Using Engineered Residual Stresses to Eliminate Damage Tolerance Inspections

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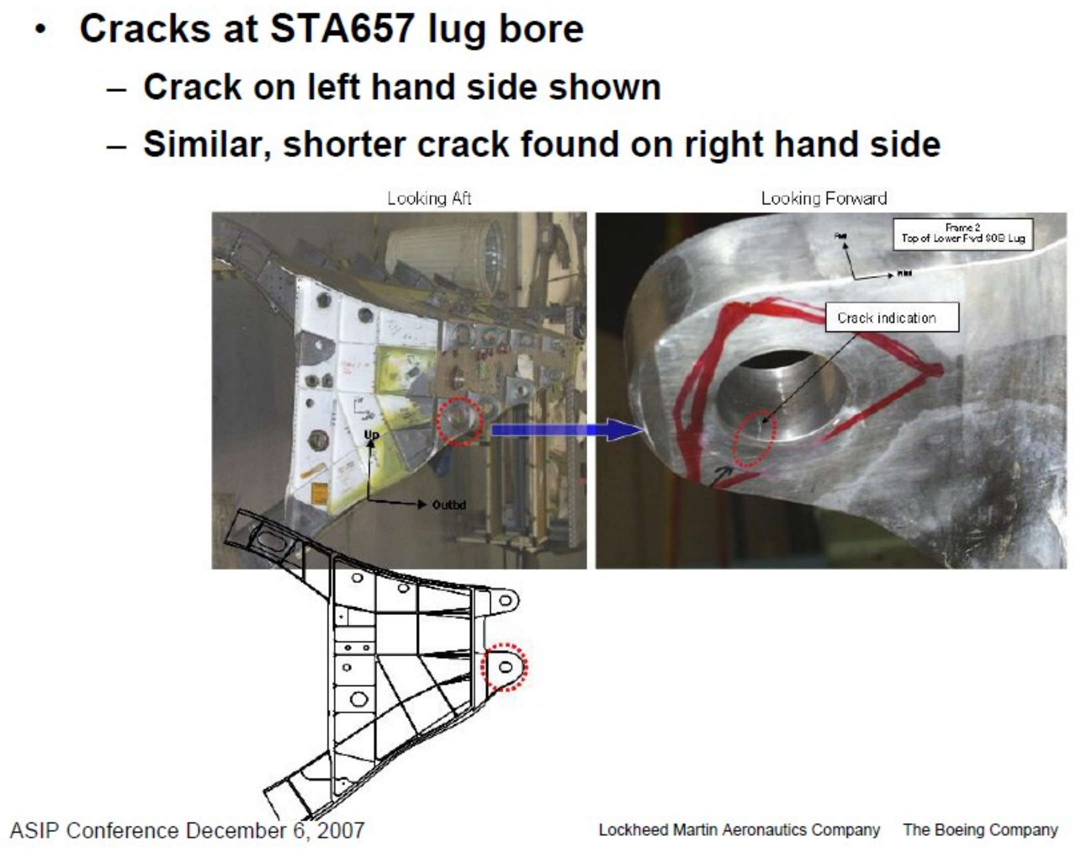
Bibliography

- Test Demonstrated Damage Tolerance of F-22 Wing-Attach Lugs with ForceMate™ Bushings, 2007 ASIP Conference
- Application of Surface Residual Stresses for Durability and Damage Tolerance Improvements in F-22 Wing Attachment Lugs, 2009 ASIP Conference
- Full Scale Component Tests to Validate the Effects of Laser Shock Peening, 2011 ASIP Conference
- Adaptation of LSP Capability for Use on F-22 Raptor Primary Structure at an Aircraft Modification Depot, 2nd International Conference on Laser Peening, 2010

