Bolted Repair in Composite Structure

Jeff Berner
787 Wing/Empennage/Landing Gear

June 4, 2009

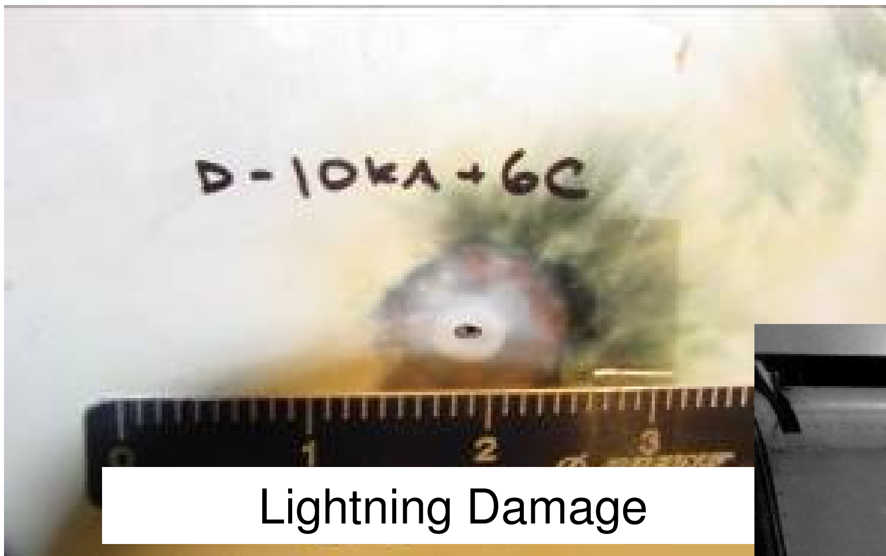
Agenda

- Introduction
- Design for Repairability
- Bolted Repair Design Considerations
- Bolted Repair Analytical Considerations
- Material/Fastener Selection
- Bolted Repair Process Sensitivity
- Conclusions

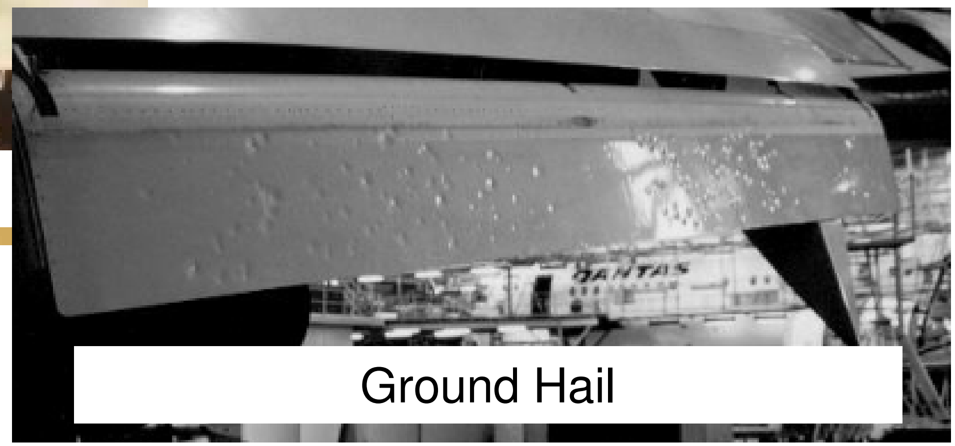
Introduction

Aircraft structure is exposed to a variety of damage threats in-service….

…from Mother Nature….



