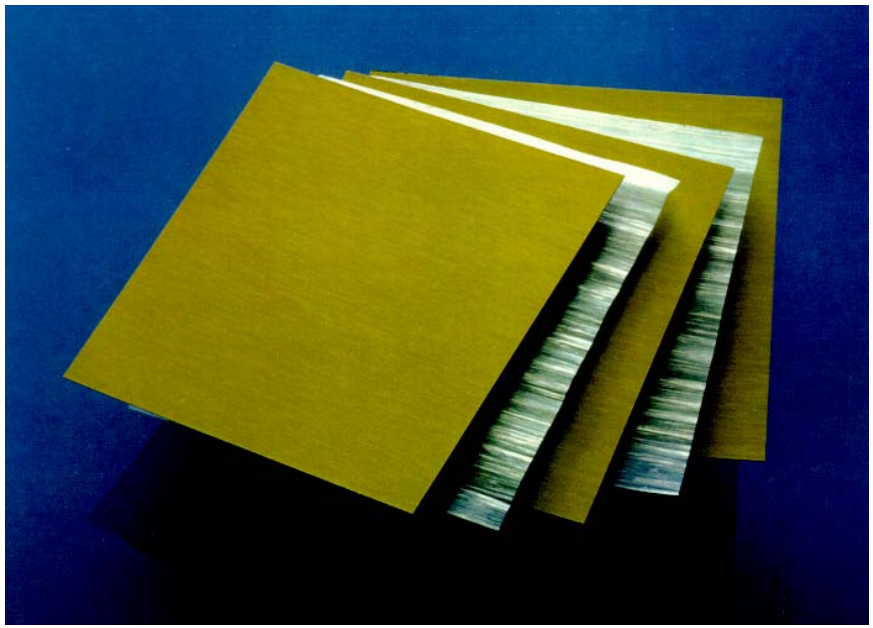
GLARE® and Bonded Repairs

Friday May 11th 2007

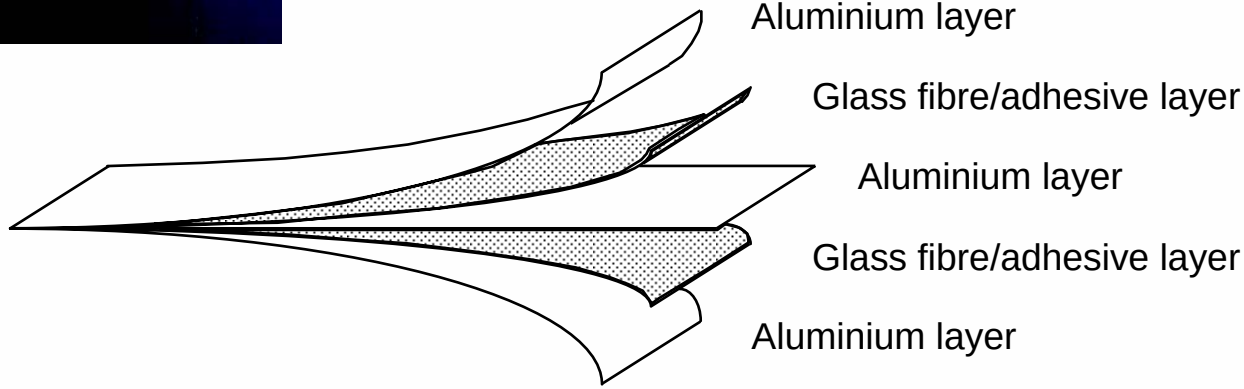
Agenda

- 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
  - 0.4 mm thick aluminium layers
  - 4 aluminium layers, 3 fibre/adhesive layers

GLARE® characteristics.

