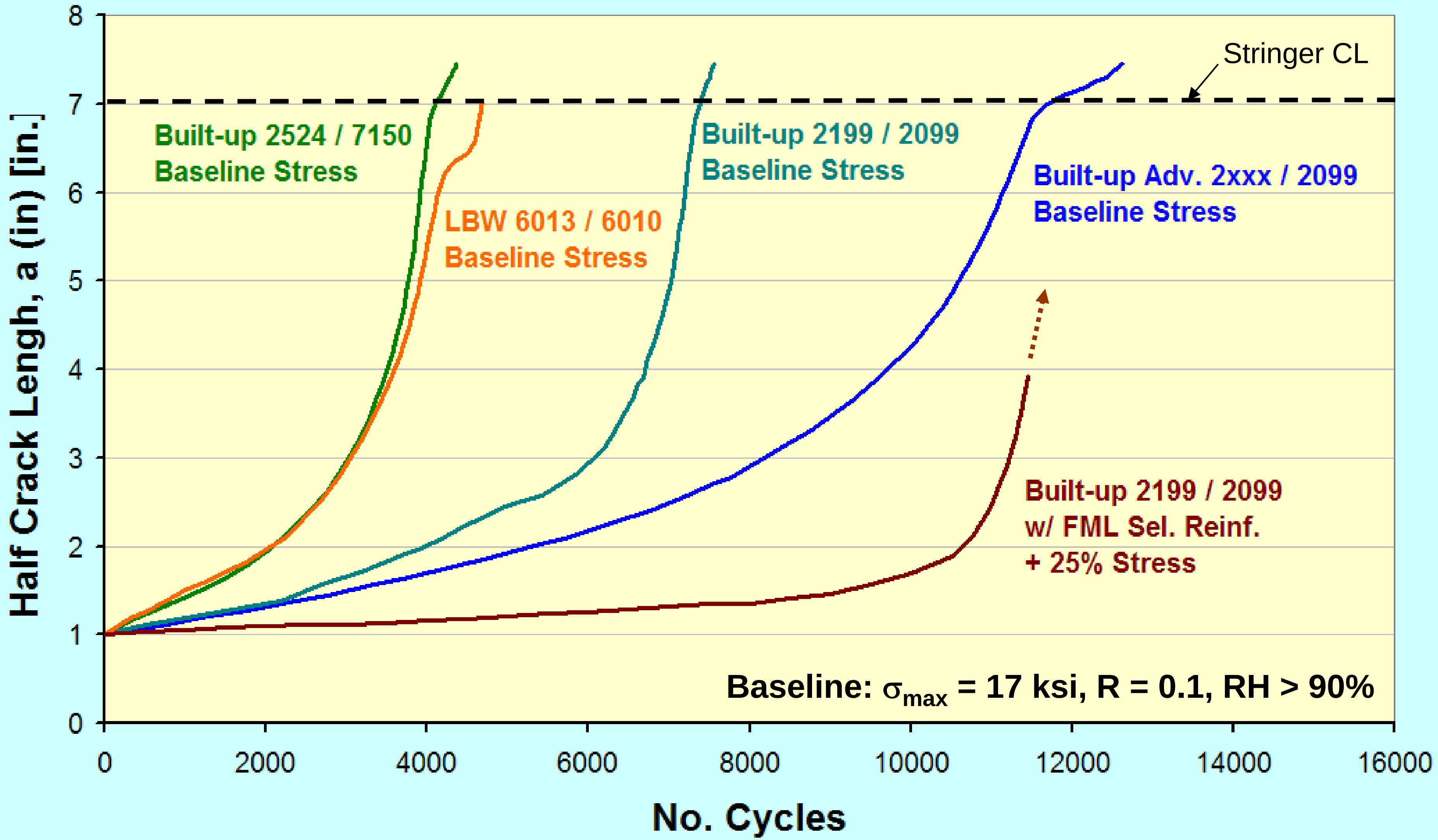
Laser beam welded panel w/ reinforcement

- 30 in x 80 in panels wi/ 5 stringers (7 in pitch)
- Total panel area = 4.38 in^2
- Stringer Area to Skin area Ratio
- As/Bt = 0.46; As/(Bt+As) = 0.32

