



GLARE® and Bonded Repairs

Friday May 11th 2007

Agenda

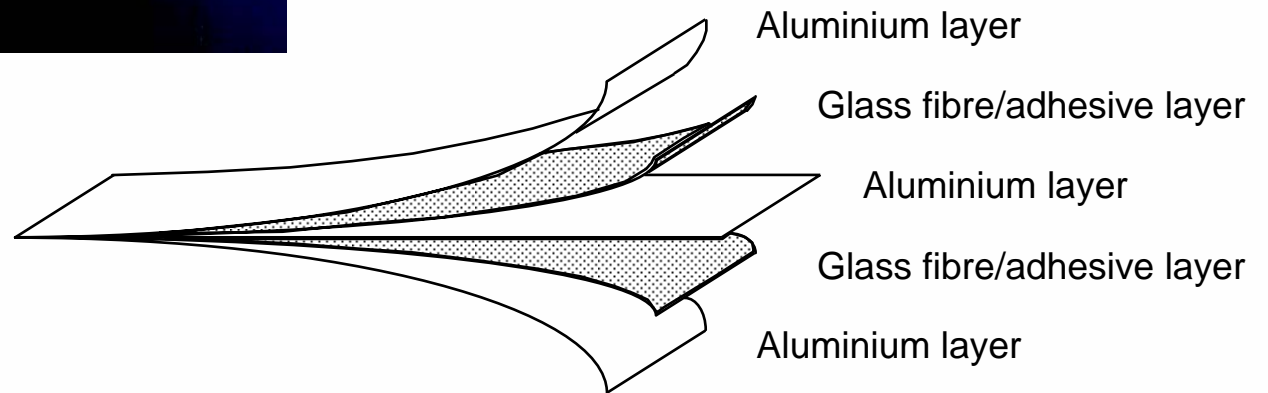
- What is GLARE[®]?
 - GLARE[®] characteristics.
 - GLARE[®] damage behaviour.
- Present repairs, riveted.
- Future repairs, bonded.
 - How to perform repair
 - Testing of repairs
- GLARE[®] repairs patches
- General developments



What is GLARE®?



- GLARE is a hybrid material built-up from alternating layers of aluminium and glass fibre reinforced metal adhesive



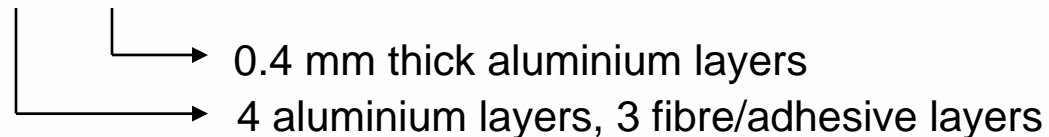
GLARE[®] build up.

- GLARE[®] build-up:
 - Aluminium layer thickness: 0.2 - 0.3 - 0.4 - 0.5 mm
 - Fibre/adhesive layer build-up from multiple 0.125 mm UD layers
 - FM94 epoxy adhesive for structural metal bonding

- Standard grades:

| | Fibre/adhesive layer thickness | Fibre/adhesive layer build-up |
|----------|-----------------------------------|----------------------------------|
| GLARE 2A | 0.25 mm | 0°/0° |
| GLARE 2B | 0.25 mm | 90°/90° |
| GLARE 3 | 0.25 mm | 0°/90° |
| GLARE 4A | 0.375 mm | 0°/90°/0° |
| GLARE 4B | 0.375 mm | 90°/0°/90° |
| GLARE 5 | 0.5 mm | 0°/90°/90°/0° |

- Example: GLARE 4B-4/3-0.4



GLARE[®] characteristics.