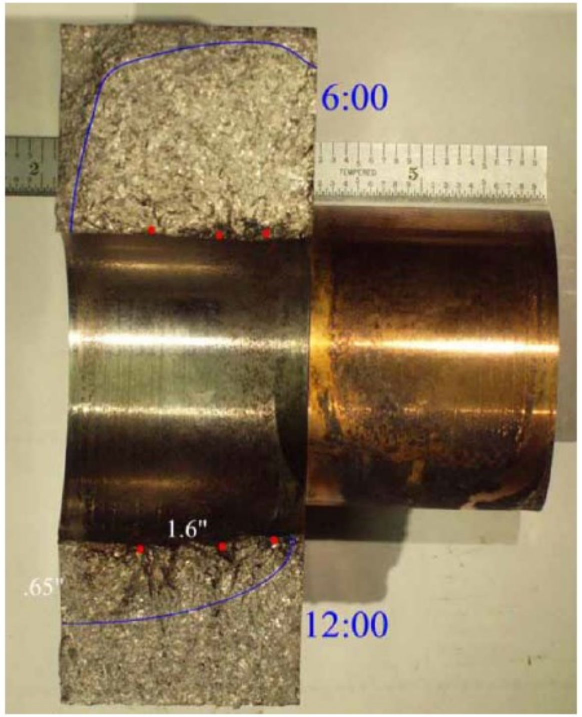
Wing attach lug bore



- Full scale fatigue test result . . .
    - Significant cracks at wing attach lug
    - Lugs on both left and right hand sides cracked

Crack initiation due to fretting

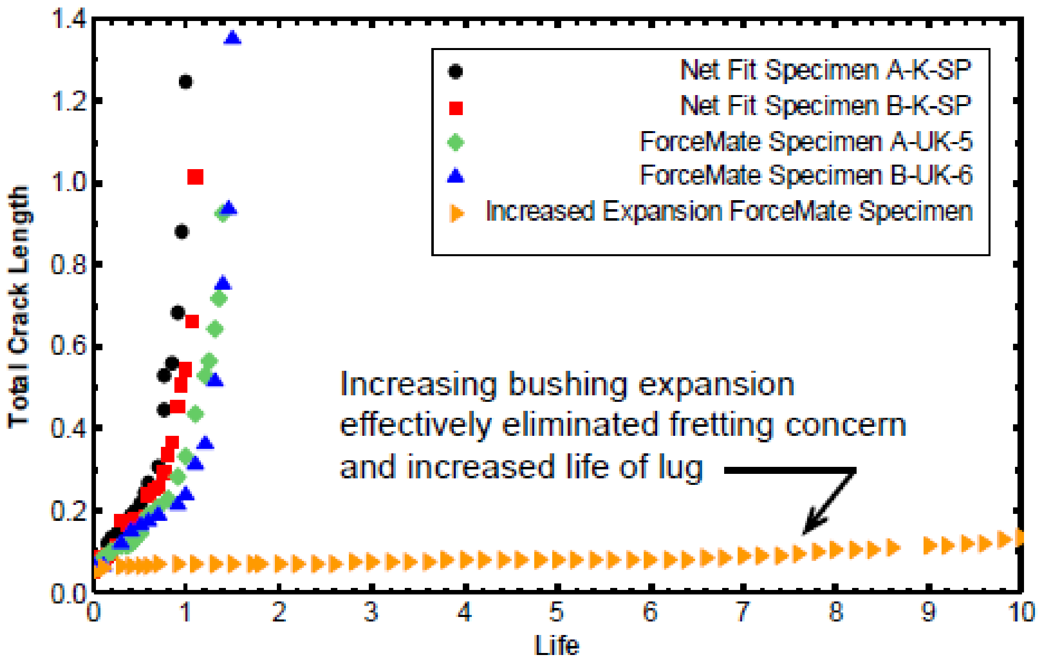
- Crack initiated along bore
  - Multiple initiation sites on both sides of bore
  - Pre-crack at EDM notch did not contribute to failure
- Evidence of fretting and galling observed on bushing and lug bore



- Component tests replicated cracking observed on FSFT
  - Identified fretting as cause of cracking
  - Insufficient cold work
  - Modified application to increase cold work

Inspections Eliminated with Design Change to Bushing

- **To increase damage tolerance capability and mitigate crack initiation due to fretting**
  - **Bushing expansion level increased**