Lightning Damage



Ground Hail

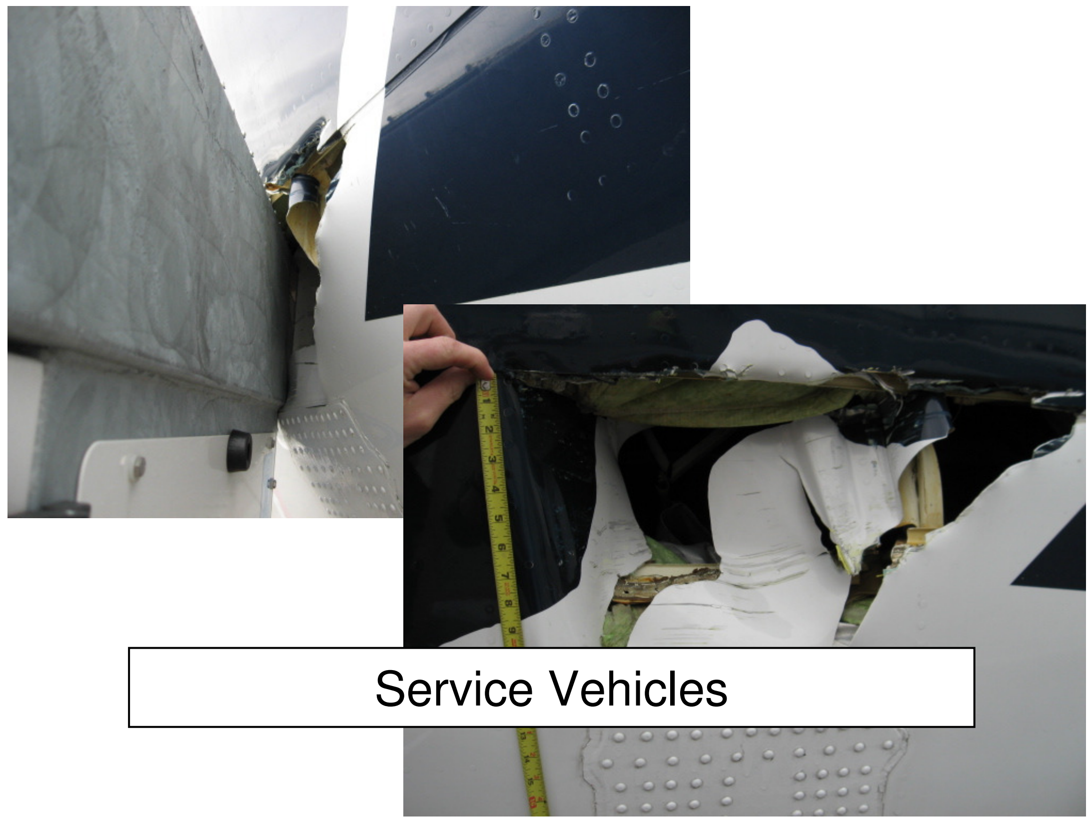
Introduction

Aircraft structure is exposed to a variety of damage threats in-service….

…from Mother Nature….

…from airport operations…

Ground Handling Equipment



Service Vehicles

Introduction

Aircraft structure is exposed to a variety of damage threats in-service….

…from Mother Nature….

…from airport operations…

…from maintenance…

Maintenance Stand

Introduction

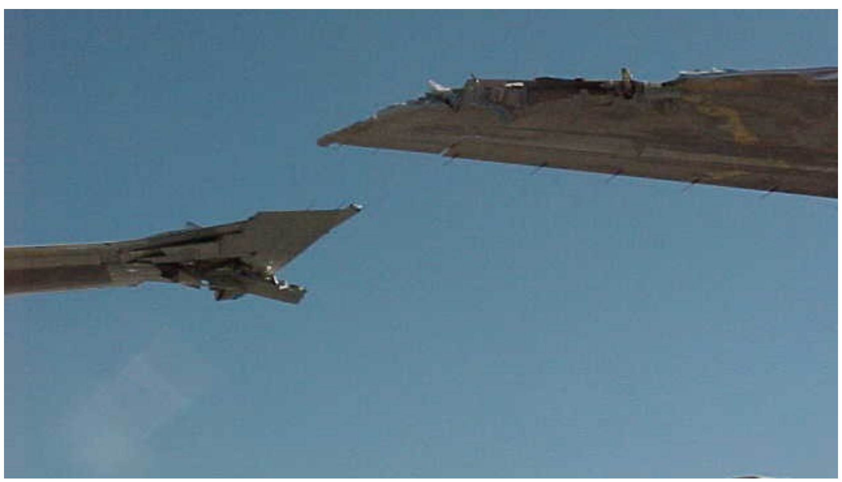
Aircraft structure is exposed to a variety of damage threats in-service….

…from Mother Nature….