- Static strength properties
 - Design values for GLARE[®] in 4/3-0.4 lay-up (MPa):

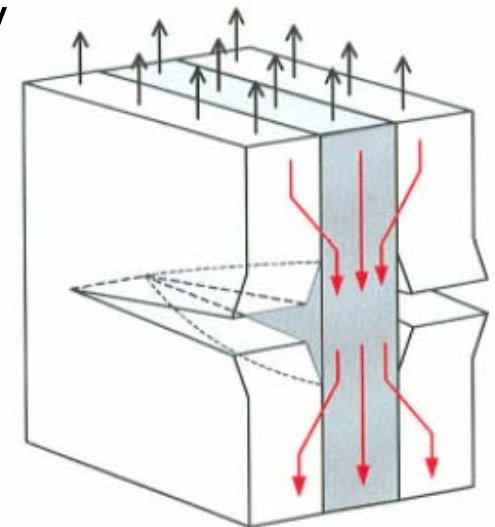
| | 2024-T3 | GLARE 2 | GLARE 3 | GLARE 4 |
|------------------|--------------|--------------|--------------|--------------|
| Tensile ult. L | 440 | 910 | 625 | 795 |
| Tensile ult. LT | 435 | 300 | 610 | 525 |
| Tensile yield L | 325 | 325 | 285 | 290 |
| Tensile yield LT | 290 | 215 | 260 | 230 |
| Compr. yield L | 270 | 305 | 260 | |
| Compr. yield LT | 310 | 230 | 270 | |
| Bearing ult. | 890 | 680 | 760 | 630 |
| Blunt notch L* | 410 | 600 | 425 | 510 |
| Blunt notch LT* | 400 | 190 | 415 | 360 |
| E-modulus L | 72400 | 66500 | 59500 | 59000 |
| G-modulus | 27600 | 20500 | 20500 | 18700 |

*:typical values

GLARE[®] characteristics. (cont'd)

- Mix of composite and metal properties/behaviour, GLARE[®] offers:
 - Static strength (tensile, compression, etc)
 - Damage Tolerance
 - Excellent Fatigue behaviour
 - Impact resistance
 - Residual strength
 - Corrosion resistance
 - Lightning strike resistance
 - Fire resistance
 - Easy workshop handling
 - Easy reparability

- Properties can be tailored:
 - Thicker or thinner aluminium layers
 - More or fewer fibre/adhesive layers
 - fibre adhesive layers at specific angles (e.g. $\pm 45^\circ$)

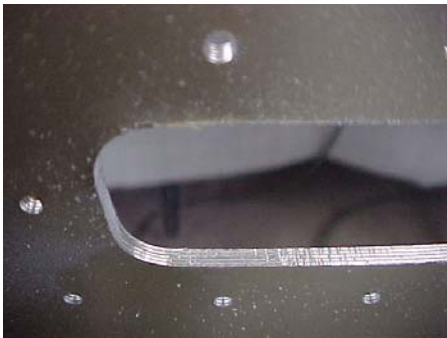


GLARE[®] damage behaviour

- FOD causes a dent (impact) or a scratch, similar to aluminium
- Inspectability of FOD similar to aluminium
- Penetration energy higher than for aluminium and composites
- Debonding sizes resulting from impact are small compared to the dent size
- Effect of FOD on compression properties similar to aluminium
- GLARE exhibits slow fatigue crack growth and high residual strength in the presence of FOD