- 2a initial = 2.0 in with broken central stiffener
- Tested at baseline & target 25% improvement stress
- Panels tested under both const ampl and representative fuselage crown spectrum
- Panels also tested for residual strength

Fuselage Crown Stringer Panel - Const. Ampl. Test Results

- ***Advanced skin alloys show much improved crack growth performance***
- ***Selective reinforcement provides 25% weight saving potential plus opportunity for substantial (~3X) inspection interval increase***



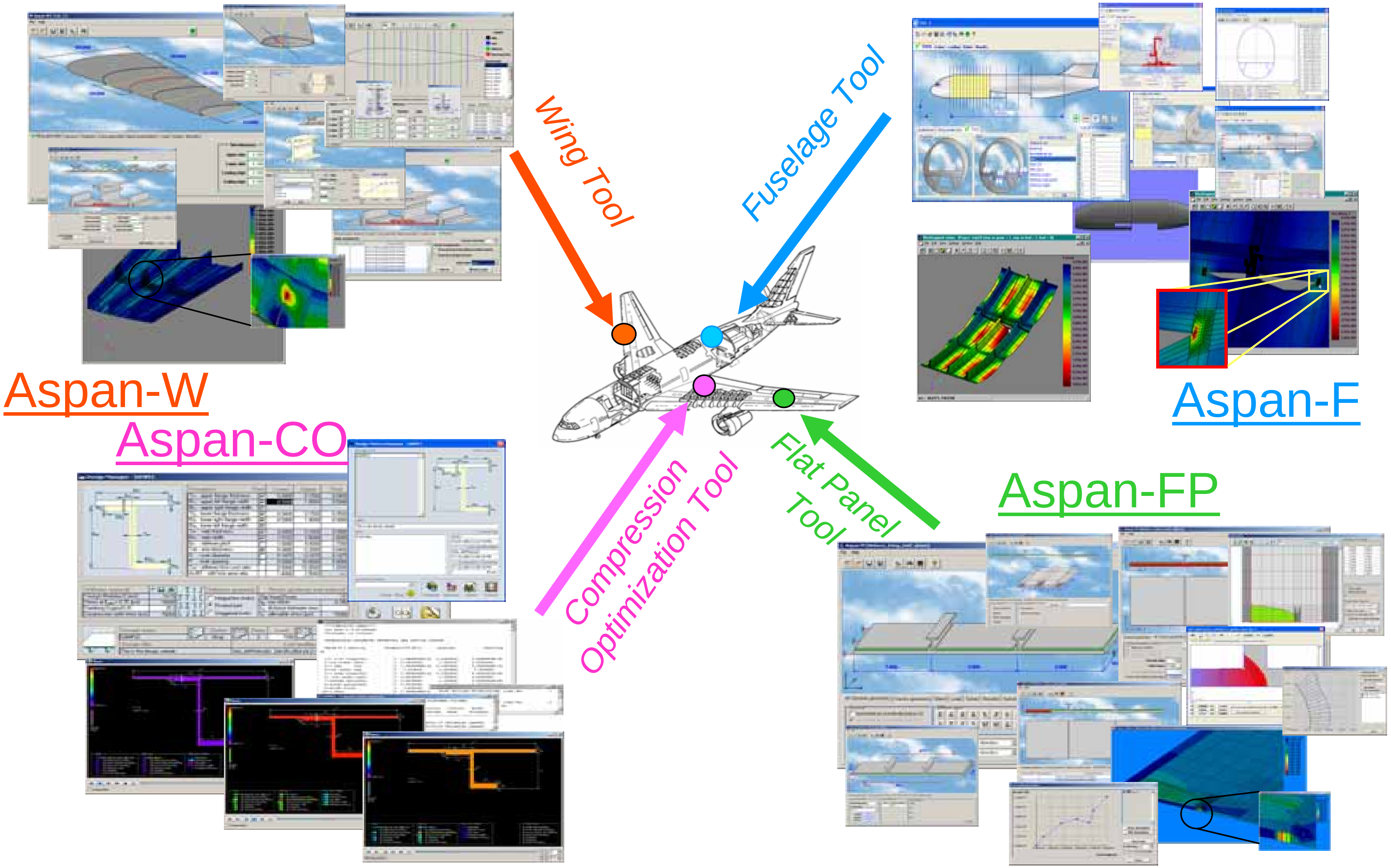
Alcoa Design Studies – *the steps*

- **Trade studies of wing & fuselage panels:**
  - ✓ **Configuation & loads representative of a generic twin-aisle aircraft**
  - ✓ **Alcoa trade study tools used to investigate multiple design drivers:**
    - ➢ **Primary drivers:**
      - **Static strength & stability**
      - **Damage tolerance (constant amplitude & spectrum cases)**
      - **Residual strength**
    - ➢ **Secondary considerations**
      - **Significant inspection interval increase at higher stress**
      - **Corrosion resistance**