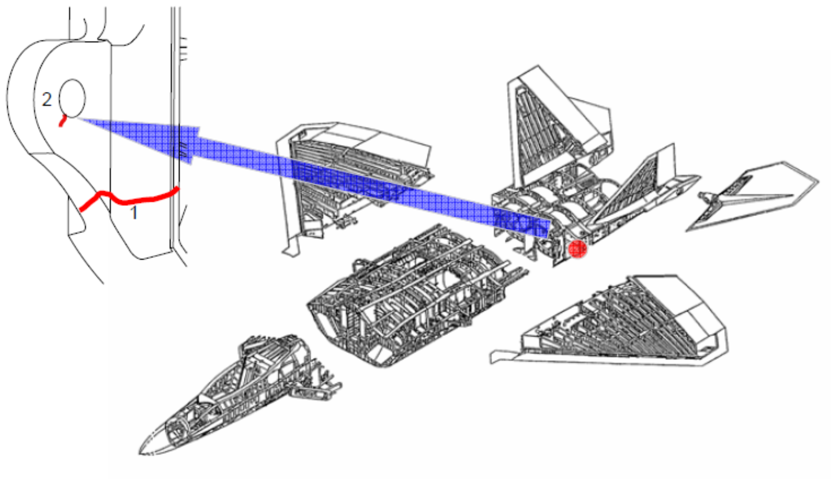
- Increasing level of cold work increased damage tolerance life
- Eliminated multiple inspections
- Eliminated cost of wing removals for inspection access
- Lesson learned: Don't assume residual stress benefit is automatic
  - i.e. Understand the parameters that impact residual stress levels

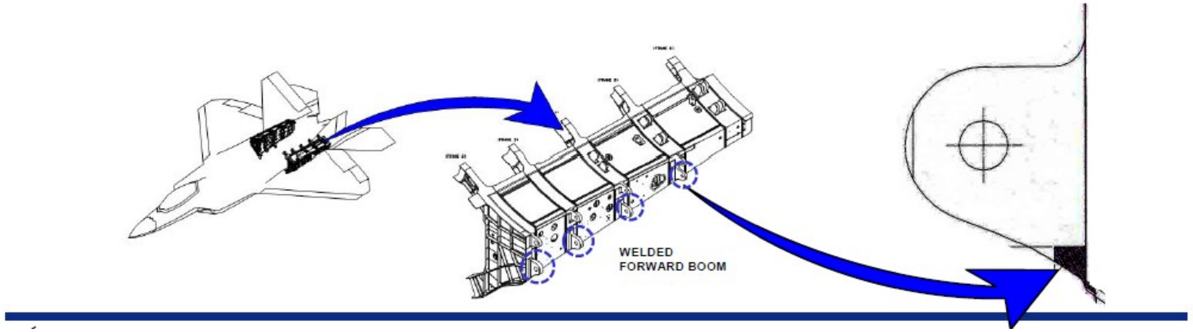
Surface residual stresses at fillet radii