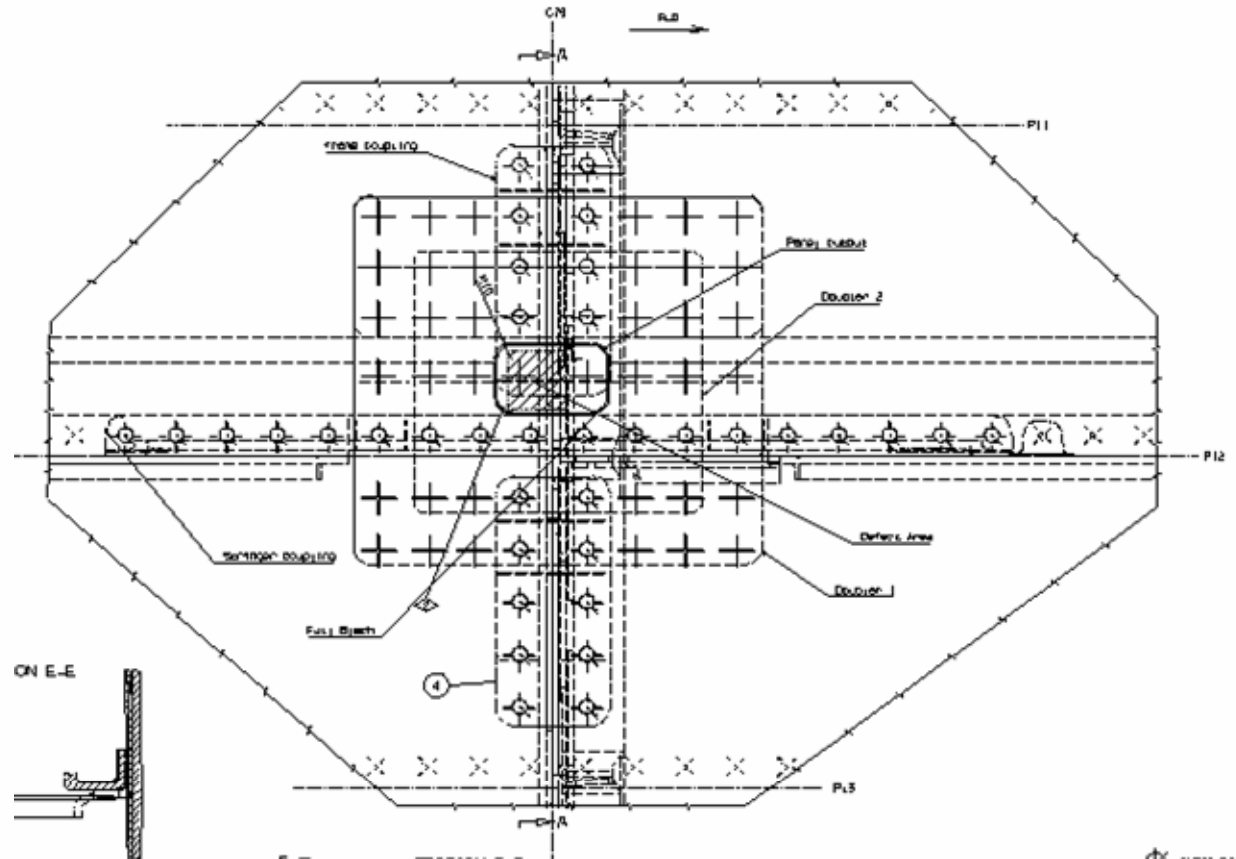
Present repairs, riveted.

- Repairability
 - The same repair methods can be applied as for aluminium
 - Superficial damage (corrosion, scratches) can be worked out
 - Riveted or bonded patches can be applied
 - Good fatigue and damage tolerance performance of repaired structure



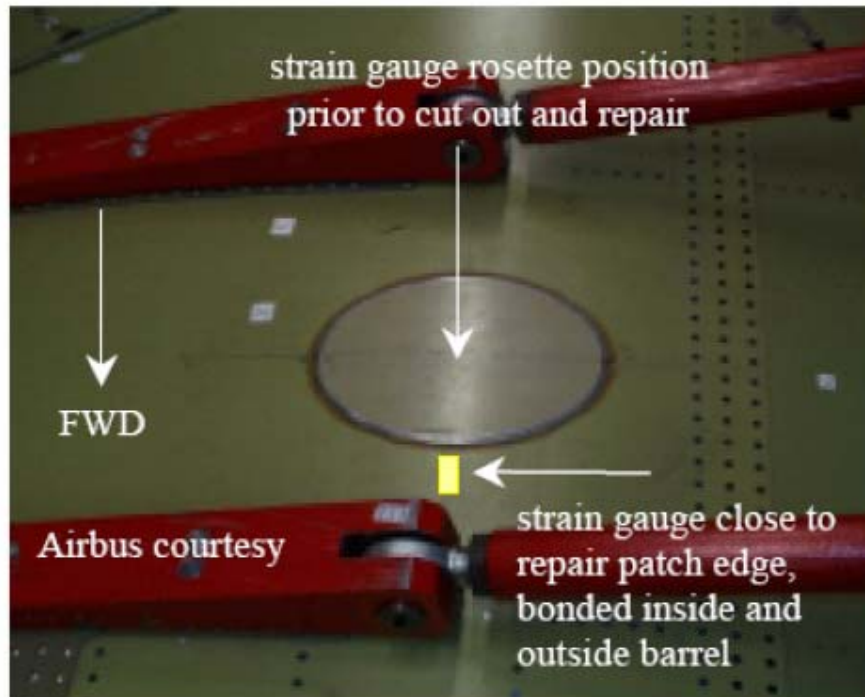
Present repairs, riveted. (cont'd)

