Presented to the Royal Aerospace Society Hamburg Branch
at Hamburg University of Applied Sciences, 29.10.2009

Presented by

Dr. Thomas Beumler
Airbus Deutschland GmbH

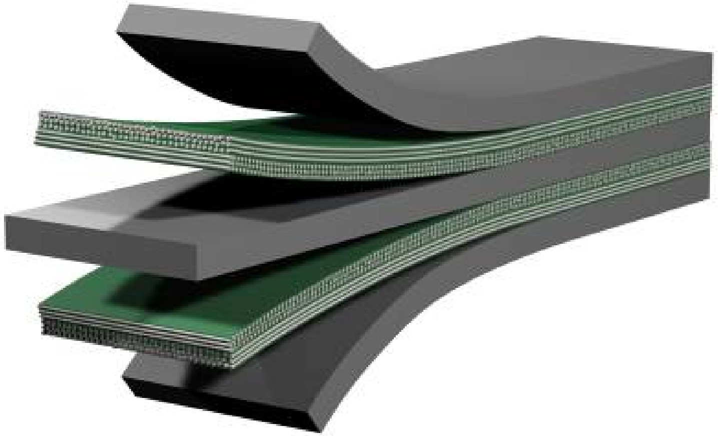
Fiber Metal Laminate Structures - from Laboratory to Application

Overview and Selected Items

AIRBUS

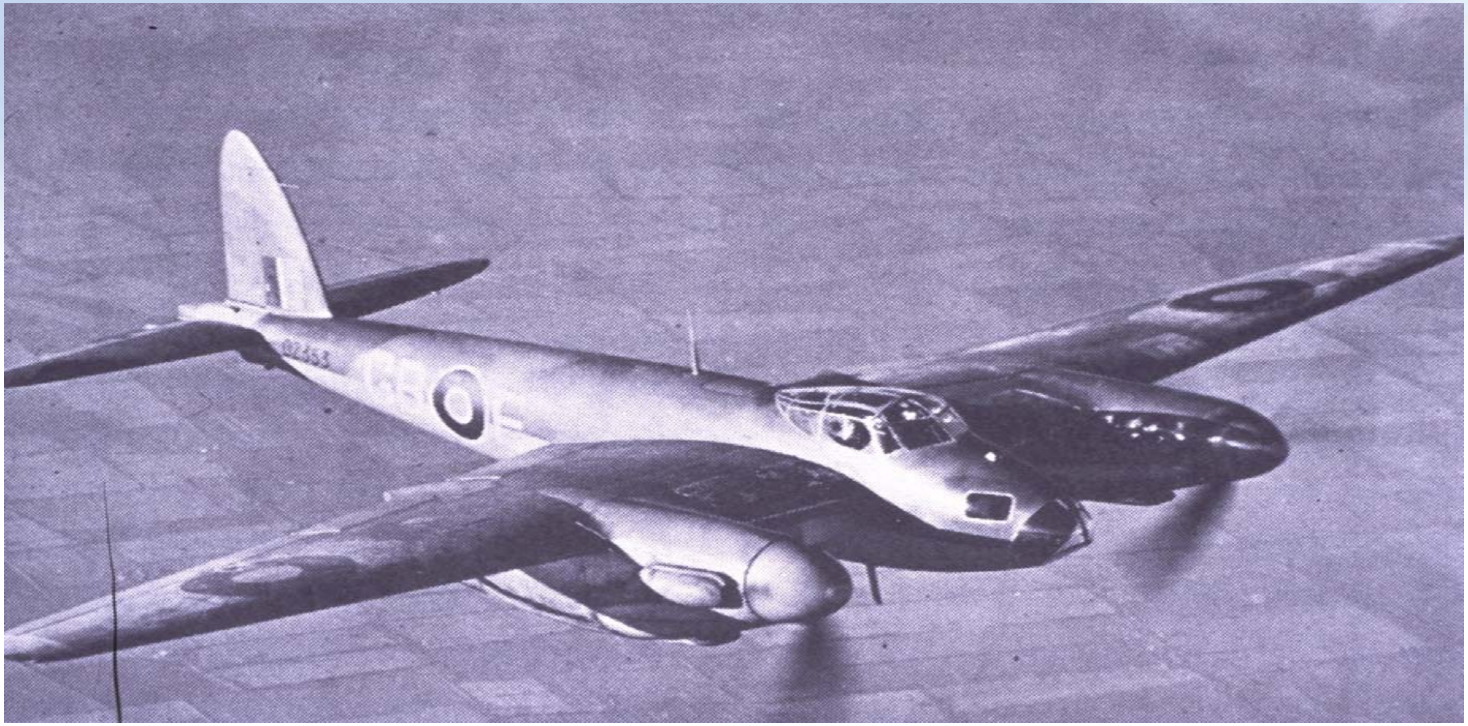
Contents

- Advantage of Bonded Structures
- Why Fiber Metal Laminates ?
- Towards A380 Certification
  - From Laboratory to Application / Selected Items



Advantage of Bonded Structures

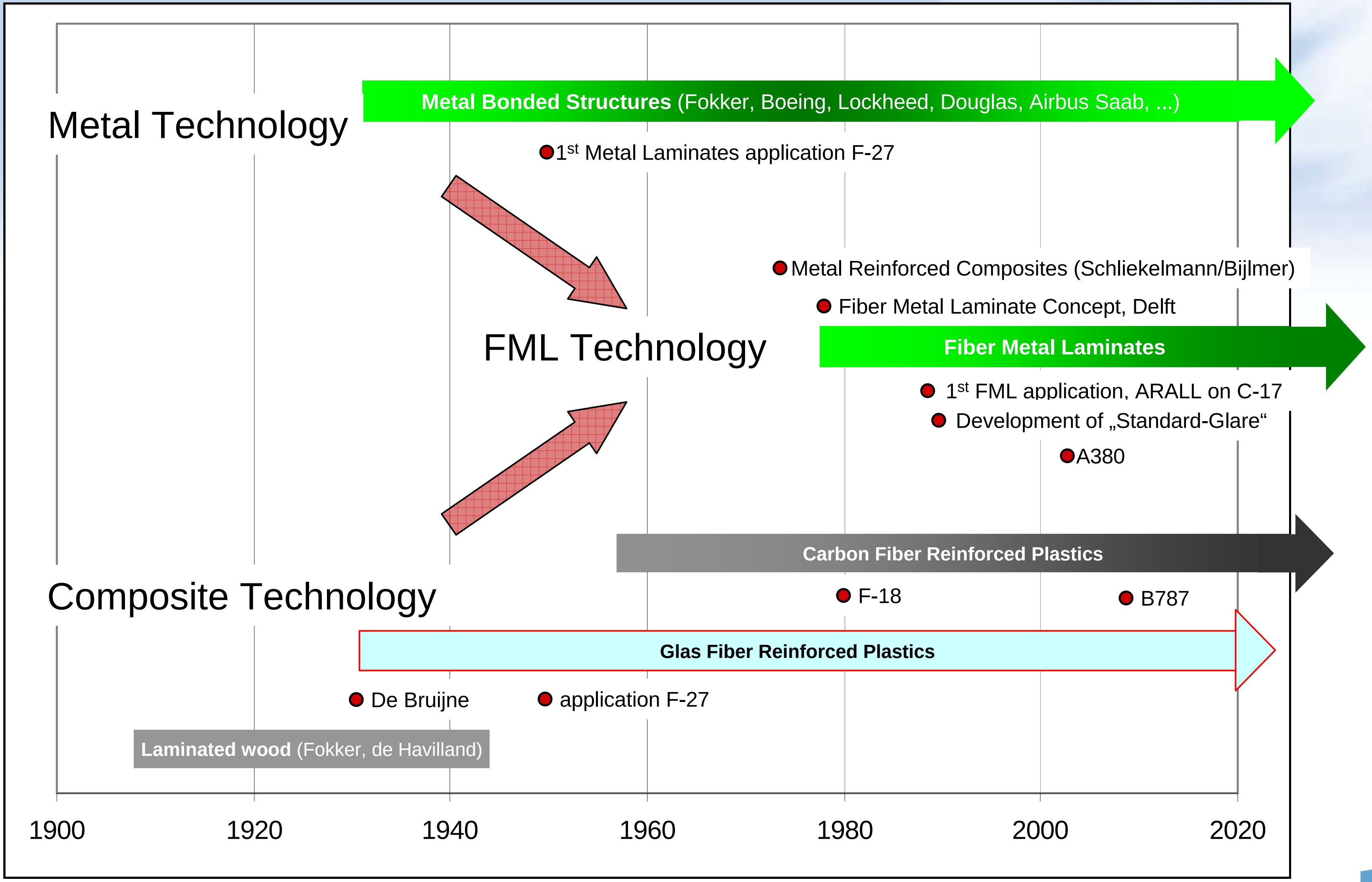
WW2: The Havilland Mosquito



First time bonding of wood to metal in a high loaded <u>primary</u> structure.