Crack "1" discovered and repaired at 1.2 lifetimes

Crack "2" dicovered during teardown after 2.5 lifetimes

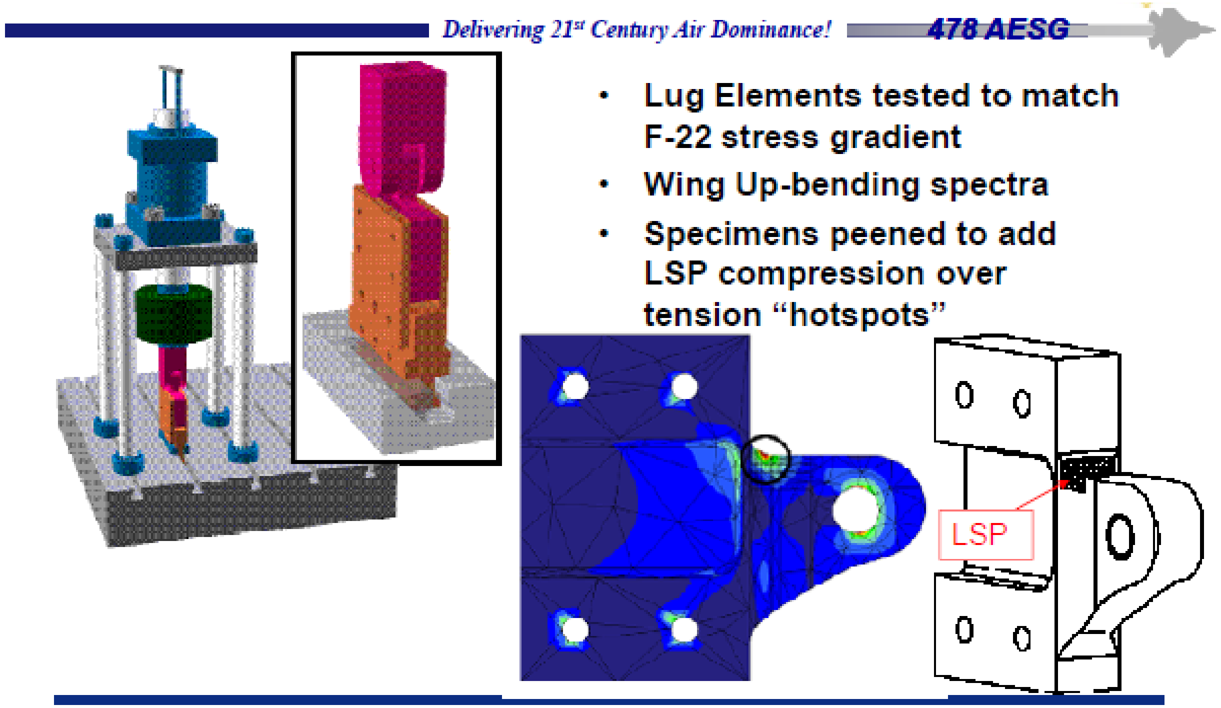
Similar cracking on left and right hand sides





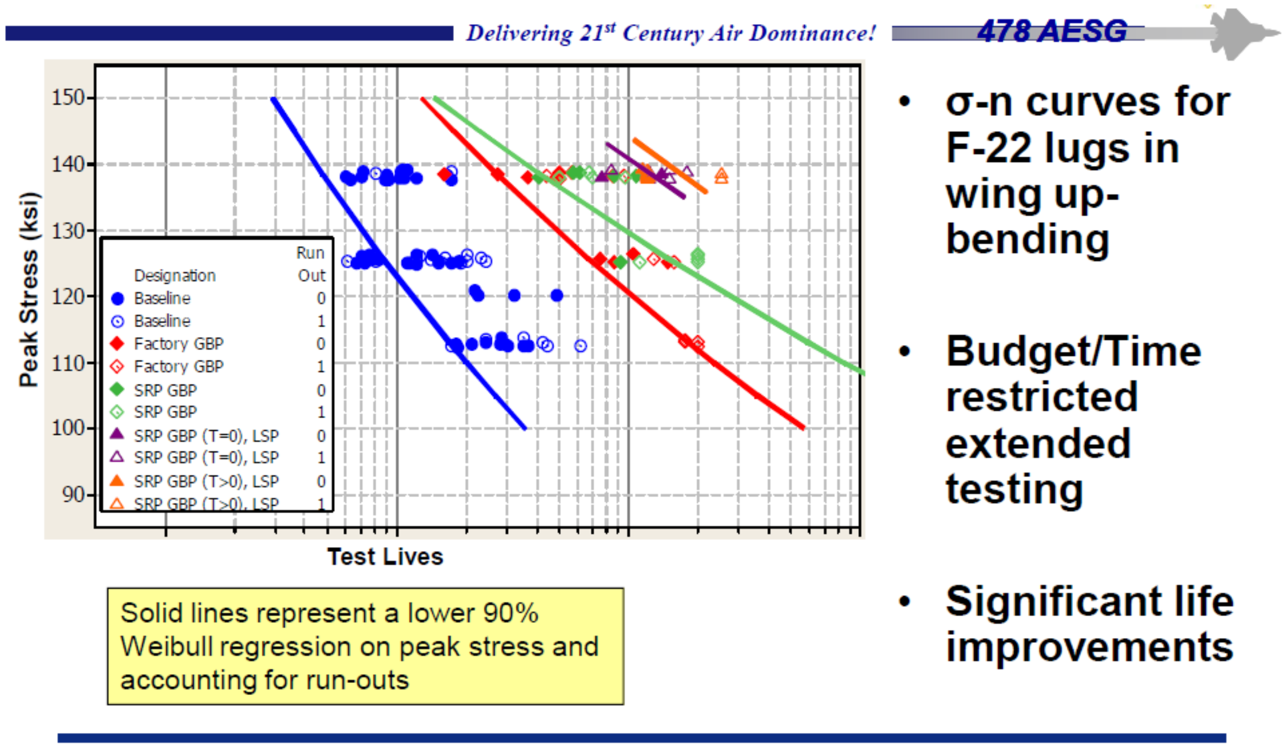
- In addition to crack at lug bore
- Cracks observed on lower fillet radii at multiple wing stations
- Limited repair options if cracks found
  - Needed pre-emptive intervention to prevent cracks