…from airport operations…

…from maintenance…

…and from pilot action.



Collision

Tail Strike

Introduction

Aircraft structure is exposed to a variety of damage threats in-service….

…from Mother Nature….

…from airport operations…

…from maintenance…

…and from pilot action.

Meeting airline expectations for repairability begins with an understanding of the threat environment and the repairs that may be expected in-service.

Airlines require a variety of repair options which permit them to choose the best repair for the situation.

When a large damage occurs, bonded repairs may become impractical or technically not feasible and a bolted repair design will be required.

Fail-safety principles may direct use of bolted repairs when a bonded repair size may exceed the residual strength of the component should the bondline fail.

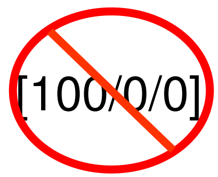
Design for Repairability

Implementation of successful repair begins in the initial design phase.

On the 787, Boeing used a disciplined process during initial design to ensure that airframe structural components could be repaired using a range of bonded repair materials and bolted repair.

Design considerations –

- Notch sensitive layups avoided

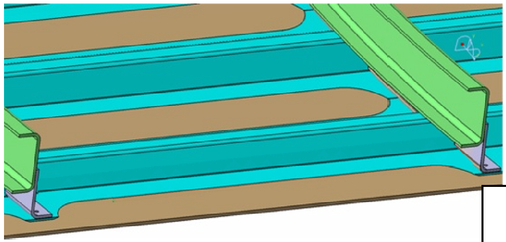


- Chord and cap widths have area and edge margin to permit fastened repairs
- Added gauge or edge margins in areas prone to damage
- Add protective features to prevent damage from occurring
- Balance weight/robustness based upon proven service experience (e.g. min gage for sandwich structure)

Design for Repairability

Common bolted repairs designed for SRM incorporation

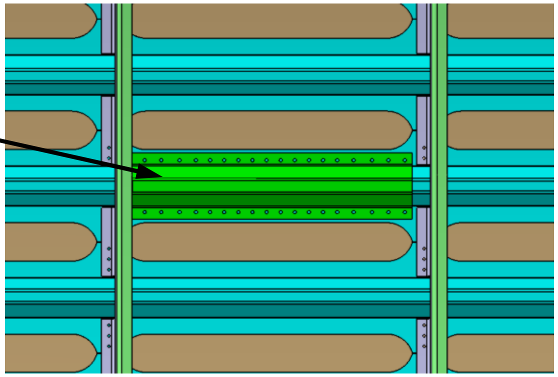
1. Identify Common Structure



Skin/Stringer

2. Evaluate risk of accidental damage
3. Develop standard repairs for scenarios judged to be frequent

Formed metallic doubler



4. Large damages or rarely damaged components will be addressed upon occurrence

Design for Repairability

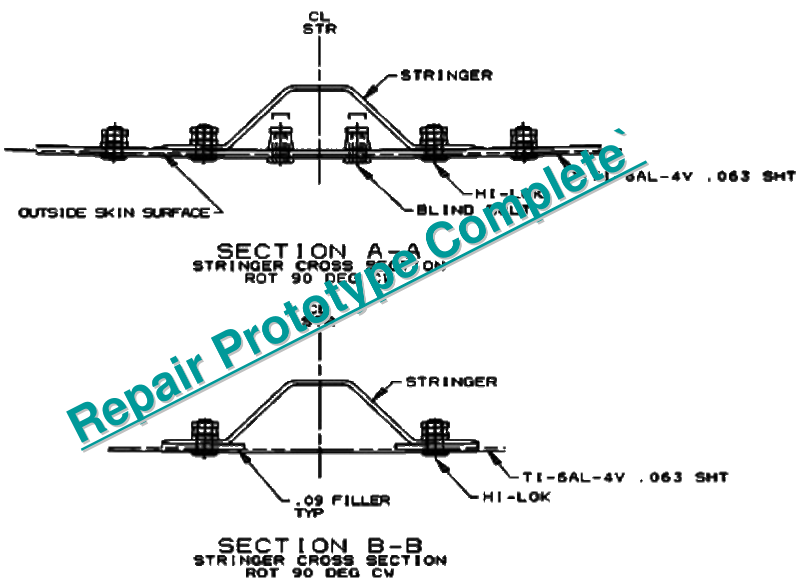
Anticipated AOG Repair Events Considered

Example: Damage Scenario - Aft Body GSE Impact

External doubler repair developed-Time-Limited & Permanent repair options.