- **Design concepts evaluated**
  - ✓ **Advanced alloys with improved properties**
  - ✓ **Use of high modulus materials**
    - ➢ **High modulus stringers to off-load skin**
    - ➢ **High modulus selective reinforcement to off-load skin & stringers**
  - ✓ **Selective reinforcement**
  - ✓ **Sandwich Reinforced Hybrid Structure**

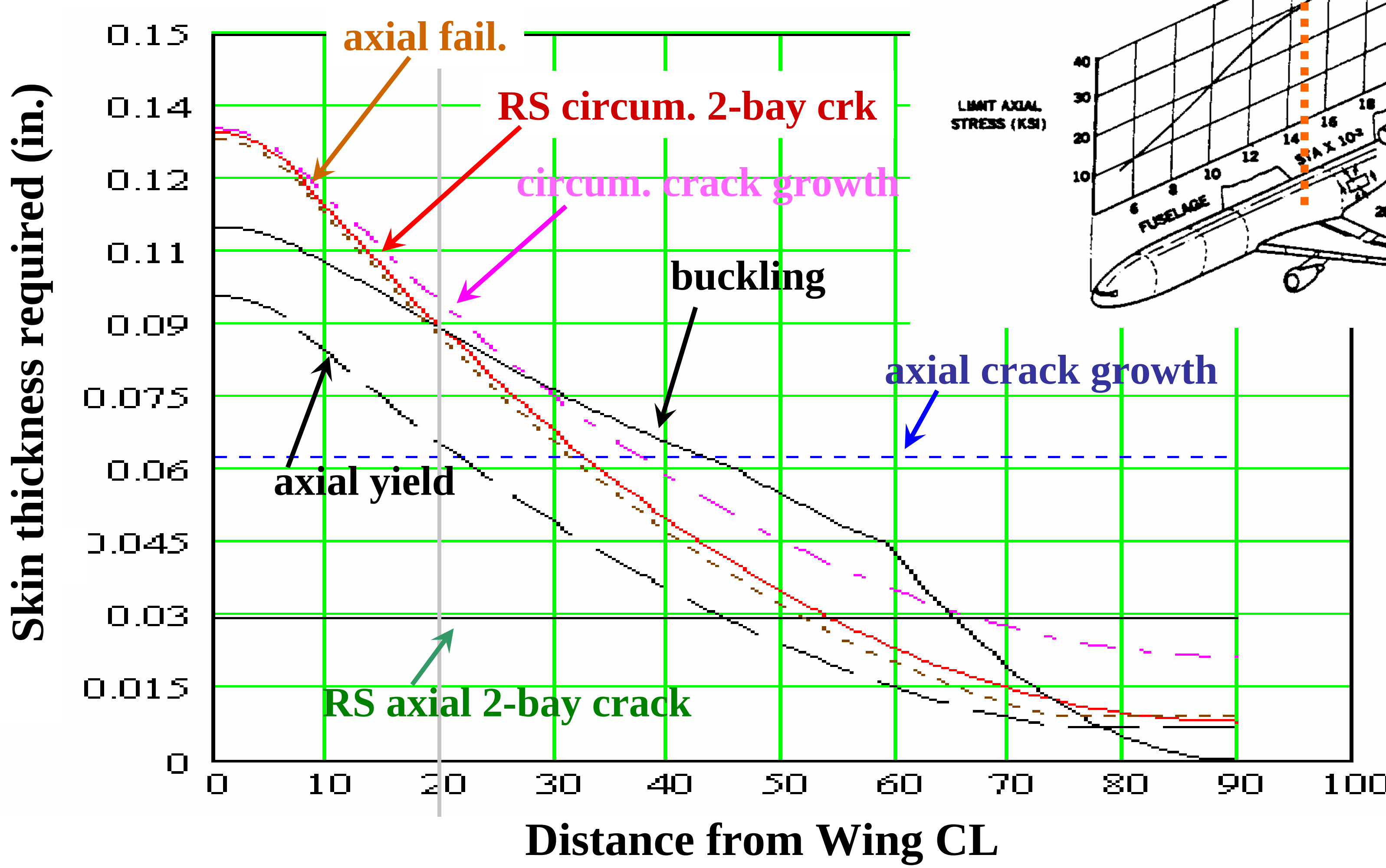
- **Structurally representative panel testing used to validate concepts, analytical tools and update trade study results**