- Typical repairs



Future repairs, bonded.

- Advantages:
 - Fatigue insensitive
 - Corrosion
 - Lower design weight, reduced skin thickness



StandGL_bondrun_out_STATUS.pdf

How to perform bonded repair

- Standard (SRM) procedures.
- No special tools or equipment.
- 1st aim hot bonded adhesive, later cold bonded



Cleaning of bonding surface



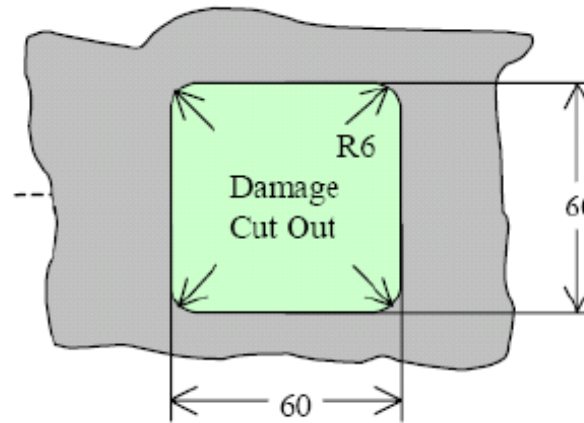
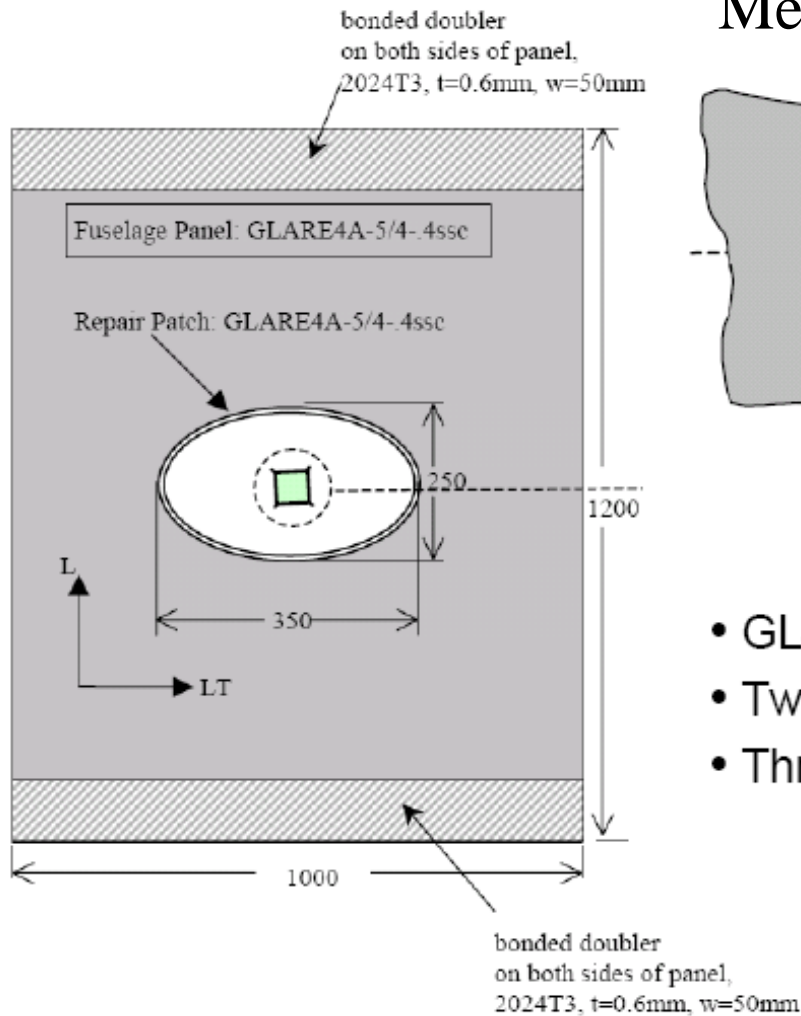
Bonding film cut to shape