Building block test verification



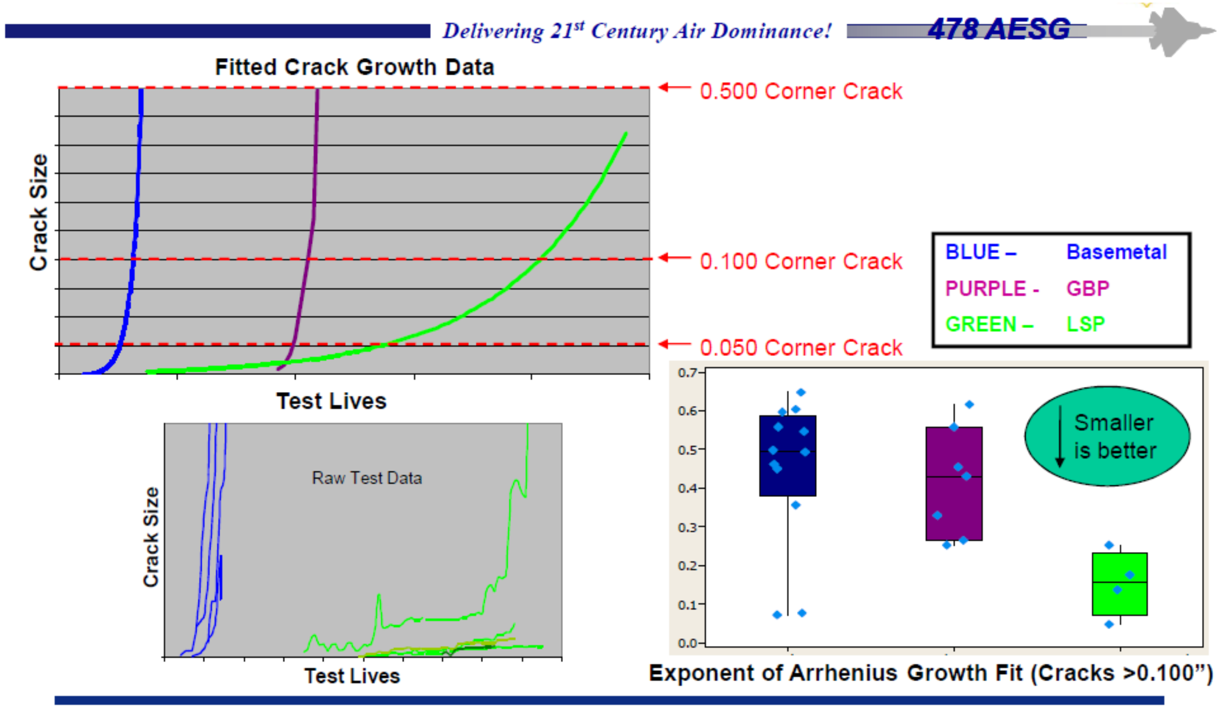
- Component test program developed to investigate fatigue life improvement
- Multiple configurations
  - Baseline (no peening)
  - Glass bead peen (GBP)
  - Laser shock peen (LSP)
  - GBP + LSP

Impressive Crack Initiation Benefit of Peening



- Crack initiation improvement impressive
- But not sufficiently better than GBP to justify cost