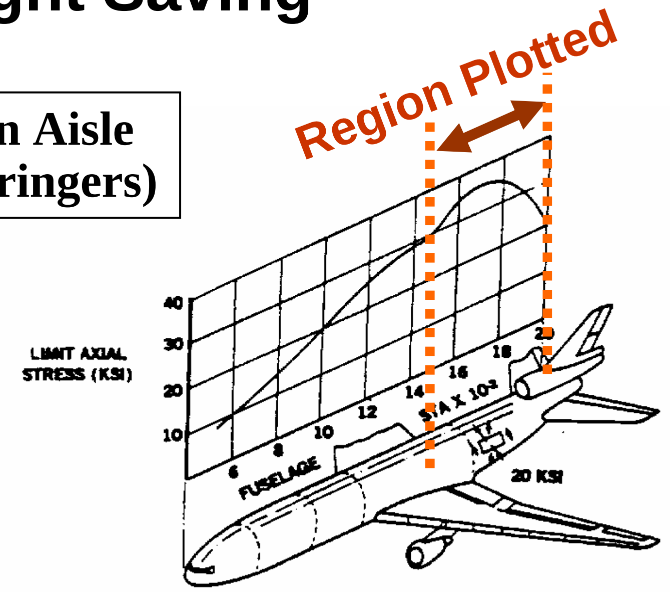
Alcoa Rapid Trade Study Tools and Rapid Testing Help Identify Benefits of New Materials and Design Concepts



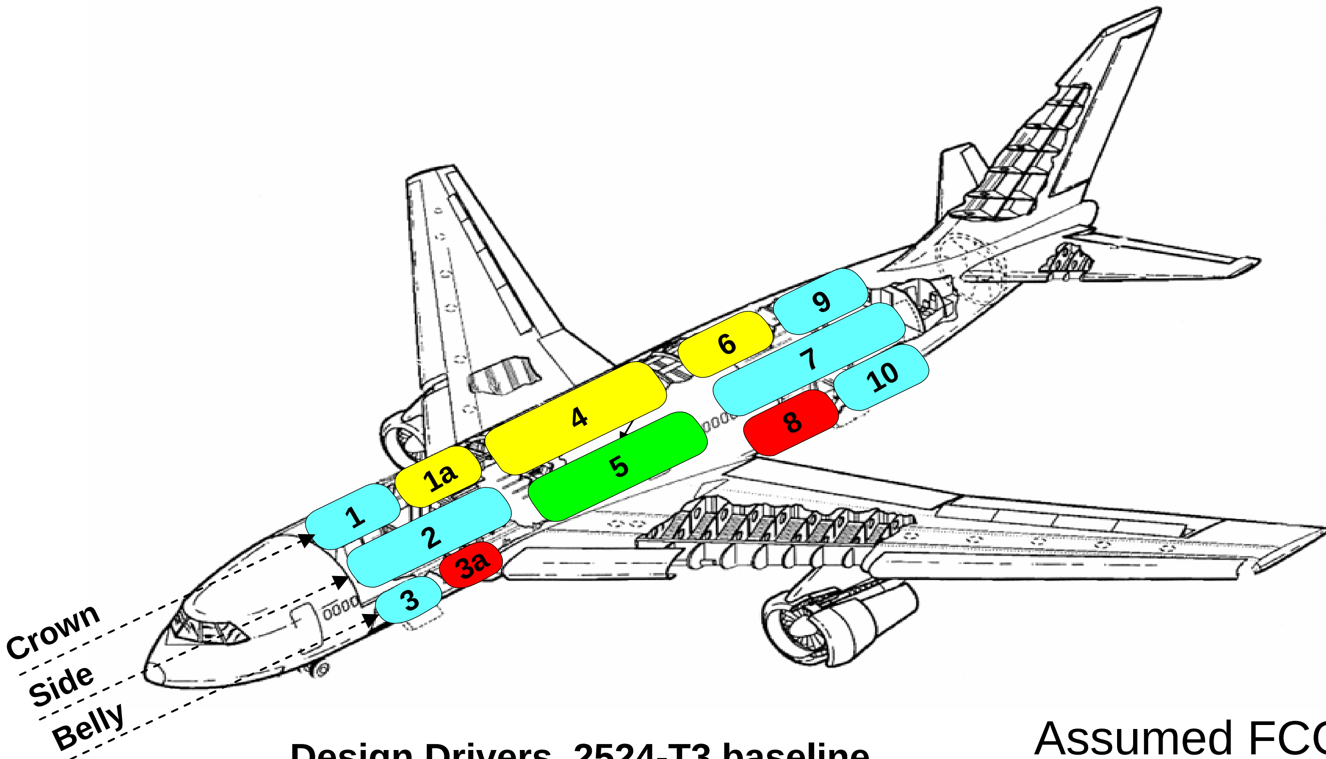
Trade Studies Help Identify Key Design Drivers to Achieve Weight Saving