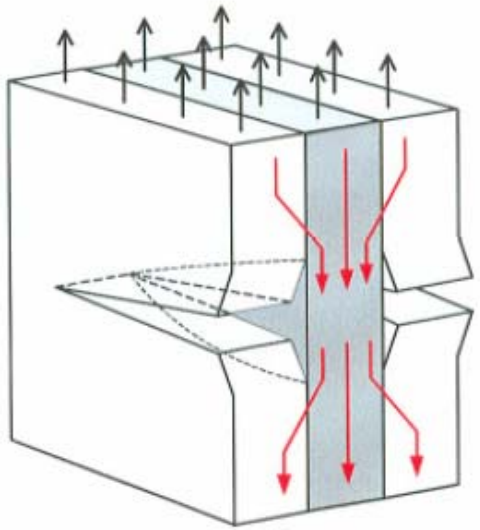
- Static strength properties
  - Design values for GLARE® in 4/3-0.4 lay-up (MPa):

	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



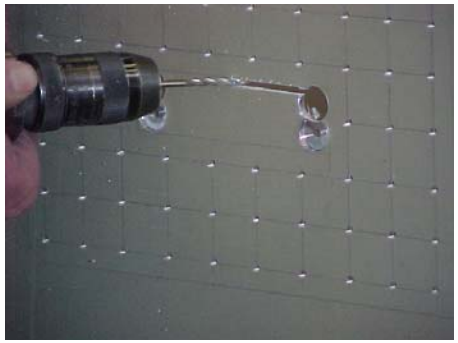
- Properties can be tailored:
  - Thicker or thinner aluminium layers
  - More or fewer fibre/adhesive layers
  - fibre adhesive layers at specific angles (e.g. ±45°)

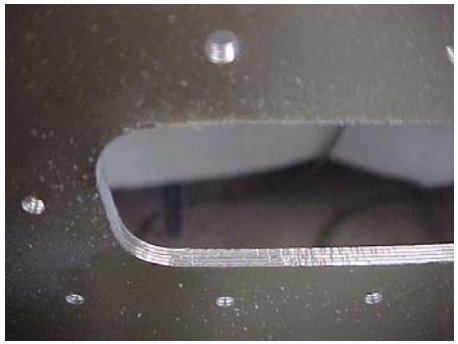
GLARE® damage behaviour

- 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.

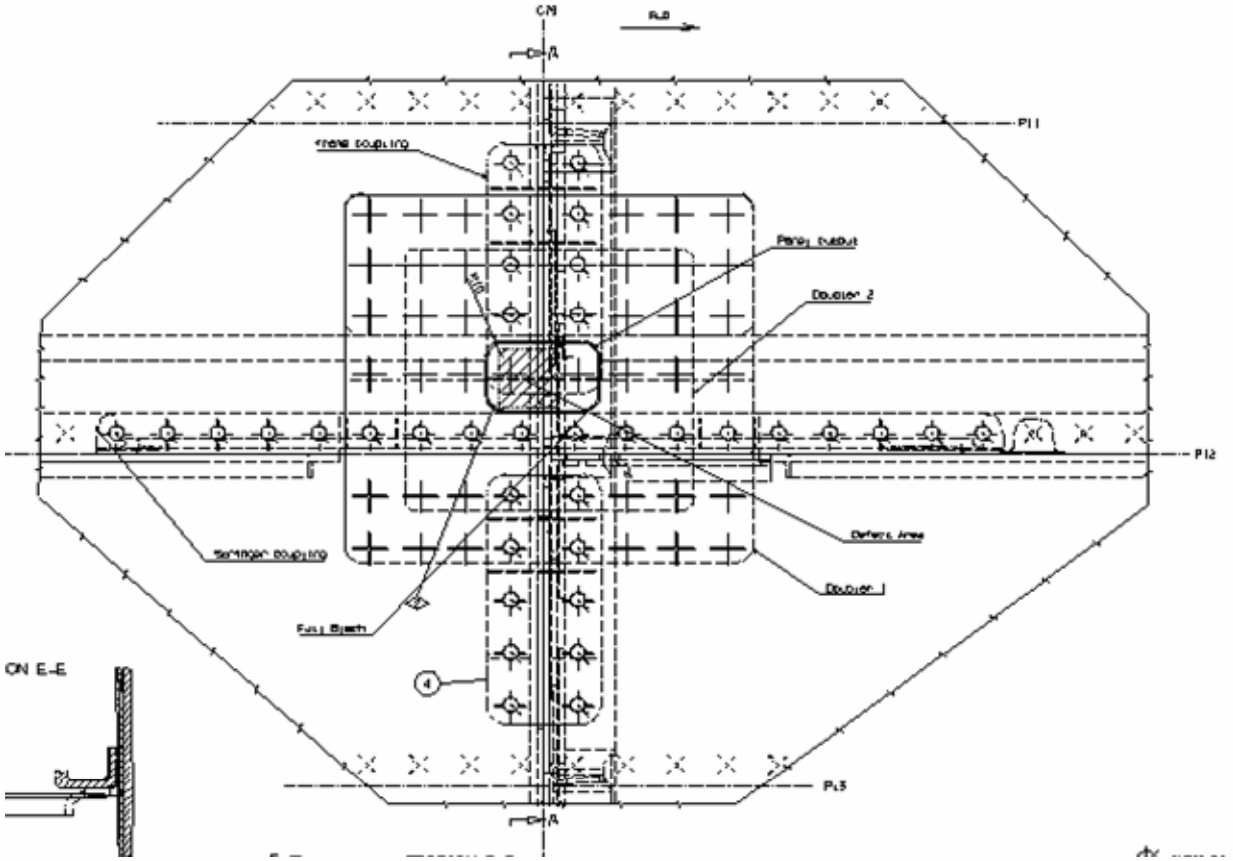
- Repairability
  - The same repair methods can be applied as for aluminium
  - Superficial damage (corrosion, scratches) can be worked out
  - Riveted or bonded patches can be applied
  - Good fatigue and damage tolerance performance of repaired structure