Application of vacuum foil, thereafter start of curing with Heatcom[®] device, low vacuum pressure

Testing of bonded repairs

Megaliner barrel bonded repairs



- GL4A-5/4-.4 patch / GL4A-5/4-.4 SSC skin
- Two CA fatigue tests
- Three outdoor exposure + CA fatigue tests

Testing of bonded repairs (cont'd)

- The tests are still ongoing:
 - No problem to bond a repair (GLARE-)patch to GLARE®
 - Fine tuning of repair patch
 - Feasibility of standard GLARE patch.
 - Outdoor exposure program to be completed. Preliminary results (after 2 years outdoor exposure): no effect of outdoor exposure (Me/Me bonding is not affected)

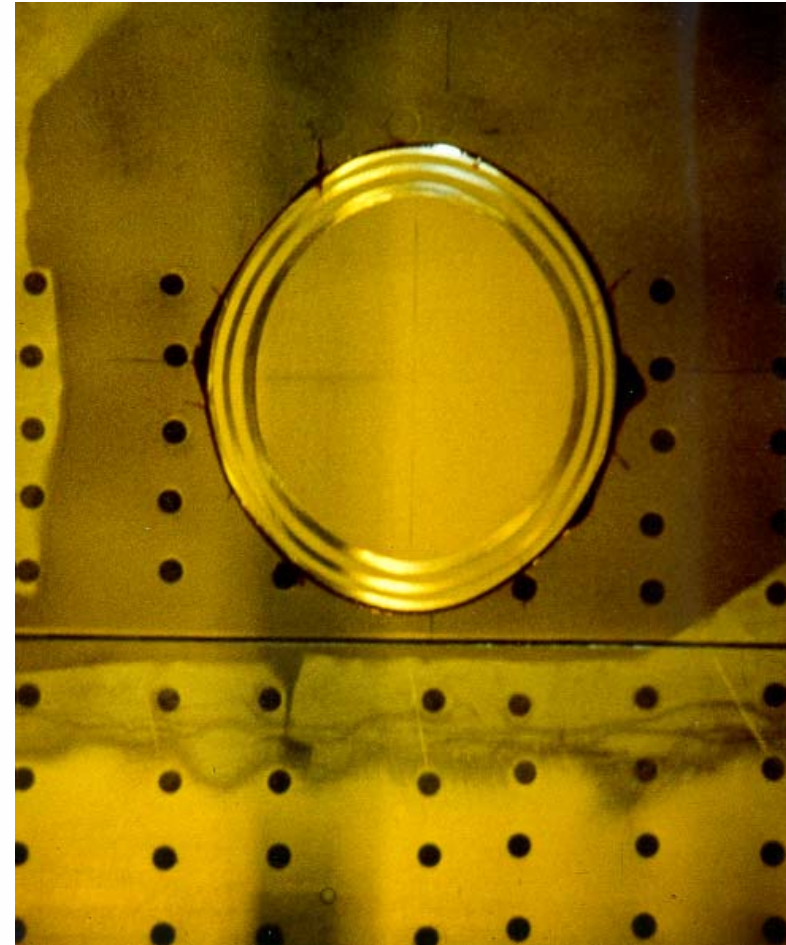
GLARE[®] repairs patches

US Air Force/Lockheed Martin C-5A Galaxy: Bonded Patch Repairs

- Material: Two GLARE 2-3/2-0.2 repairs installed October 1995
- Design: Patch bonded over a fuselage longitudinal butt-joint with AF 163-2M
- Due to the poor fatigue performance of the aluminium 7079-T6 skin, significant fatigue damage did occur. When riveted aluminium patches were used, new cracks typically nucleate in the skin at the corners of the patches, leading to ever larger repairs.
- Status:
 - No skin crack extension
 - No debonding
 - No damage to GLARE patch

GLARE[®] repairs patches (cont'd)

- Status:
 - No skin crack extension
 - No debonding
 - No damage to GLARE patch

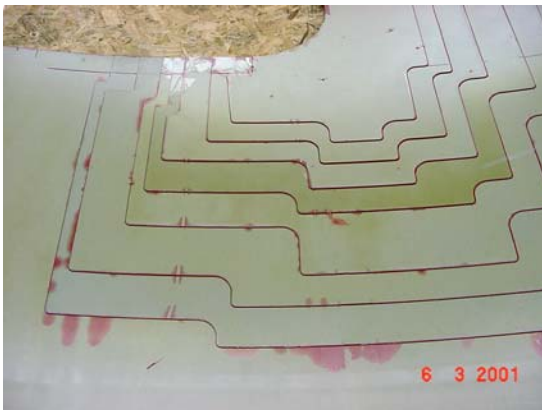


General developments

- Integrated systems, e.g.:
 - De-icing system leading edge nose skin
 - No bleed air required (energy decrease)
 - Full electrical aircraft (weight decrease)
- Friction stir welding to eliminate splices. (with 2024 GLARE)
- Improving GLARE properties (and Fibre Metal Laminates)
 - Higher static properties: to be achieved by higher strength alloys
 - Lower density due to lower density aluminium alloys (e.g. Al/Li)
 - Increase stiffness: to be achieved by higher stiffness fibres
- Automation of pretreatment (continue process), lay up and inspection (US).
- Larger Skin panels →

General developments (cont'd)

- Larger panels:
 - Easier Assembly
 - Less joints



Dimensions: 3.5 x 11 meters (10x33ft)

17

STORIK[®] *knows-how*

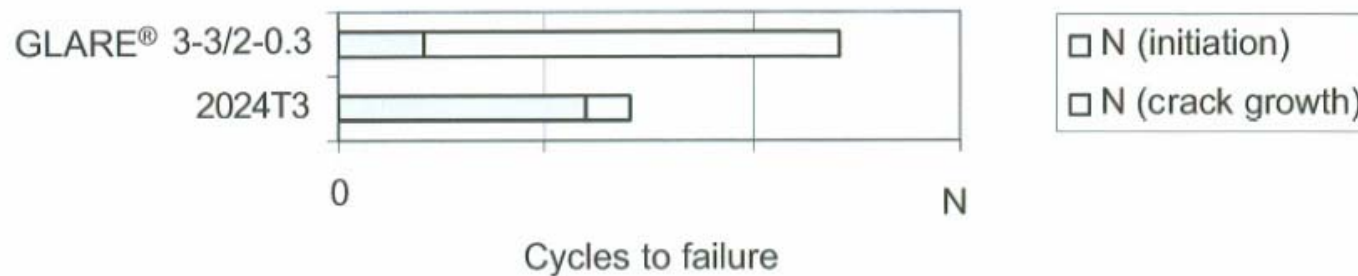
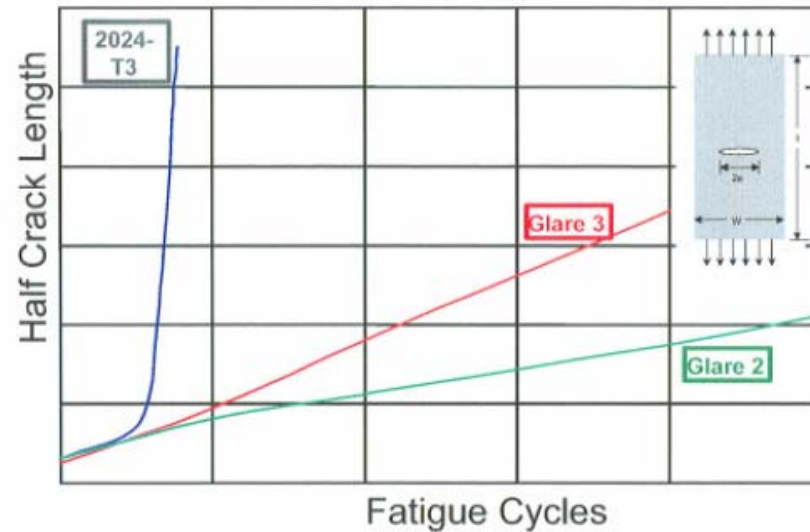
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Crack Propagation is no Sizing Parameter