– **Estimated flow & resources**

<u>Time Limited Repair</u>	<u>Permanent Repair</u>
2 Calendar days	3 Calendar days
3 Mechanics	3 Mechanics
~132 Manhours	~198 Manhours



Bolted Repair Design Considerations

When developing the design for a bolted repair, the repair engineer needs to account for –

Replacing load paths

Matching EA, EI
- hardpoint effects (load increase factor)
- repair effectiveness to reduce stress concentration due to damage

Determining the repair materials which may be available, e.g. titanium sheet, aluminum sheet

What fasteners might be available (type, diameter, grip length)

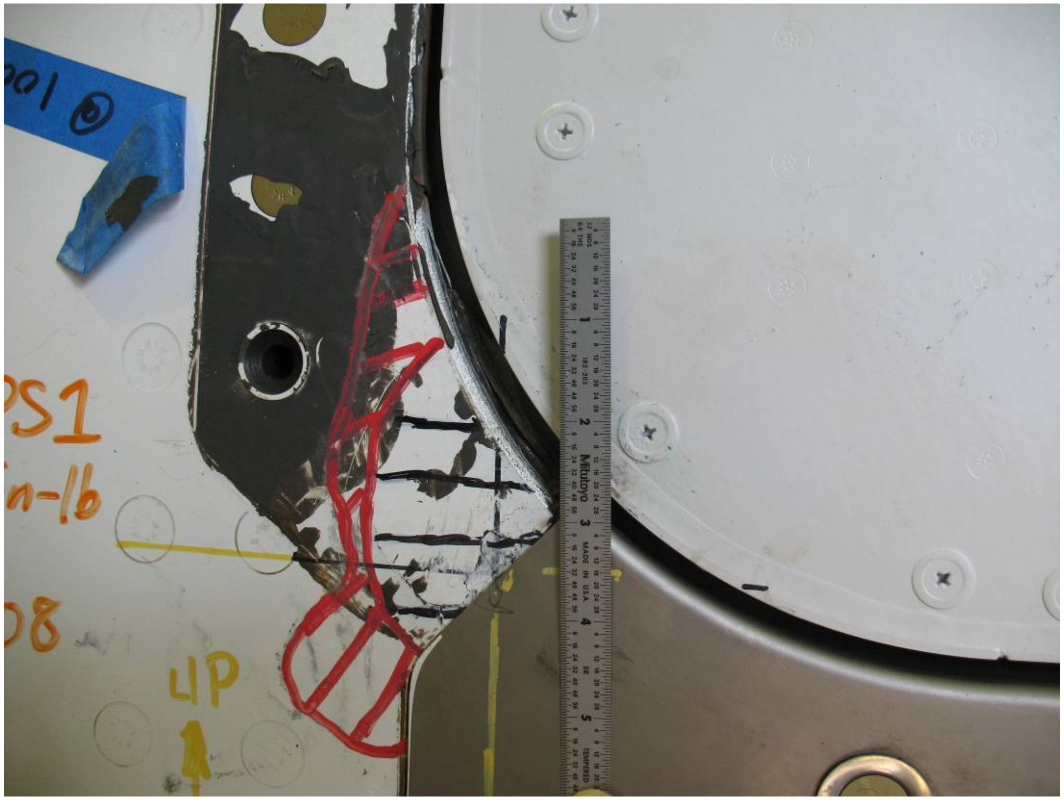
Producibility considerations, e.g. bend radius for formed sheet stock, accessibility for drill motors, one-sided access, etc.