The start of metal bonding.

Crack Bridging



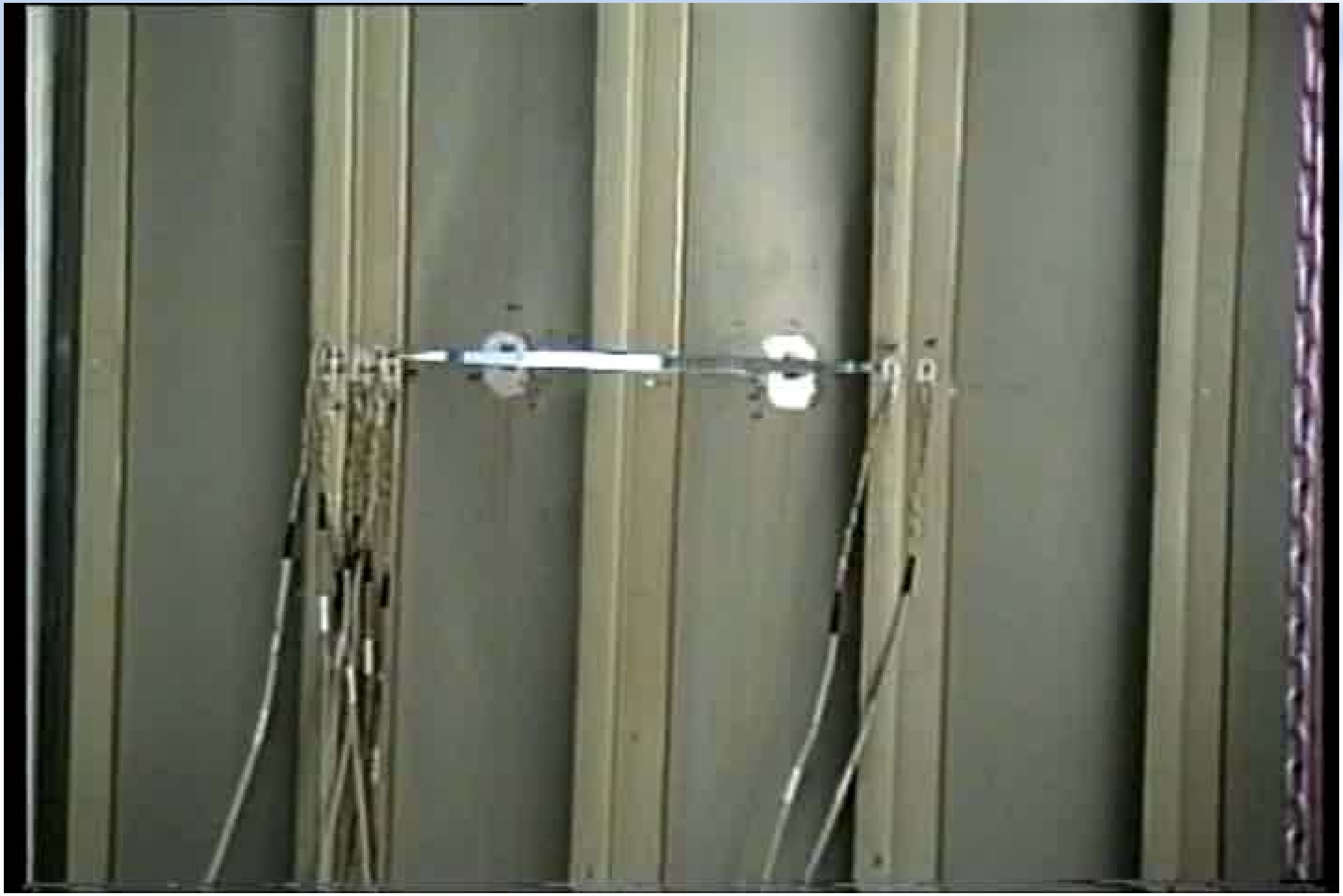
Advantage of Bonded Structures

Advantage of bonded structures compared with riveted or integral structures:

- Multiple load path structures
- ... allows to join materials tailored to their specific tasks
- ... without introduction of fatigue sensitive items (i.e. holes)
- ... leading to high stress allowables and therefore low weight structures.
- Static advantage: Large load carrying width between skin and stiffener increases onset-of-buckling load.

Advantage of Bonded Structures

Example Residual Strength of <u>bonded</u> stringer stiffened panel:



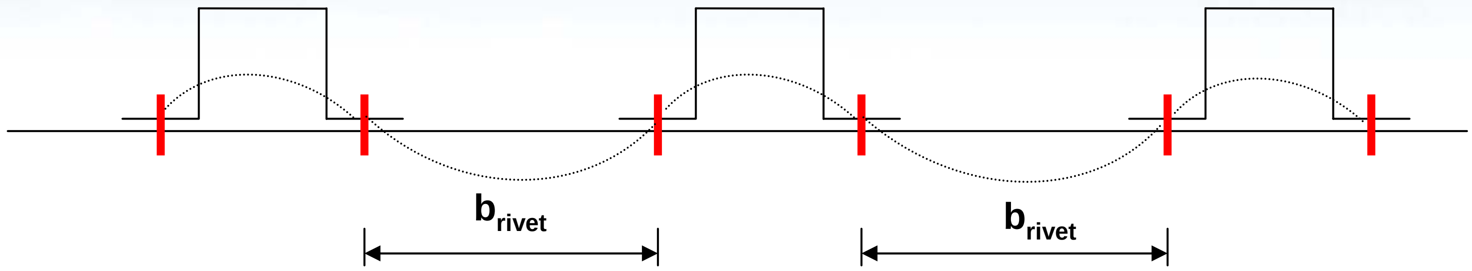
Allowable stress with bonded stringer ~20% > riveted stringer.
Allowable stress with bonded stringer 50% > integral panel.