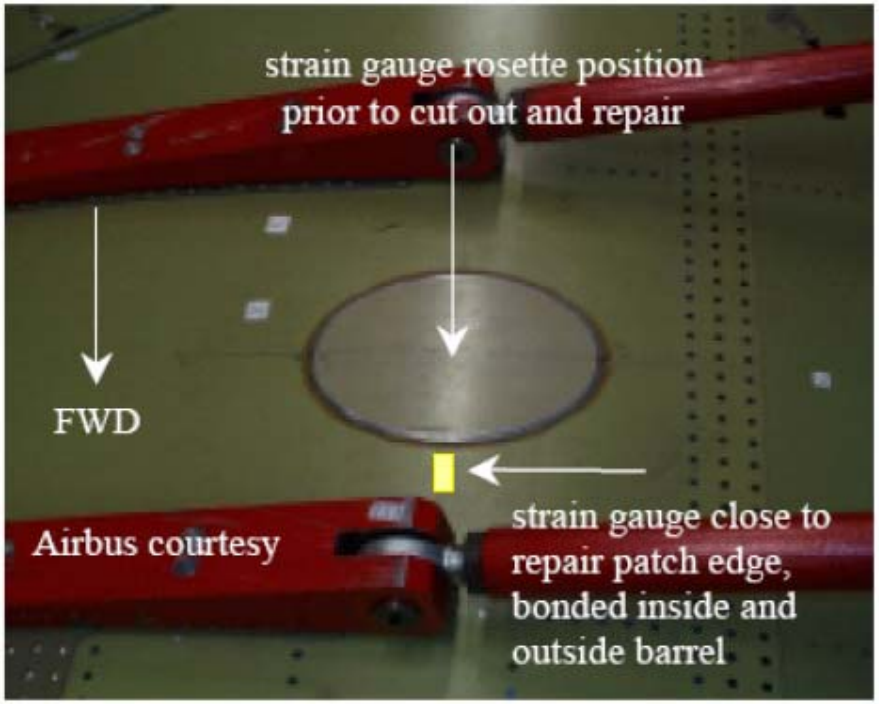
Present repairs, riveted. (cont'd)