Capability of mechanics conducting the repairs

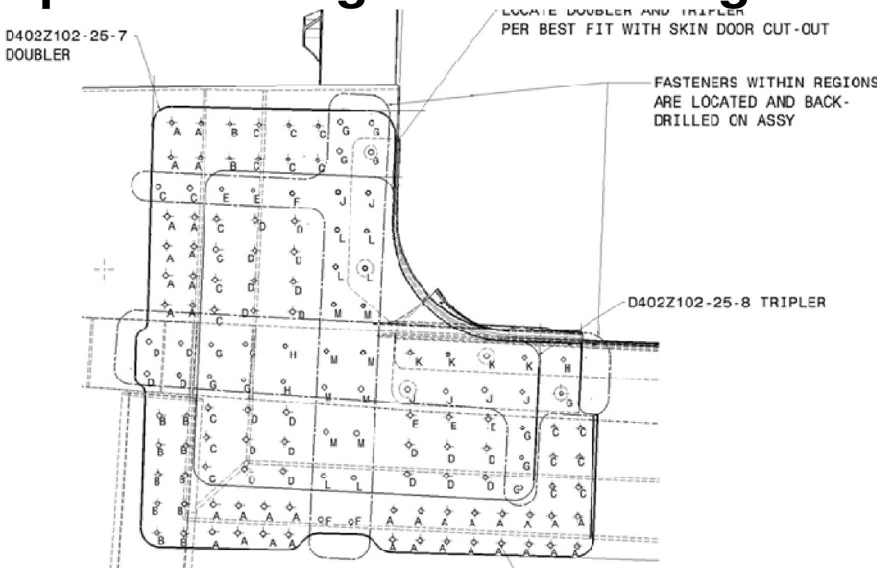
Bolted Repair Design Considerations

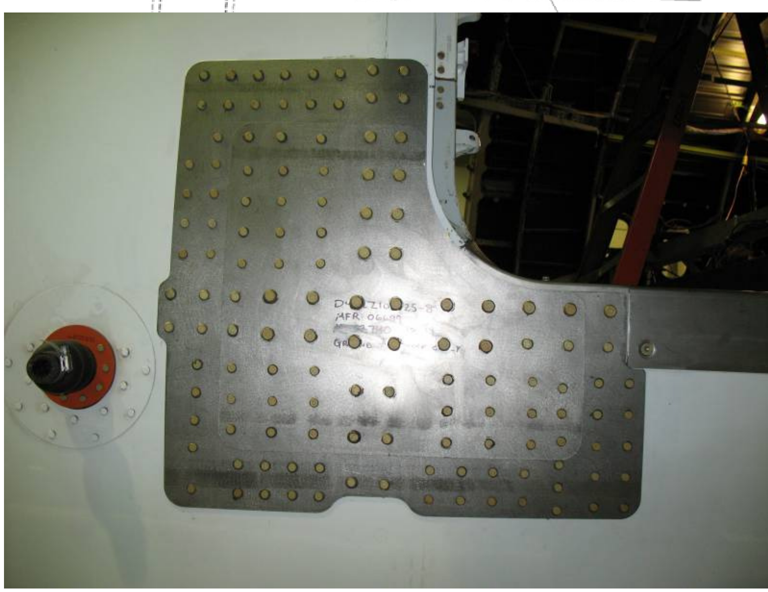
Example: Passenger Door Damage

Visible Impact Damage



Example: Passenger Door Damage





Repair Design

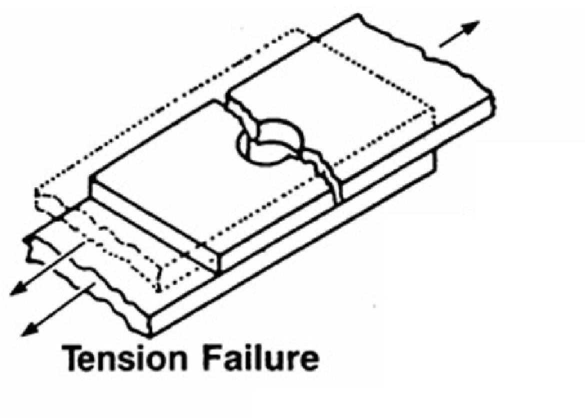
Protruding Tension Head HiLok Fastener

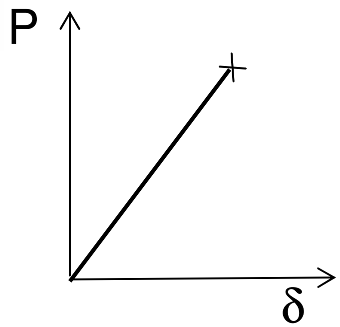
.125” titanium sheet doubler

.125” titanium sheet tripler

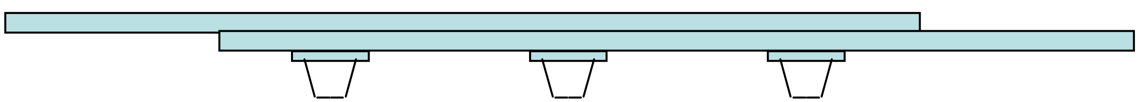
Bolted repair design and installation can be easy to implement.

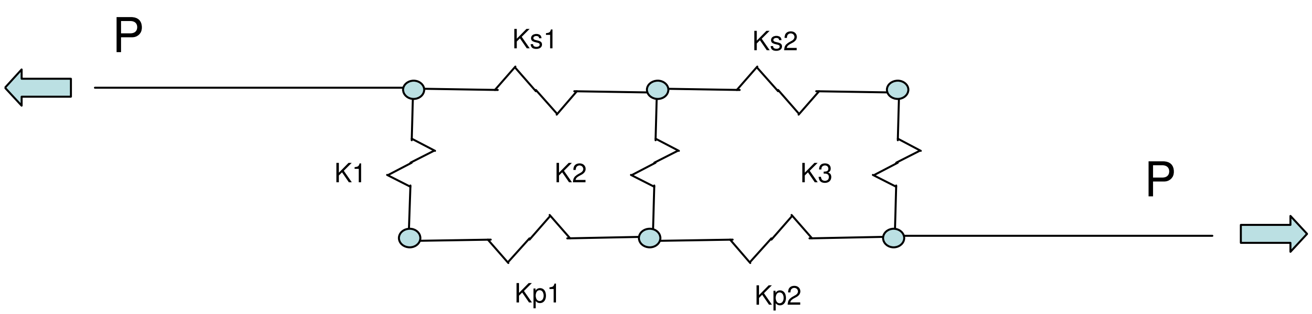
Bolted Repair Analysis Considerations