Advantage of Bonded Structures

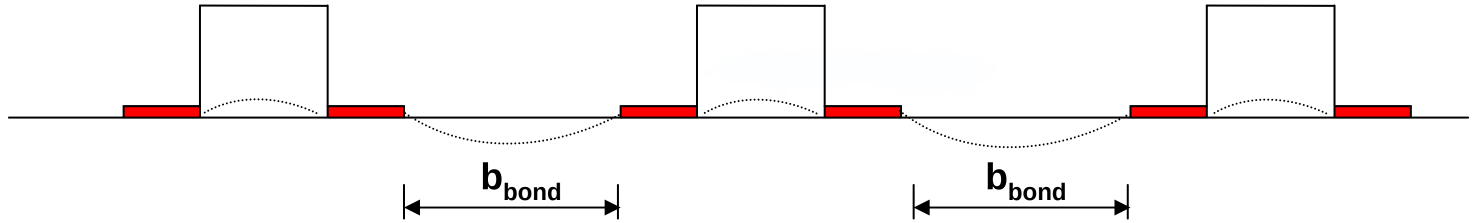
Example

Comparison of load carrying width: buckling of riveted and bonded panel:

Riveted structure



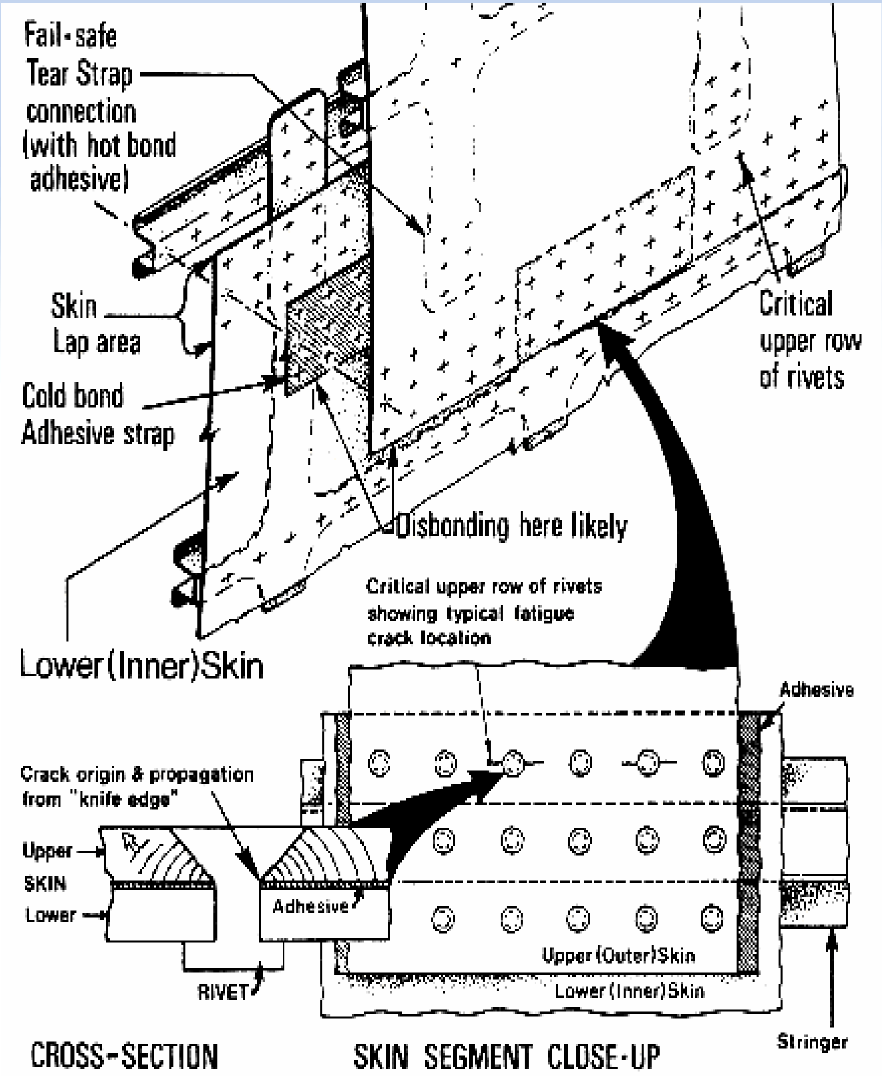
Bonded structure



Contents

- Advantage of Bonded Structures
- **Why Fiber Metal Laminates ?**
- Towards A380 Certification
  - From Laboratory to Application / Selected Items

MSD Phenomenon in Riveted Joints



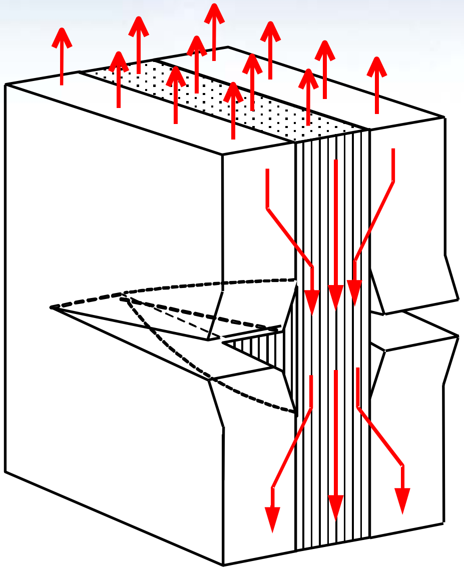
ALOHA incident

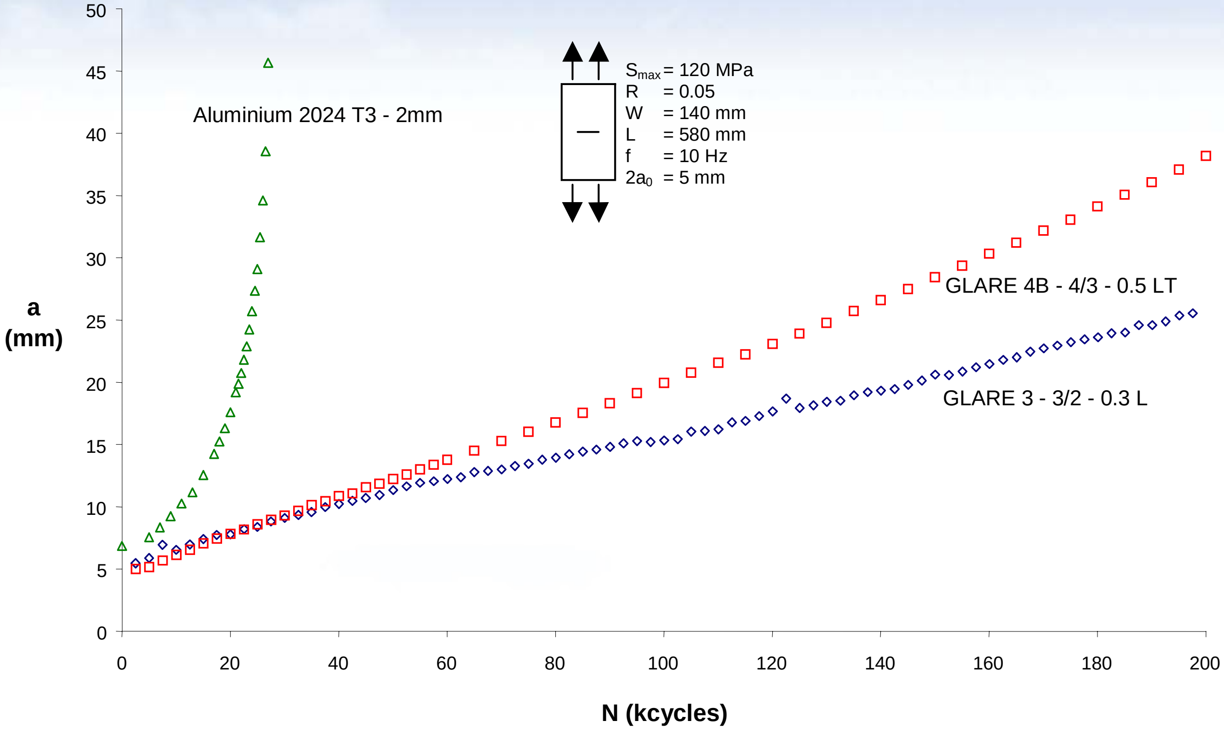
- Disbond of longitudinal joint (cold bond film adhesive)
- Aluminium skin stress increased, skin fatigued (MSD) and failed under internal pressure load

- Separation of panels

Crack Bridging

- Fatigue cracks occur in aluminium layers only, starting in outer aluminium layers
- Fibers stay intact and bridge the fatigue crack





- Slow crack growth rate and high residual strength compared to aluminium

Sizing Cases

Consider:

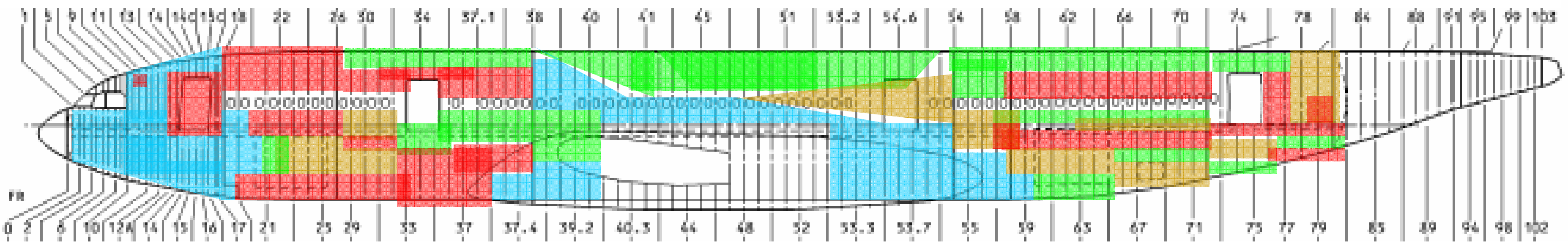
Today 60% to 80% of the pressurized fuselage shells are designed by F&DT.