Est. Crown Design Drivers - Twin Aisle (2524 Skins + 7150-T77511 stringers)





Estimated Fuselage Primary Design Drivers
Alcoa Internal Trade Study - Generic Twin Aisle Aircraft



Design Drivers, 2524-T3 baseline

- da/dN (constant amplitude)
- Spectrum Crack Growth
- Compressive strength
- Shear strength

<u>Assumed FCG skin stresses</u>

Skin Hoop Stresses < 12 ksi

Axial GAG Stresses < 18 ksi

Alcoa Fuselage Trade Study Example (generic twin-aisle aircraft)*

- ***Advanced alloys alone offer double digit weight saving opportunity***
- ***New concepts offer opportunity for further significant weight & cost savings***

	Design Concept			Crown Panel		Side Panel		Belly Panel	
Min. Thk. (mm)	**Skin Material**	**Stringer Material**	**Joining Method**	**Limiting Design Driver**	**Weight Saving (%)**	**Limiting Design Driver**	**Weight Saving (%)**	**Limiting Design Driver**	**Weight Saving (%)**
1.5	**2524-T3**	**7055-T76511**	Riveted	▪ 70% circum FCG ▪ 30% axial FCG	1990's Baseline	▪ 90% axial FCG ▪ 10% Shear / axial FCG / RS axial 2-bay crk	1990's Baseline	▪ 75% Compress / Shear ▪ 25% axial FCG	1990's Baseline
1.5	**2524-T3 + Sel Reinf**	**7055-T76511**	Riveted	▪ 65% circum FCG ▪ 35% axial FCG / RS axial 2-bay crk	**19.6**	▪ 60% axial FCG / RS axial 2-bay crk ▪ 40% Shear	**15.5**	▪ 85% Compr / Shear ▪ 15% Axial FCG / RS axial 2-bay crk	**6.4**
1.5	**2199**	**2099-T83**	Riveted	▪ 60% circum FCG / RS circum 2-bay crk ▪ 40% RS axial 2-bay crk	**14.2**	▪ 100% RS axial 2-bay crk	**6.2**	▪ 90% Compr / Shear ▪ 10% RS axial 2-bay crk	**7.3**
1.5	**2199 + Sel. Reinf**	**2099-T83**	Bonded	▪ 65% circum FCG ▪ 35% RS axial 2-bay crk	**14.4**	▪ 100% RS axial 2-bay crk	**6.2**	▪ 90% Compr / Shear ▪ 10% RS axial 2-bay crk	**7.3**
1.5	**2199 + Sel. Reinf.**	**2099-T83**	Riveted	▪ 50% circum FCG / RS circum 2-bay crk ▪ 50% RS axial 2-bay crk	**28.8**	▪ 75% RS axial 2-bay crk ▪ 25% Shear Buck.	**20.7**	▪ 90% Compr / Shear ▪ 10% RS axial 2-bay crk	**12.6**
1.5	**HT Al-Li**	**2099-T83**	Riveted	▪ 75% circum FCG ▪ 25% Axial FCG / RS axial 2-bay crk	**15.7**	▪ 70% RS axial 2-bay crk ▪ 30% Shear Buck	**20.6**	▪ 90% Compr / Shear ▪ 10% axial FCG / RS axial 2-bay crk	**12.4**
1.5	**HT Al-Li + Sel Reinf**	**2099-T83**	Riveted	▪ 60% circum FCG ▪ 40% Min. Gage	**26.9**	▪ 60% Shear Buck. ▪ 40% Min Gage	**22.2**	▪ 90% Compr / Shear ▪ 10% Min Gage	**13.0**
1.3	**HT Al-Li + Sel Reinf**	**2099-T83**	Riveted	▪ 65% circum FCG ▪ 35% RS axial 2-bay crk / Min Gage	**31.5**	▪ 65% Shear Buck. ▪ 35% RS axial 2-bay crk / Min Gage	**27.5**	▪ 85% Compr / Shear ▪ 15% RS axial 2-bay crk / Min Gage	**16.1**
1.5	**GLARE-4**	**GLARE-1**	Riveted	▪ 55% RS circum 2-bay crk ▪ 45% RS axial 2-bay crk	**32.1**	▪ 90% Shear Buck ▪ 10% RS axial 2-bay crk	**12.8**	▪ 95% Compr / Shear ▪ 5% RS axial 2-bay crk	**9.8**
1.5	**Gr/Epoxy**	**Gr/Epoxy**	Bonded	▪ 50% RS circum 2-bay crk ▪ 50% RS axial 2-bay crk	**21.6**	▪ 100% RS axial 2-bay crk	**31.1**	▪ 50% Compression ▪ 50% RS axial 2-bay crk	**21.6**