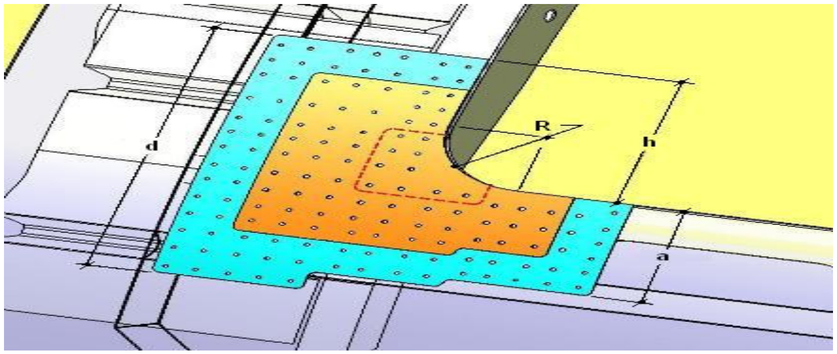
- Linear strain to failure and net-tension failure modes of CFRP composite require load share analysis for bolted joints.
- 2-D analysis is appropriate for components loaded along a single axis, e.g. stringers





Bolted Repair Analysis Considerations

- **3-D analysis is appropriate for components with complex geometry or loaded with varied internal loads, e.g. door surround**



Objective:

- Build FEM of the door surround bolted corner repair to validate analysis methodology by correlating FEM output with calculated values.

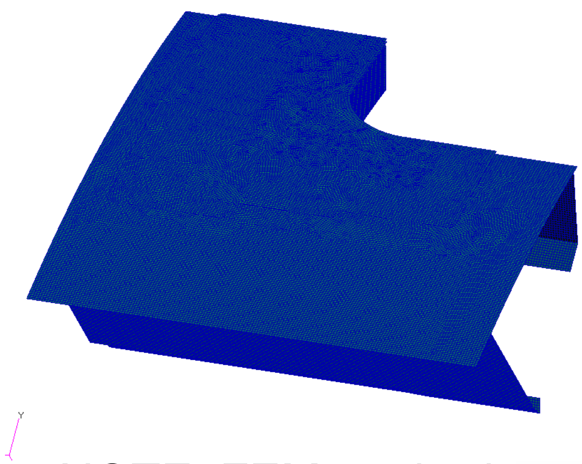
FEM output requested.