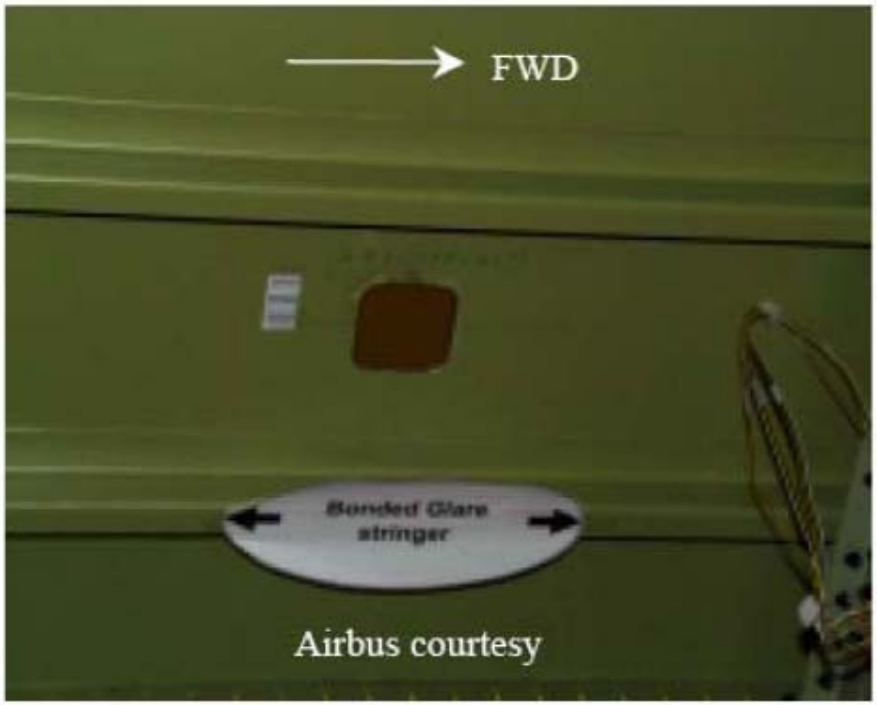
- Typical repairs



Future repairs, bonded.

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





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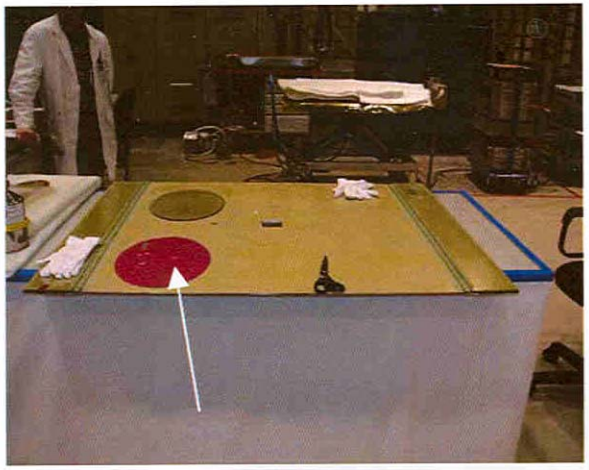
How to perform bonded repair