Fatigue Crack Propagation

Damage Tolerance (LDC)

Static Ground Load Cases

Static Flight Load Cases



Controlling the Damage with FML's

DT Material + DT Design

$$\underbrace{\textbf{DT Material} + \textbf{DT Design}}$$

High Design Allowables for high Performance

and

Damage Tolerance for Maintenance

→ Flexibility for Maintenance Plan

Repairs of Dents, Scratches, Scribe Marks, etc.

Contents

- Advantage of Bonded Structures
- Why Fiber Metal Laminates ?
- **Towards A380 Certification**

  - From Laboratory to Application / Selected Items

FML Certification Tasks for A380

Information flow in **G**LARE **T**echnology **P**rogram environment

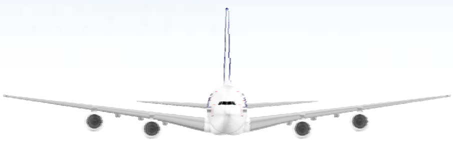
GLARE Certification Group (WG3B)

Conducts working sessions with European and US AA's.
Invites specialists for support.
Directs tasks to cluster.
Presents results from cluster.

GTP Working Groups

- M&P Qualification
- Material Properties
- Durability
- Methods Static
- Methods F&DT
- Design Guidelines
- Industrial Manufacturing
- NDI
- Repairs & SRM
- Specialties

Cluster conduct technical tasks according to A380-800 milestone planing. Task results required for aircraft sizing and design,strength justification and aircraft certification.

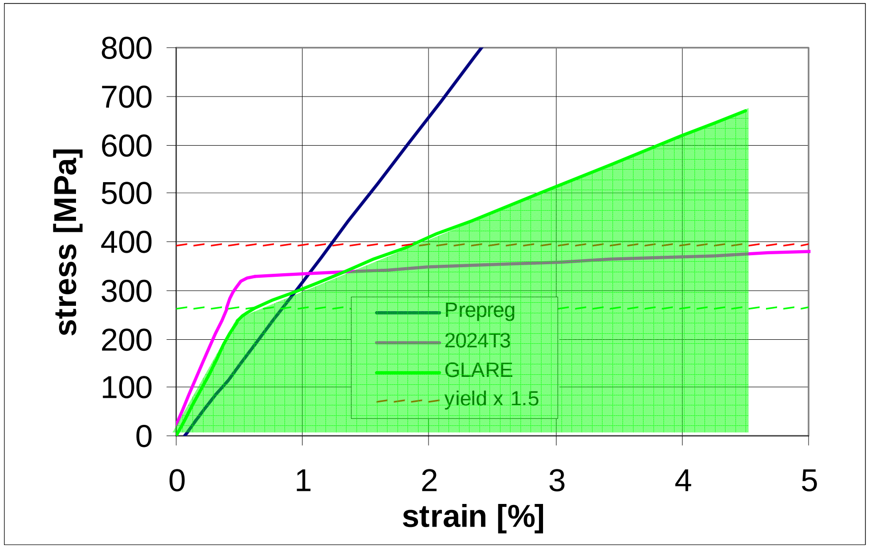


A380 stressmen, designers and manufacturing specialists define tasks for cluster and use cluster know-how for aircraft strength justification and aircraft structural certification.

Material Characterisation for Certification

GLARE® has been qualified and certified as a metal under consideration of 6 characteristic and important properties:

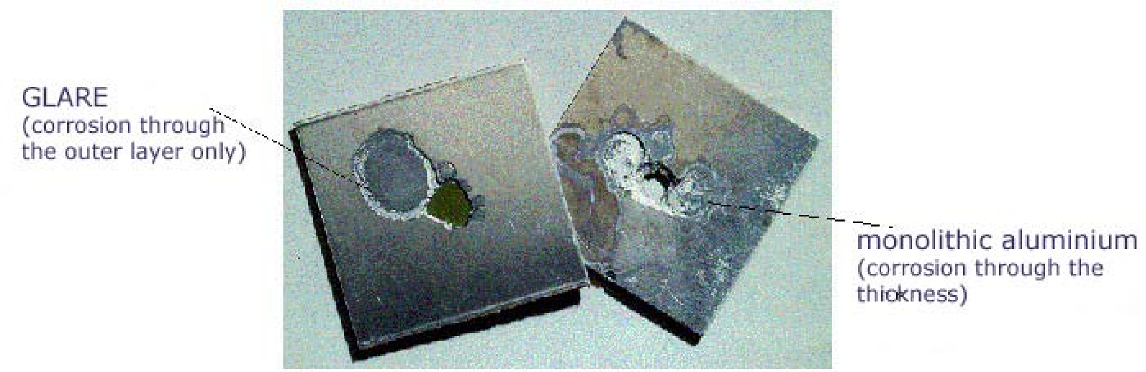
1) Ductility. The material has the capability to yield and to absorb energy with gradual and predictable strength degradation. The ductility is mainly dependent on the aluminium type applied.



Stress-strain diagram Standard-GLARE

Material Characterisation for Certification

2) Oxidation. The laminate is as <u>sensitive to corrosion</u> as the applied metal



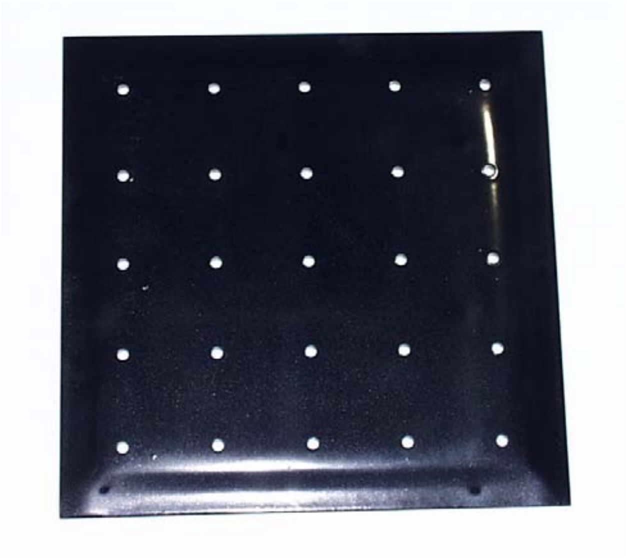
3) The <u>sensitivity to fatigue</u> (crack initiation).