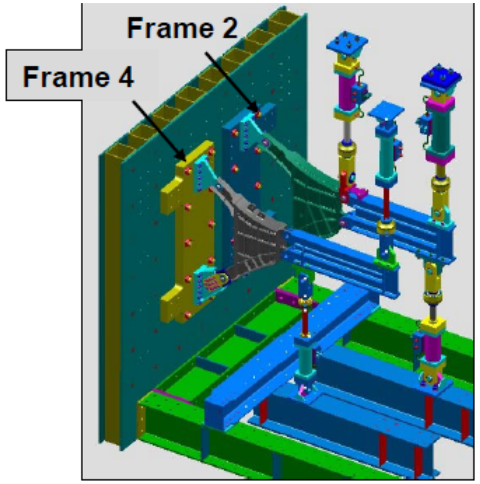
Potential crack growth benefit more impressive



- Crack Growth results on the other hand . . .
  - . . . Indicated LSP could significantly reduce inspection intervals
  - . . . If validated on full scale components

Significant Test Program to Validate Benefit

- **Test Objectives**
  - **Validate test setup to match Full Scale Fatigue Test**
  - **Establish baseline life**
  - **Obtain crack growth fatigue data**
  - **Validate benefit of LSP over GBP**
    - **Durability**
    - **Crack growth**



Fatigue Test Setup

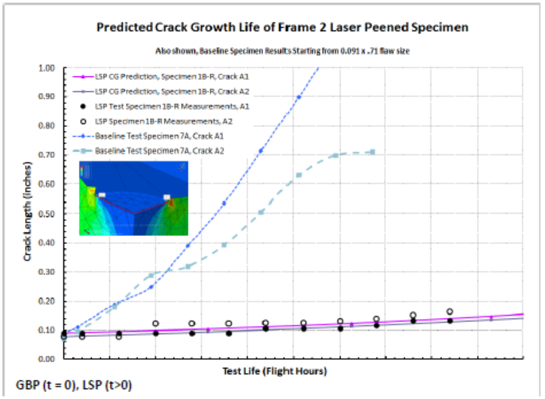
CONFIGURATION *	BASELINE	GBP	LSP over GBP
Frame 2 Durability	x 2	X	X
Frame 2 Crack Growth	X		X
Frame 4 Durability	x 2		X
Frame 4 Crack Growth	x 3		x 2

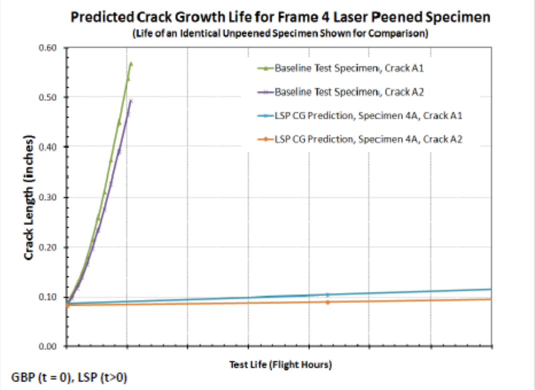
** Test articles produced from Ti-6Al-4V F-22 Production Die Forgings*

- Multiple full scale components including pre-cracked damage tolerance tests

Results:
Damage Tolerance Benefit Predicted and Validated

- LSP over GBP applied to full scale frames at same flight hour requirements as structures retrofit aircraft
- Frames pre-cracked prior to LSP in order to gather CG data
- Test Results:
  - LSP successfully retards cracks in thick titanium structure
  - Validates subcomponent findings [2]