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

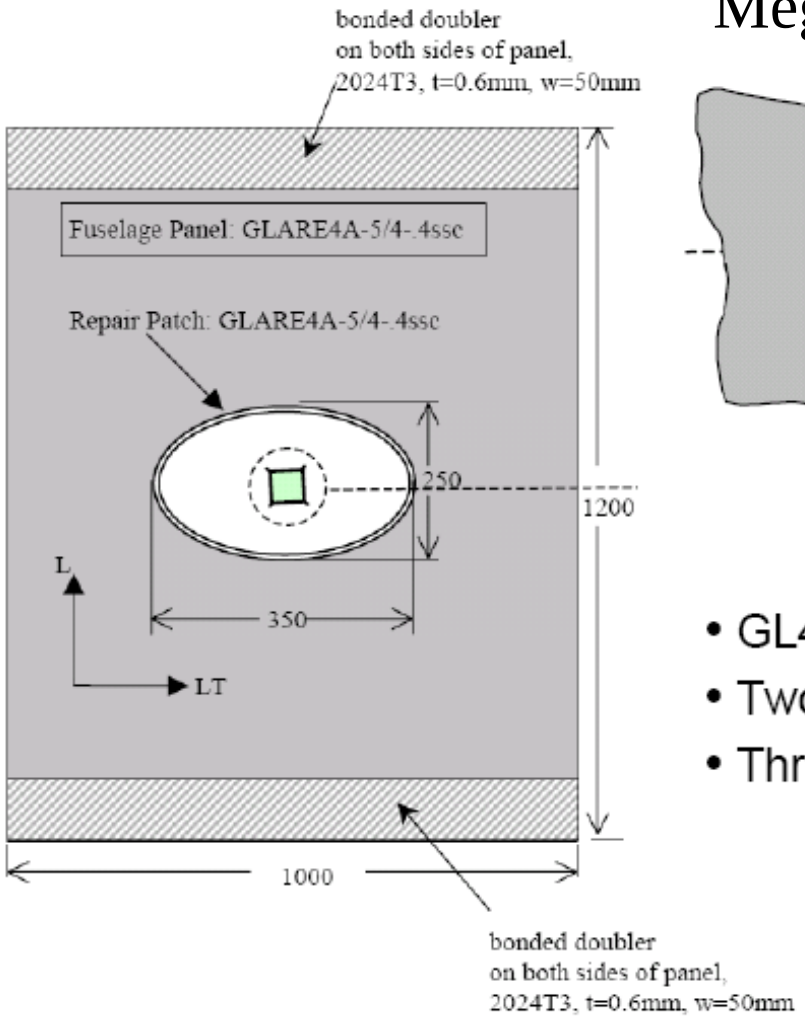
Cleaning of bonding surface



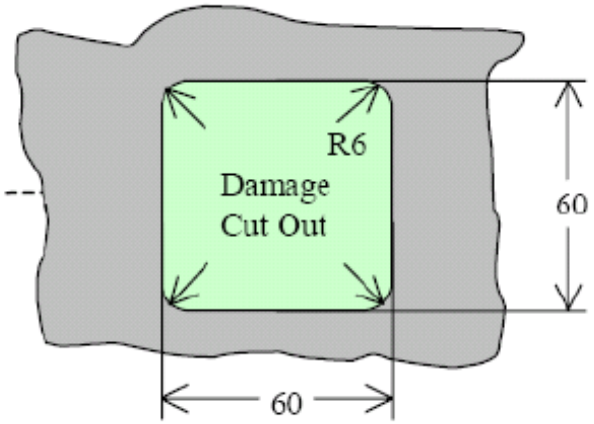
Bonding film cut to shape

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)