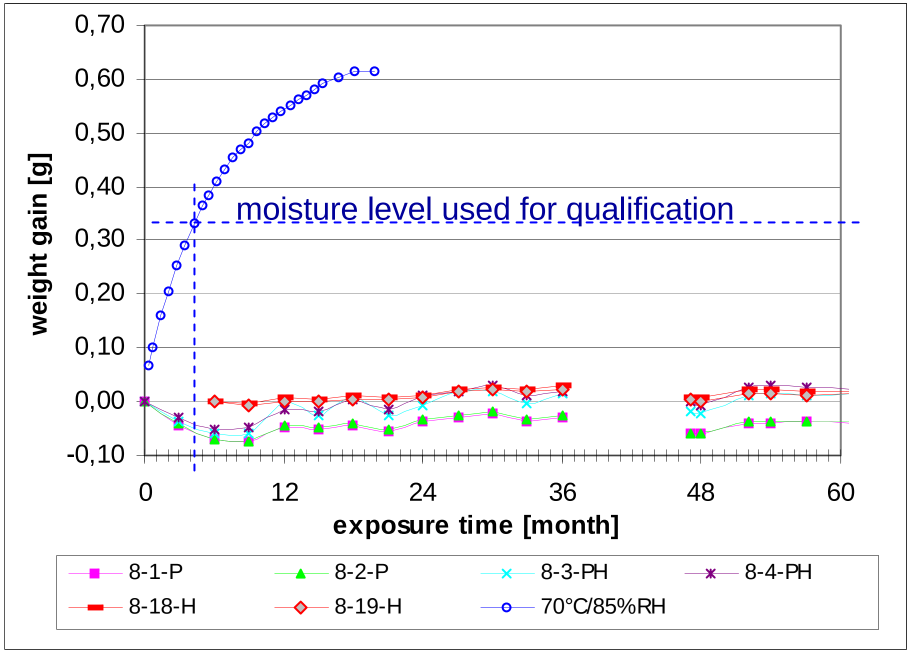
4) <u>Electrical conductivity</u>.
Similar as for monolithic aluminium.

Material Characterisation for Certification

5) Machining processes are not equal but quite similar to monolithic aluminium.

6) Environmental influences due to diffusion into the prepreg are limited to drilled holes and damages.





FML Certification

Both „Standard GLARE“ and „HSS-GLARE“ have been certified as metal under JAR/FAR without a Special Condition.

FML Tasks for A380

Information flow in GTP environment

Why FML's ?

GLARE Certification Group (WG3B)

Conducts working sessions with European and US AA's.
Invites specialists for support.
Directs tasks to cluster.
Presents results from cluster.

GTP Working Groups

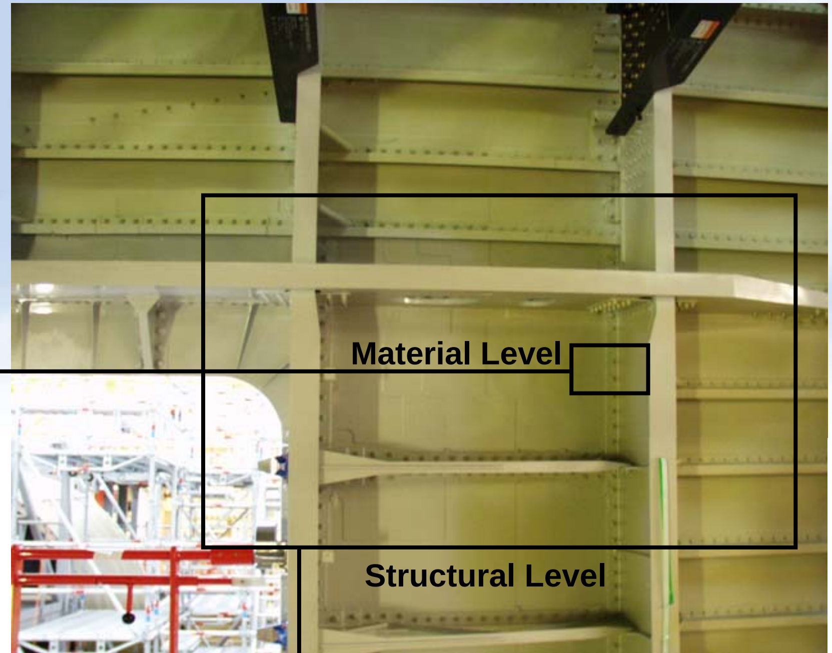
- M&P Qualification
- Material Properties
- Durability
- Methods Static
- Methods F&DT
- Design Guidelines
- Industrial Manufacturing
- NDI
- Repairs & SRM
- Specialties

Cluster conduct technical tasks according to A380-800 milestone planing. Task results required for aircraft sizing and design,strength justification and aircraft certification.

A380 stressmen, designers and manufacturing specialists define tasks for cluster and use cluster know-how for aircraft strength justification and aircraft structural certification.

Controlling the Damage …

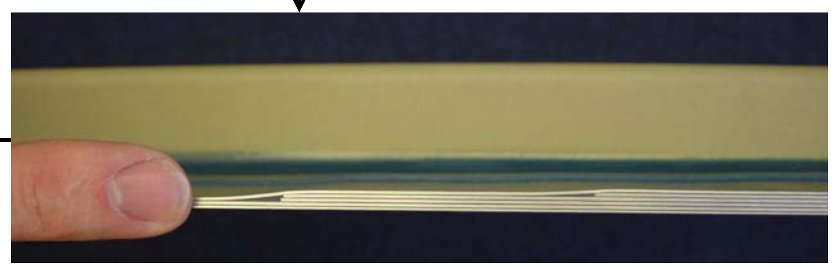
- … on Structural Level
- … on Material Level



through material properties
→ JAR 25.613(a,b,c,d)

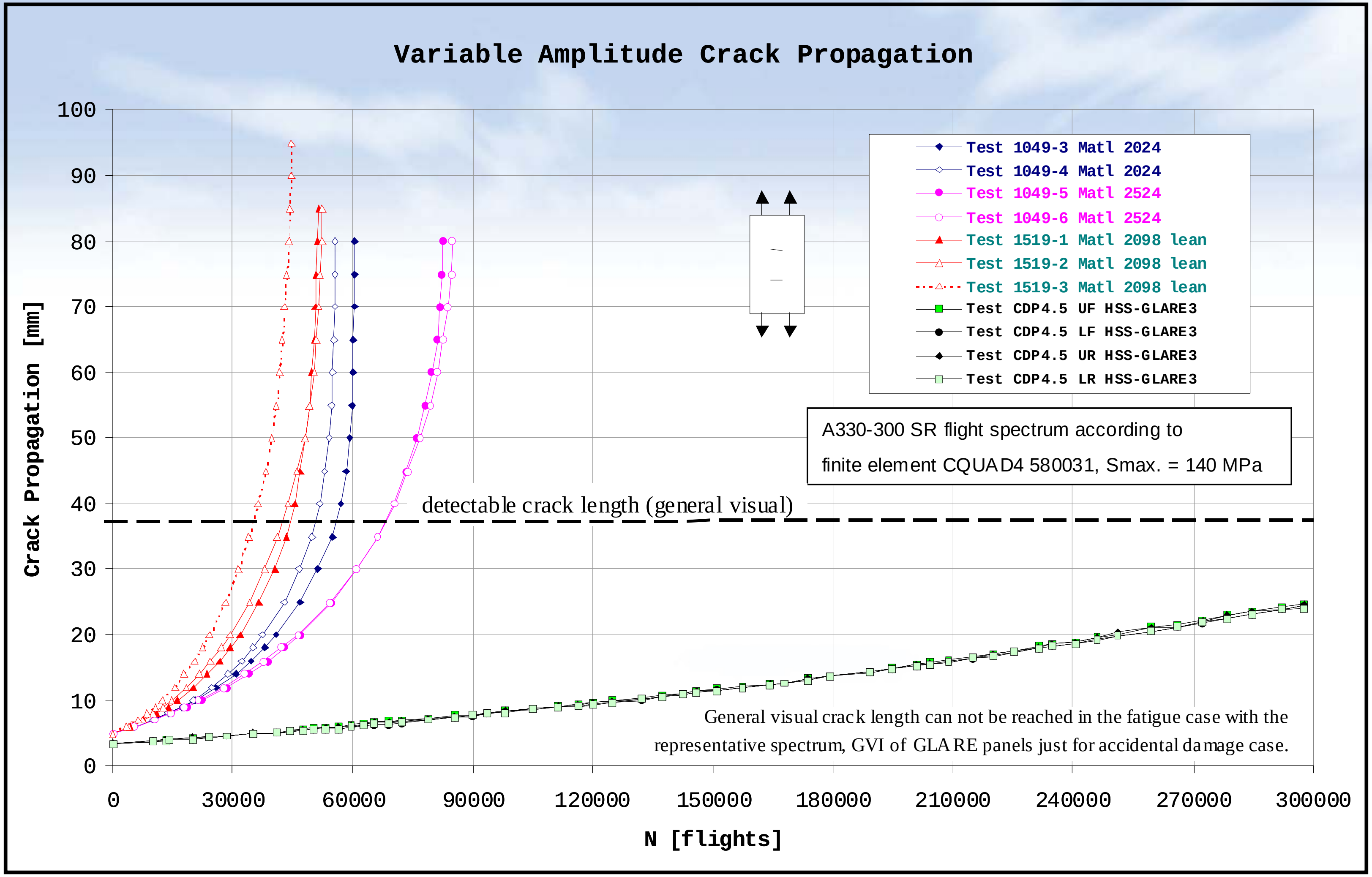
Under strict consideration of JAR 25.1529: Continuous Airworthiness

through design features
→ design values, JAR 25.613(e)