* Baseline: Circa 1990's fuselage panels sized to meet target next gen. cabin diameter, 1.1x pressure & 2x insp. interval increases

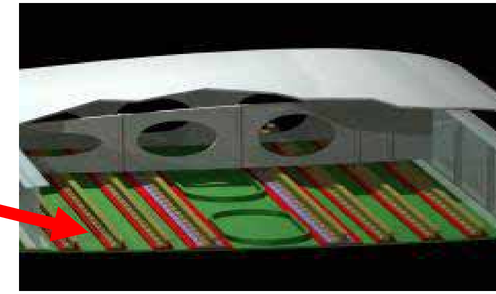
Lower Wing Concepts Offering Significant (>20%) Wt / Cost Saving Opportunity have been Identified & Demonstrated

Near Term Concepts

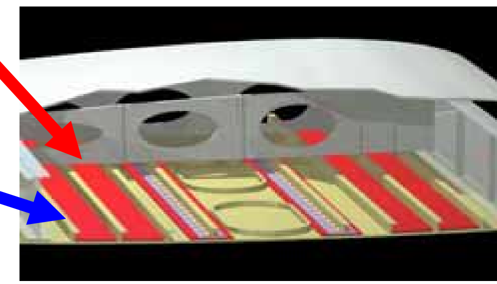
- Selective reinforcement (built-up or integral)
  - ➢ Improve fatigue crack growth performance
  - ➢ Improve residual strength
  - ➢ Improve static Strength
- Integrally Stiffened Panels
  - ➢ FSW wide extrusions
  - ➢ Machined Thick Plate
- Damage containment features
  - ➢ For Built-up Panels
  - ➢ For Integral Panels
  - ➢ With & without reinforcing straps

Future Design Concepts/Improvements

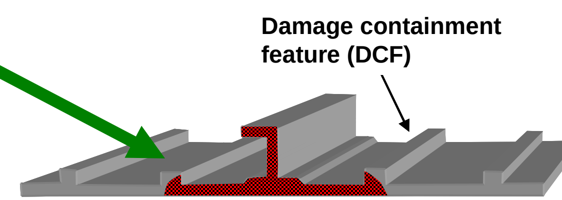
- Sandwich Reinforced Hybrid Structural Concepts
  - ➢ Improved usage of high strength alloys & reinforcing materials
  - ➢ New FML systems
    - High Modulus to offload skin and stiffeners
    - Improved crack bridging
    - Offset EI, GJ stiffness loss due to gage reduction