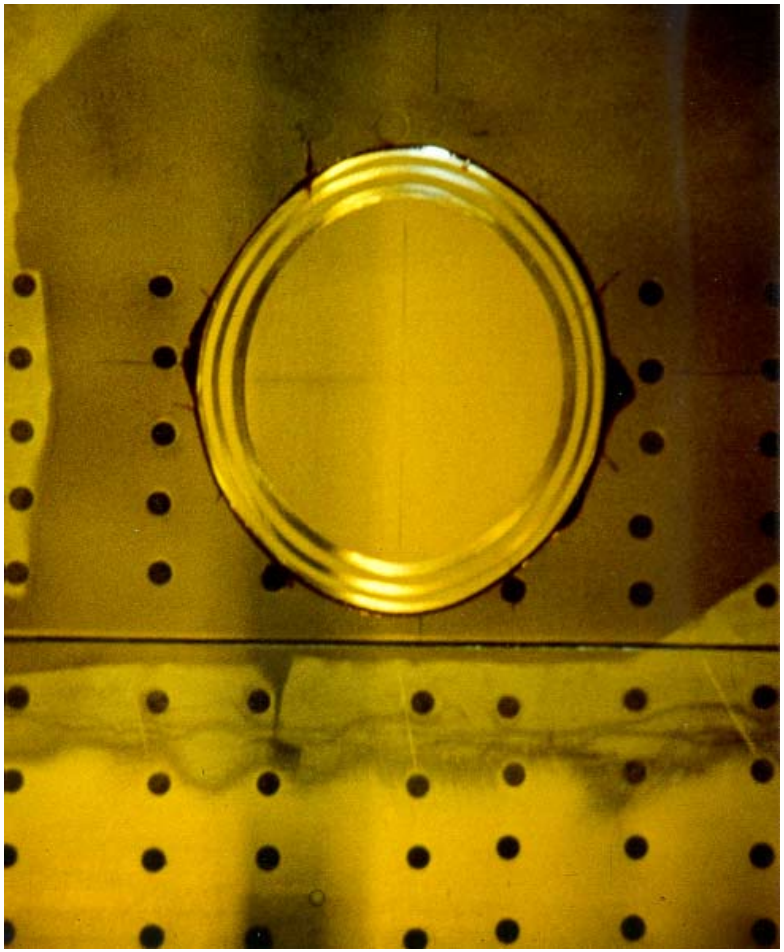
GLARE® repairs patches

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)

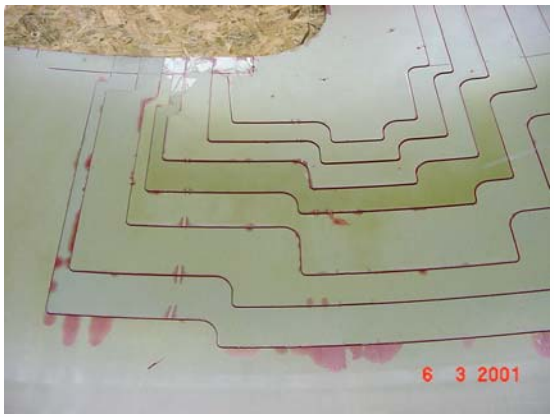
- Improving GLARE properties (and Fibre Metal Laminates)
  - Higher static properties: to be achieved by higher strength alloys
  - Lower density due to lower density aluminium alloys (e.g. Al/Li)
  - Increase stiffness: to be achieved by higher stiffness fibres

- Automation of pretreatment (continue process), lay up and inspection (US).

- Larger Skin panels →

General developments (cont'd)

- Larger panels:
  - Easier Assembly
  - Less joints



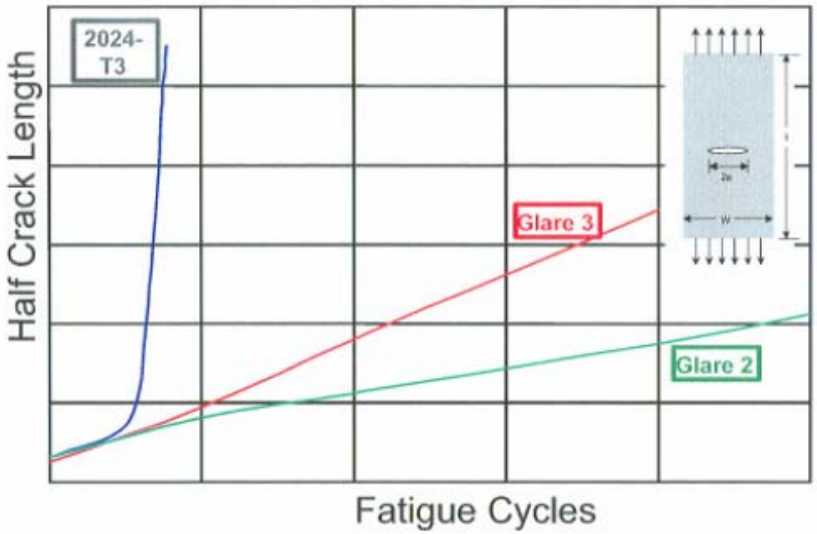
Dimensions: 3.5 x 11 meters (10x33ft)