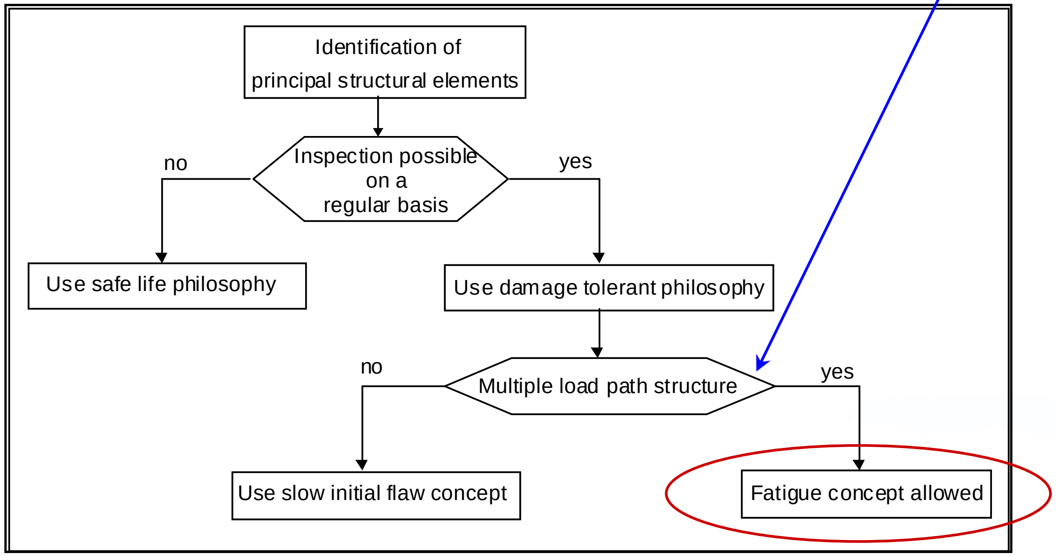
Damage Tolerance on Material Level

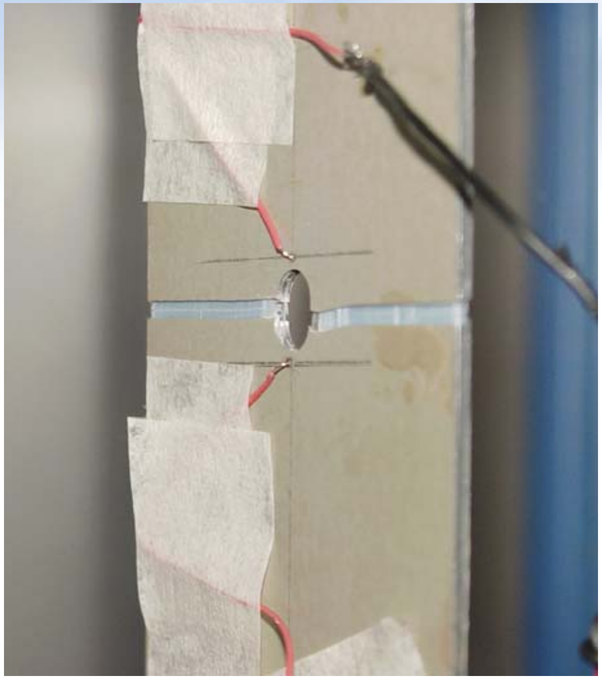
Slow fatigue crack propagation rates



Damage Tolerance on Material Level

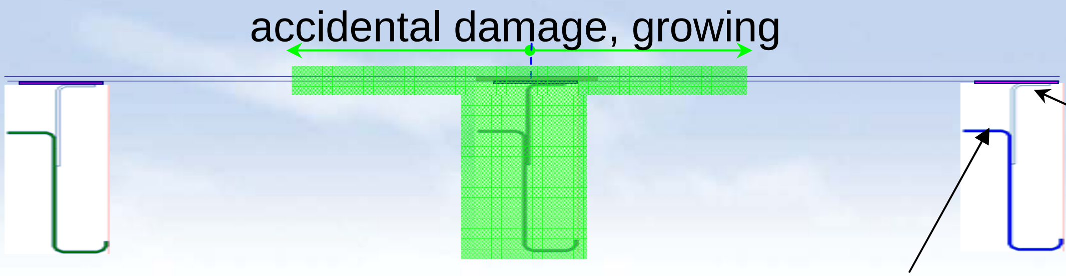
The laminate itself is considered as a second load path material, with the fibers backing up the aluminium.



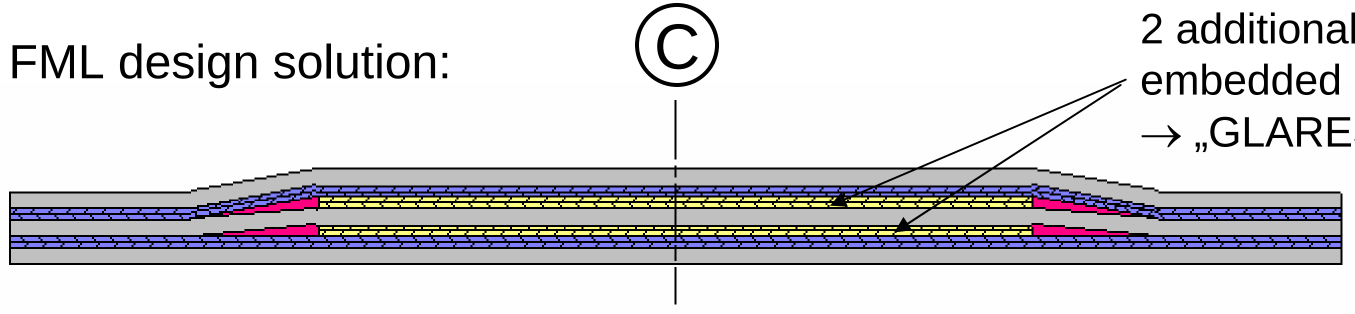


Damage Tolerance on Structural Level

Aluminium design solution to cover Large Damage Capability Criterion :



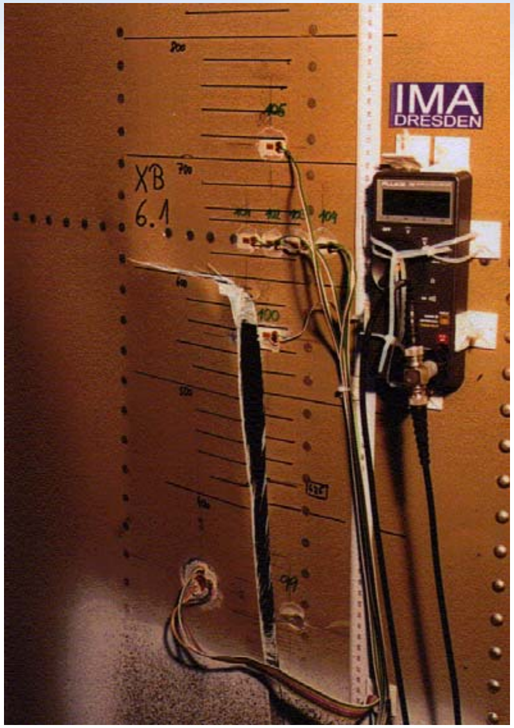
FML design solution:

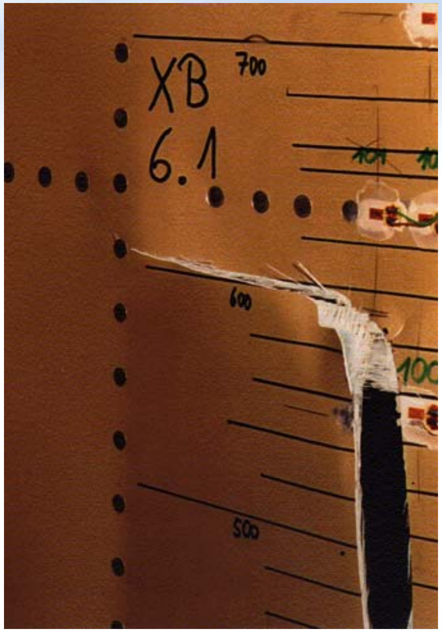


Damage Tolerance on Structural Level

Large Damage Capability of GLARE3improved

Crack turning





Damage stopped
(1170mbar achieved,
685mbar required)

Test performed within TANGO Program FWP2

→ LDC is no sizing criterion for GLARE3improved

FML Certification Tasks for A380

Information flow in GTP environment..

GLARE Certification Group (WG3B)

Conducts working sessions with European and US AA's.
Invites specialists for support.
Directs tasks to cluster.
Presents results from cluster.

GTP Working Groups

- M&P Qualification
- Material Properties
- Durability
- Methods Static
- Methods F&DT
- Design Guidelines
- Industrial Manufacturing
- NDI
- Repairs & SRM
- Specialties

Cluster conduct technical tasks according to A380-800 milestone planing. Task results required for aircraft sizing and design,strength justification and aircraft certification.

A380 stressmen, designers and manufacturing specialists define tasks for cluster and use cluster know-how for aircraft strength justification and aircraft structural certification.

-

FML Certification Tasks for A380

Information flow in GTP environment

GLARE Certification Group (WG3B)

Conducts working sessions with European and US AA's.
Invites specialists for support.
Directs tasks to cluster.
Presents results from cluster.

GTP Working Groups

- M&P Qualification
- Material Properties
- Durability
- Methods Static
- Methods F&DT
- Design Guidelines
- Industrial Manufacturing
- NDI
- Repairs & SRM
- Specialties

Cluster conduct technical tasks according to A380-800 milestone planing. Task results required for aircraft sizing and design,strength justification and aircraft certification.

A380 stressmen, designers and manufacturing specialists define tasks for cluster and use cluster know-how for aircraft strength justification and aircraft structural certification.

GLARE® Qualification Program

- **Step 0** **Qualification of the single materials**

  AL-foil acc. to FAe-material specification,
  Prepreg acc. to FAe-material specification
  Processing (in) Glare to FAe-technical specification
  FAe-quality specification
  Pre-treatment and bonding already confirmed processes by Airbus Deutschland ESWCG reports

- **Step 1** **Qualification flat semi-finished GLARE® products**
  in Glare 2B (butt-strap), Glare 3 and Glare 4B (skin)
  and Spliced Glare 3 and Glare 4B

- **Step 2** **Qualification Manufacturing of GLARE® Components**
  including Glare 2A/2B (doubler and stringer)
  and Glare 6 (doubler)

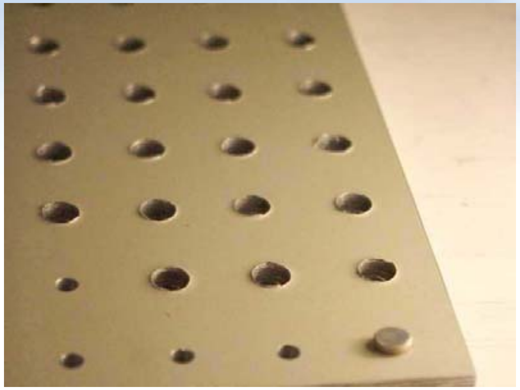
GLARE®, Qualification Material & Machining

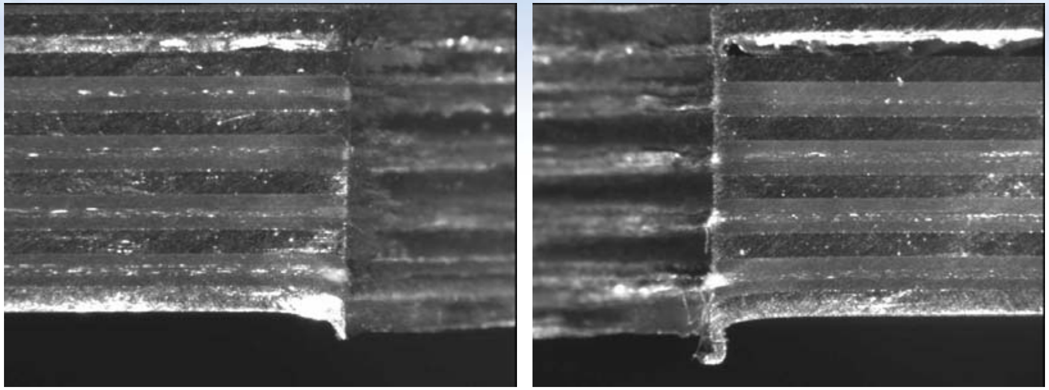
Drilling:

Bad rivet hole drilling

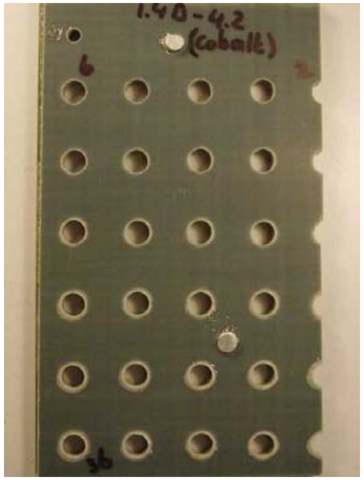
•Drilling trials FAe

Manual drilling





Cross-section of hole 32



•Drilling with cobalt coated standard drill, total 43 holes

•Burr too high (> 0,2 mm) after 28 holes

•Resin and fibres disturbed

Last layer of aluminium etched away

GLARE®, Qualification Material & Machining

Milling:

Contour milling

- Milling specimen by A-D Nordenham, UFM III
- Determination milling parameter, measurement emission

Preparation Milling station, assembling measure points for dust-emission measurement

Checking edges

16-PKD Shaft mill

Milled edge

Results

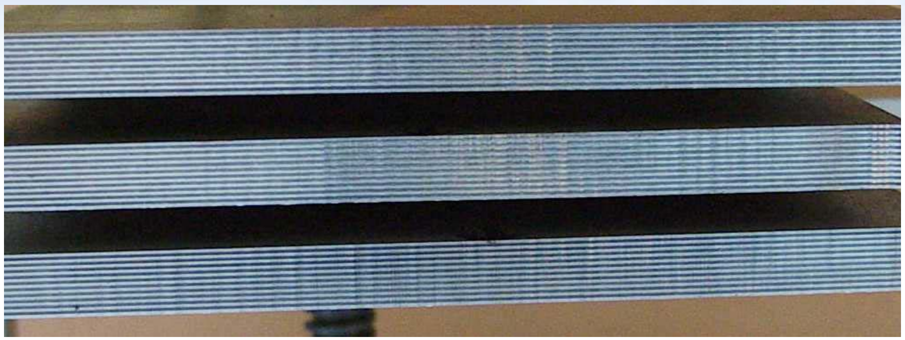
- Good results with PCD or Full Hard Metal mill
- Equal milling parameter as for conventional Al-alloys
- First results show no critical dust emission