General differences of GLARE® compared with Aluminium:

- Fatigue life is longer
- Crack initiation is earlier
- Contribution of crack propagation period on total fatigue life is larger

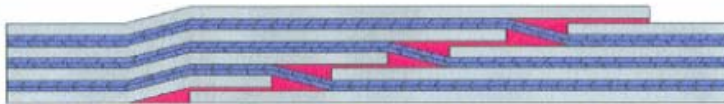


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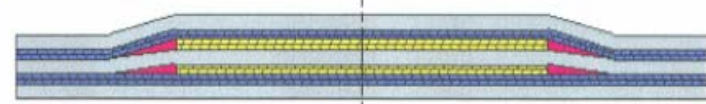
GLARE® Design Features – “Giant” Tool Box

Splice in skin panel or doubler



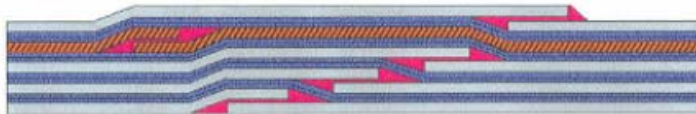
Limitation of aluminum sheet width
Internal stress level in double curved panels

Additional glass fiber layers



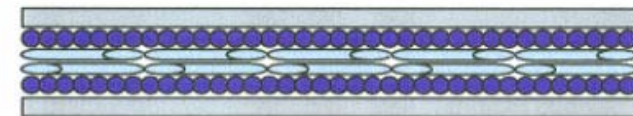
embedded at frame locations

Inter-laminar doublers



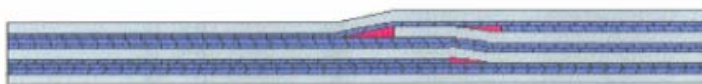
spliced or go thru depending on length and orientation

Fiber Orientation and Lay-up



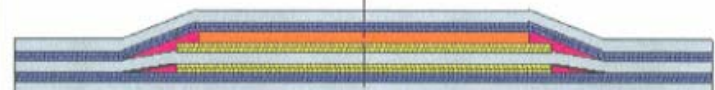
Adjust properties to loading condition

Transition of GLARE® type



e.g. from GLARE® 4 to GLARE® 3

Additional layers



Aluminum sheet locally at frame station
Glass fiber layers locally between two aluminum sheets

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Fire resistance

- GLARE shows excellent fire resistance behaviour
 - fire wall tests: 15 minutes minimum at 1100°C
 - No flame penetration
 - Exposed aluminium layer melts
 - Epoxy around glass fibres carbonizes and protect remaining aluminium layers.
 - Backside temperature reduced by more than half due to isolating effect of delaminated glass fibre layers