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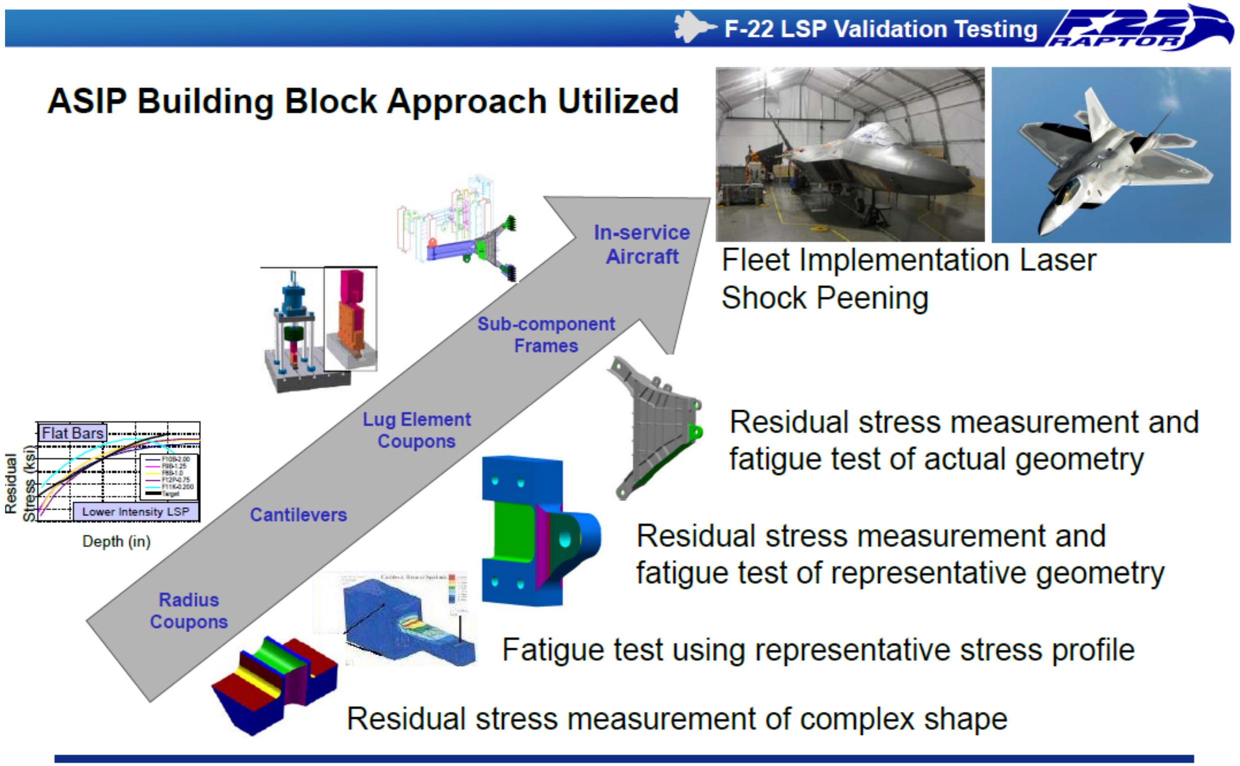
[2] Reference R. Bair, et. al., "Application of Surface Residual Stresses for Durability and Damage Tolerance Improvements in Wing Attachment Lugs", 2009 ASIP Conference, Jacksonville, FL.

- Significant inspection relief achieved by implementation of LSP
- Residual stress profile predicted and modeled
- Damage tolerance predictions validated by test

Goal Achieved



- Results achieved
  - Eliminated expensive and intrusive inspections
  - Improved flight safety
  - Reduced cost of ownership
- Methodology
  - Multi-year test program
  - 2000 lbs of titanium converted to test specimens
- How can engineered residual stresses find wider application at lower cost?

Design guides discourage use of engineered residual Stresses

- Design guides drive toward goal of weight efficient design without considering residual stress benefits
- From JSSG 2006: To maximize safety of flight and to minimize the impact of potential manufacturing errors, it should be a goal to achieve compliance with the damage tolerance requirements of this specification without considering the beneficial effects of specific joint design and assembly procedures such as interference fasteners, cold expanded holes, or joint clamp-up. In general, this goal should be considered as a policy but exceptions can be considered on an individual basis. The limits of the beneficial effects to be used in design should be no greater than the benefit derived by assuming a .005 inch radius corner flaw at one side of an as-manufactured, non-expanded hole containing a neat fit fastener in a non-clamped-up joint. A situation that might be considered an exception would be one involving a localized area of the structure involving a small number of fasteners. In any exception, the burden of proof of compliance by analysis, inspection, and test is the responsibility of the contractor.
- Language of design guides drives discussion for sustainment even though requirements are different.

Modifications to guidelines needed to reflect sustainment realities and to promote a culture of accepting the benefit of residual stresses
Culture of acceptance backed by test and experience

Engineered Residual Stress for Damage Tolerance Benefit

- Path to broader acceptance
  - Standardization of processes
    - Process specifications should result in definable benefit
    - Benefit obtained from residual stress must be independent of vendor
    - Variables affecting level of benefit should be predictable
  - Broader acceptance of prediction and measurement methods
    - Challenge of education→ and building user base