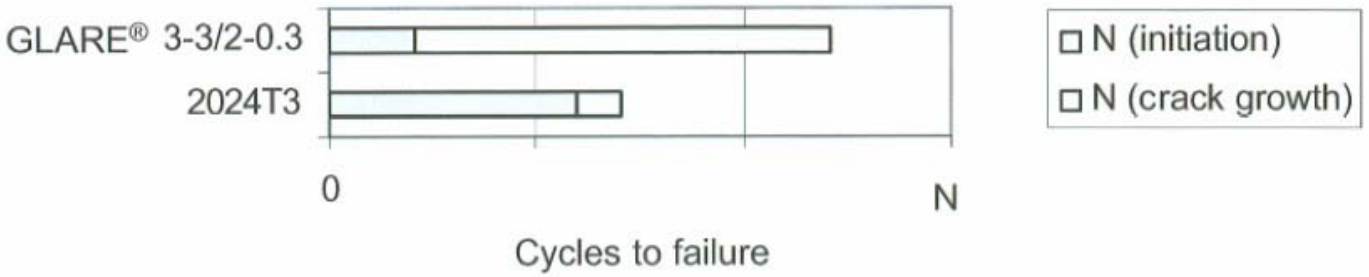
STORK® knows-how

Crack Propagation is no Sizing Parameter

General differences of GLARE® compared with Aluminium:

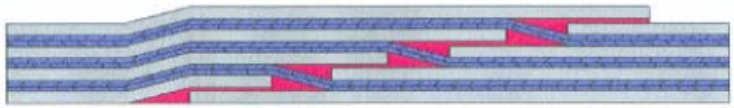
- Fatigue life is longer
- Crack initiation is earlier
- Contribution of crack propagation period on total fatigue life is larger





GLARE® Design Features – "Giant" Tool Box

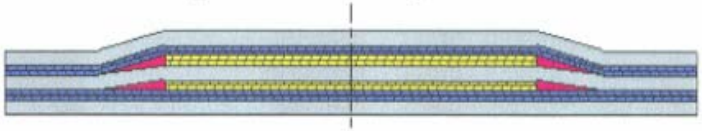
Splice in skin panel or doubler



Limitation of aluminum sheet width

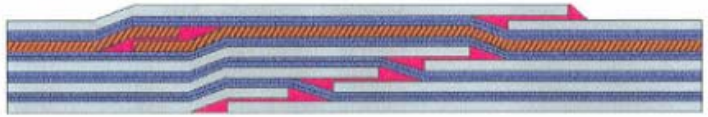
Internal stress level in double curved panels

Additional glass fiber layers



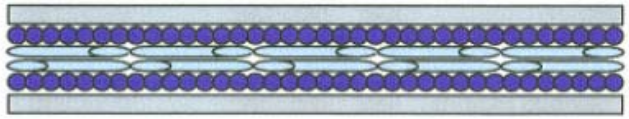
embedded at frame locations

Inter-laminar doublers



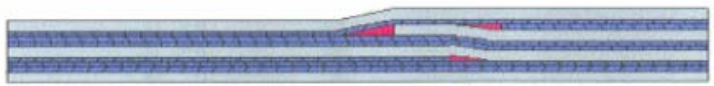
spliced or go thru depending on length and orientation

Fiber Orientation and Lay-up



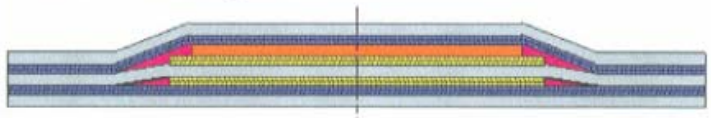
Adjust properties to loading condition

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

Airbus Costumer Benefit from Fiber Metal Laminates - ESAS - Ref. L53PR0605135 - Issue 1 May 2006 Page 5

AIRBUS

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