- FEM Load Application
- Doubler Stress
- Highest fastener load (ULT)
- Percentage of load transfer - compare with hand analysis/2-D assessments.
- Kt in corner (doubler)

Bolted Repair Analysis Considerations

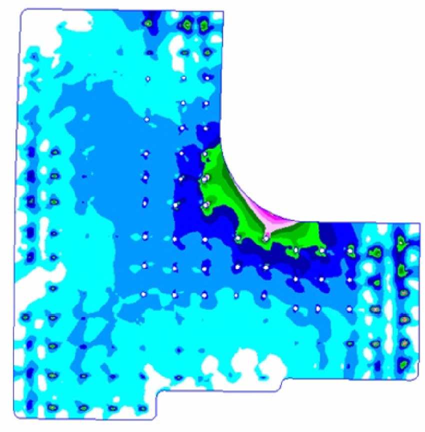
Door Surround Detailed Finite Element Model

Detailed FEM



NOTE: FEM methods requires validation through comparison to hand-analysis or to test results.

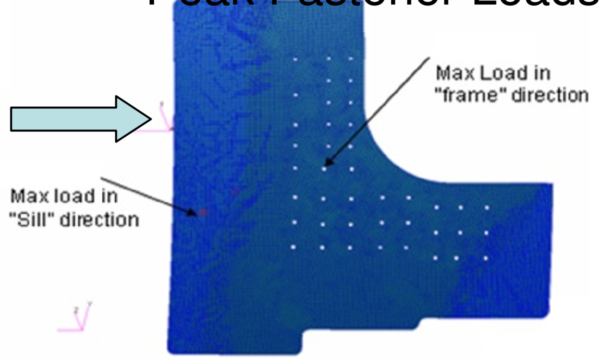
Maximum Stresses



Calculate doubler peak stresses

Fatigue assessment

Peak Fastener Loads



Fastener shear

Fastener bending

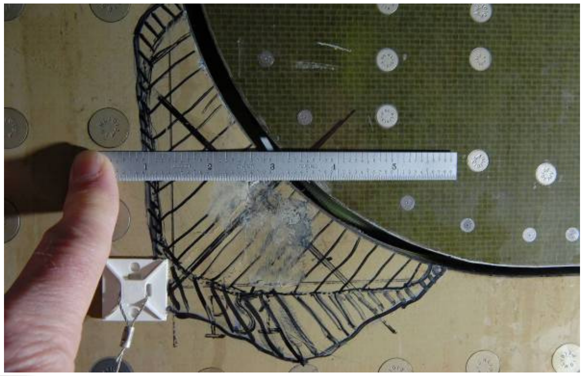
Composite bearing/bypass interaction

Doubler bearing stress

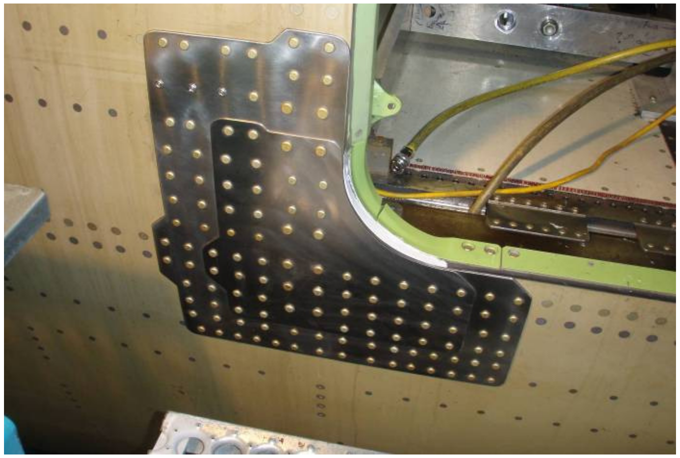
Bolted Repair Analysis Considerations

Repair Validation by Test

Door Surround Impact Damage



Bolted Tripler Repair



One-Piece Barrel Test Validation

Composite barrel design proved through a series of incremental tests:

- limit load
- 150 percent of limit load (ultimate load)
- destruct-condition maneuver beyond two and a half times the force of gravity.

http://www.boeing.com/news/releases/2008/q1/080228b_pr.html

Bolted Repair Analysis Considerations

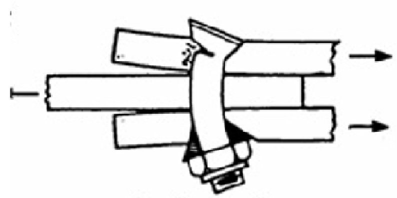
Concerns for Composite Bolted Repair

Since CFRP is linear-elastic, repair materials should exhibit linear stress-strain relationship. Good: Ti 6Al-4V Poor: Al 2024, CRES 301

Differences in material coefficients of thermal expansion (CTE) need to be taken into account in the analysis. CTE mismatch adds fastener load to critical fasteners. FE methods are appropriate.

Eccentricities may be larger in composite-metal repairs due to thicker gages of composites as compared to metal repair materials.

Fastener failure modes need to be avoided-
- high t/d ratios
- weak fastener heads (e.g. 130-deg, 100-deg reduced shear)
- thick shims ➔ eccentricity
- loss of clamp-up
- clearance fit holes
- high-load reversals / vibratory environment which may cause hole wear and fastener rotation
- fay-surface sealant
- shim type (e.g. peelable shims)



Bolt Failure

1/4-Inch Diameter Titanium Hex-Drive Fasteners with CRES Tension Collars, Ti-CFRP-Ti Stacks, t/d = 2.1–2.7

Material/Fastener Selection

Materials, Finishes and Fasteners need to be consistent with structural requirements, EME requirements, and corrosion protection requirements

- Repairs need to be tested to validate that EME requirements are met. Fuel tanks and airplane systems may dictate different EME requirements than for metal airframe structure.
- Repair materials need to be either compatible for galvanic corrosion or finishes/sealants must prevent galvanic corrosion. Sealants may reduce fatigue life and adversely affect static joint strength.
- One-sided fasteners where used require back-side inspection. One-sided fasteners may require more frequent inspection due to concerns with loss of clamp-up.

Bolted Repair Process Sensitivity

Bolted repairs exhibit process sensitivity which needs to be accounted for:

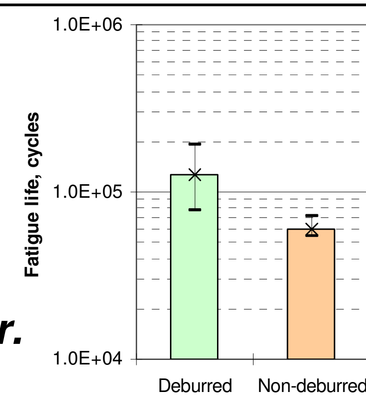
- using backup to avoid fiber breakout
- using dull drill bits or incorrect speeds/feeds which can cause heat damage to metal or “burn” composite
- drilling through metal/composite stackup. Metal chips can cause damage to composite holes
- drill wandering or hole misalignment if drill guides are not used
- deburring holes
- meeting close tolerance hole requirements
- shimming & fit-up stresses
- application of sealant

When they occur, such failures in process are likely to occur throughout the repair and not at individual locations within the repair.

“burned” hole

Mis-start hole

Effect of burr on fatigue life



Conclusions

- **Ability to accomplish bolted repairs needs to be considered during initial design when choosing layup and structural configuration**
- **Bolted repairs may be planned for based upon service experience which indicates susceptibility to damage and the types of damage events**
- **Structural analysis for bolted repair will likely require as extensive analysis (if not more) than what is required for initial design. This is required because failure-modes are different for composite-metal bolted repairs than for repairs to metal aircraft**
- **As with any repair, materials, fasteners and finishes need to be selected to be compatible with the application and requirements.**
- **As with any repair, attention to detail and adherence to processes are required**