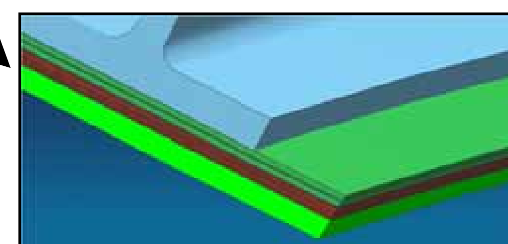
Strap Reinforced built-up Structure



Strap Reinforced Integral Structure



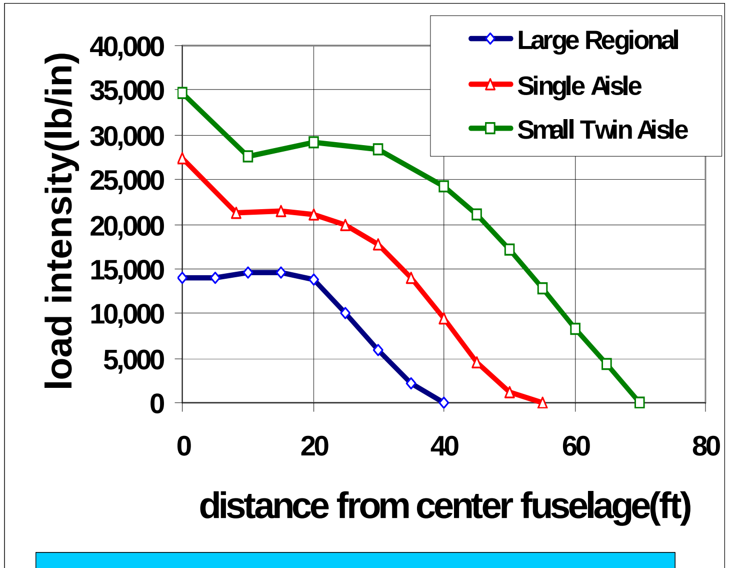
Crack slows through each feature

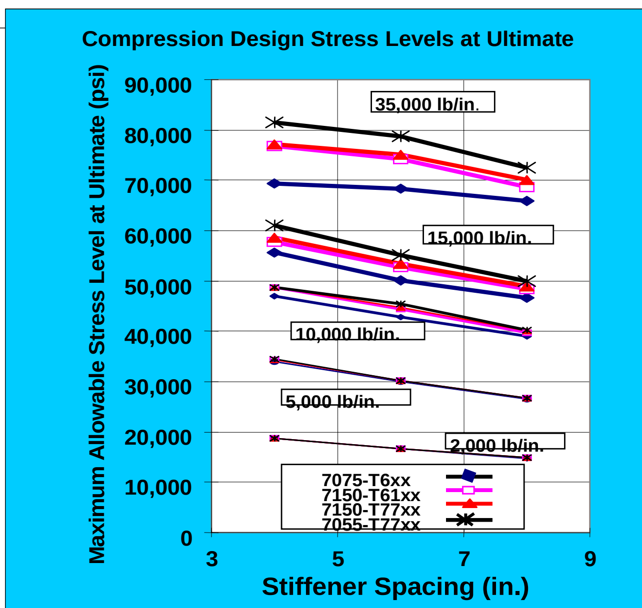


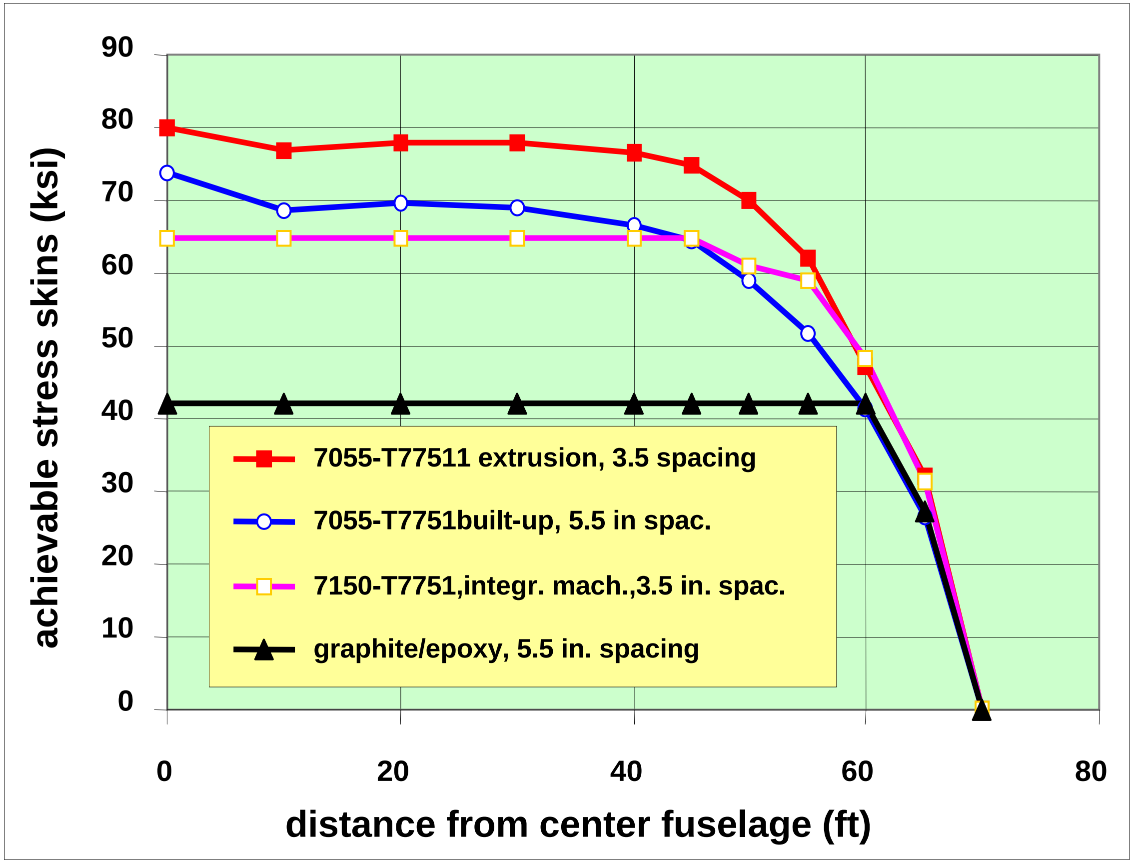
Sandwich Reinforced Hybrid Structure

Al Alloys Compete Well for Highly-Loaded Upper Wing Structure

Current composites do not appear to offer significant wt advantage over metallic baseline







- Assumptions: Gr/Ep stiffened panel allowable estimate
  - ✓ Limited by compression after impact
  - ✓ 3800$\mu\varepsilon$ Strain cutoff w/ avg. modulus of 11 Msi
- Gr/Ep derived compressive working stress = 42 ksi

Summary - Alcoa Internal Wing & Fuselage Studies

Wing:

- Lower Covers:
  - R&D has focused on overcoming the DADT deficit where Al most vulnerable to Gr/Ep
  - Solutions that compete with both current and stretch composite technology can be developed in the next 2-4 years
    - ✓ Near Term: selective reinforcement, damage containment, stiffener tailoring
    - ✓ Longer term: sandwich reinforced hybrid concepts
  - Advanced metallic and hybrid structural options are being validated – results are credible and look very good to date
    - ✓ 20% and higher weight/cost saving improvements over baseline is well within reach with further improvement feasibility demonstrated
    - ✓ Significant reductions in inspection/maintenance burden appear achievable
- Upper Covers:
  - Current composites offer little, if any, weight saving advantage over today's metallic baseline

Fuselage:

- Advanced alloys alone offer double-digit weight saving opportunities
- Innovative near term manufacturing approaches can save cost & weight
  - LBW stringer panels
  - FSW can potentially replace fuselage panel lap joints
  - Bonded Stiffeners
- Selective reinforcement will significantly improve static strength, damage tolerance, and possibly S/N fatigue

Conclusions

- **Advanced metallic & hybrid structural concepts are capable of achieving dramatic weight & cost saving improvements over current state-of-the-art with substantial reduction in inspection / maintenance burden**
  - **Combines benefits of existing design / mfg infrastructures**
  - **The concepts are highly tailorable with design flexibility to optimize the cost / performance trades**
  - **The technology is being validated – results are credible & look very good to date**
  - **Participation of OEMs, certifying agencies, suppliers and research establishments are needed to mature the technologies**

Alcoa Aerospace Vision - Advanced Hybrid Aerostructure

Re-defining perf., cost & value of tomorrow's aircraft matls & structures