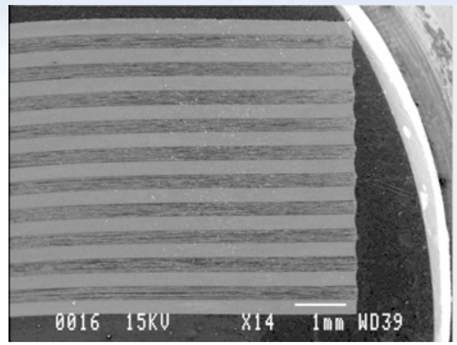
GLARE®, Qualification Material & Machining

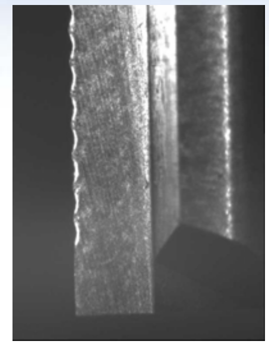
Milling:

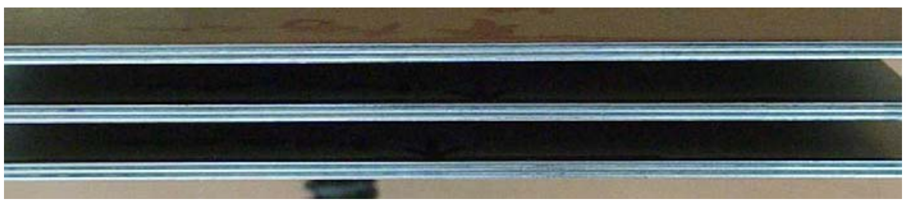
Requirements

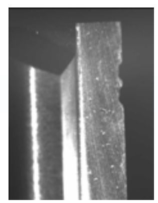
- no delamination of the milled edge
- no large deformation of the material edge
- no fracture of the tool before a milling distance of 25 mtr

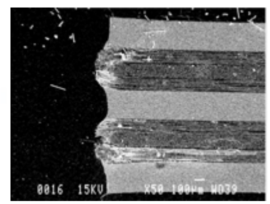












Good results

Mill diam. 6 – 8 mm

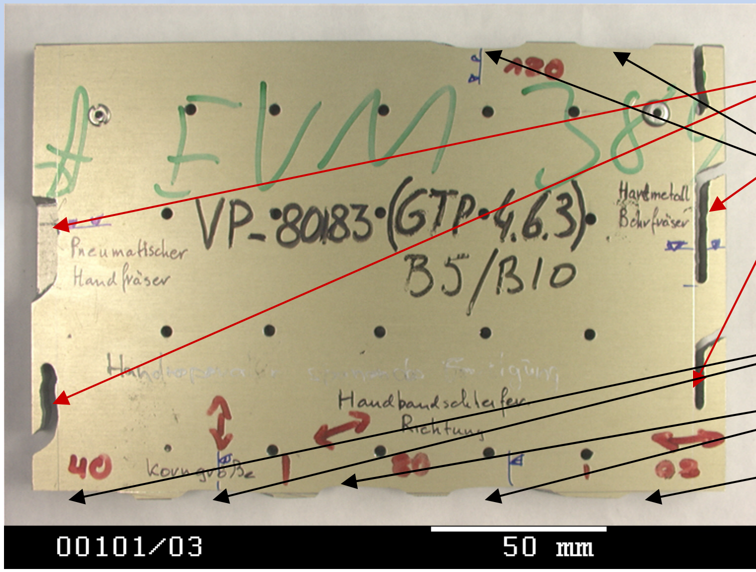
Speed 8000 rpm

Feed 1200 mm/min

GLARE®, Qualification Material & Machining

Milling:

Hand-milling for repair



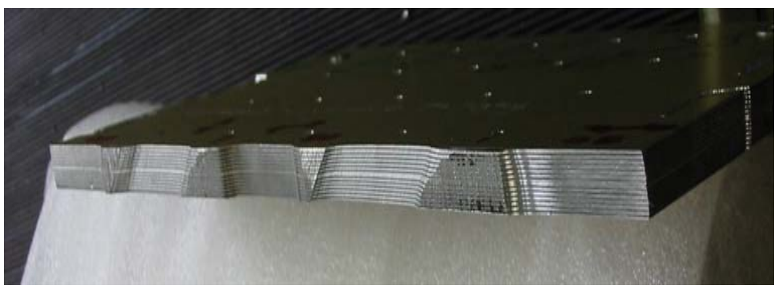
- Pneumatic hand cutter 6mm and 4 mm
- Pneumatic hand drill-cutter 3 mm and 2 mm
- Pneumatic hand belt-grinder

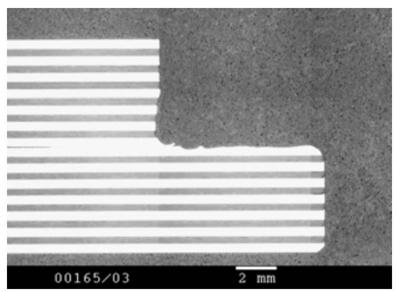
  90 degree, core-size 180

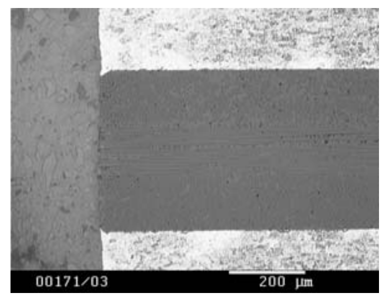
  90 / 45 degree core-size 40

  90 / 45 degree core-size 80

  180 degree core-size 80







GLARE®, Qualification Material & Machining

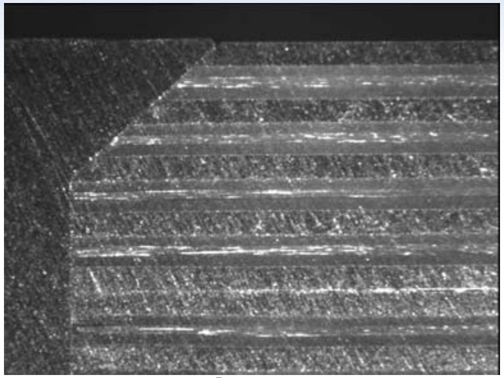
Riveting:

Solid riveting

- Riveting trials FAE, ESWAG
- Determination riveting parameter

Countersunk head side

Upset head side



Cross section

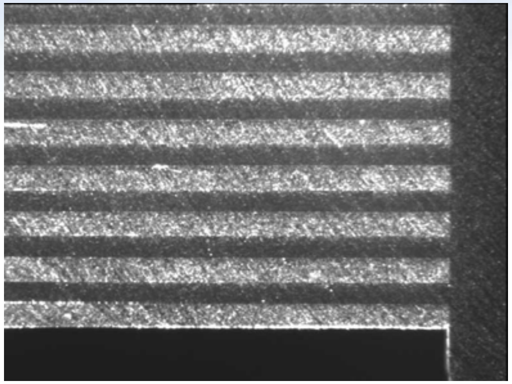
Results

- Good result by automatic riveting with ductile rivets and by manual riveting with heat treated rivets

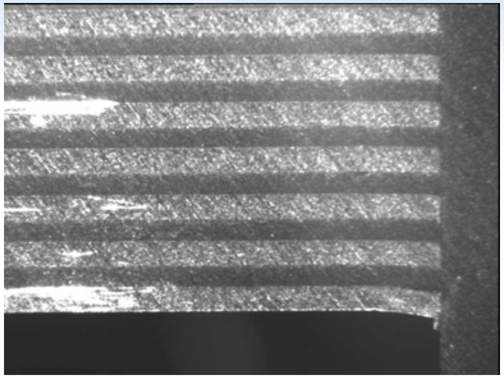
GLARE®, Qualification Material & Machining

Installation Hi-Loks, Lockbolts:

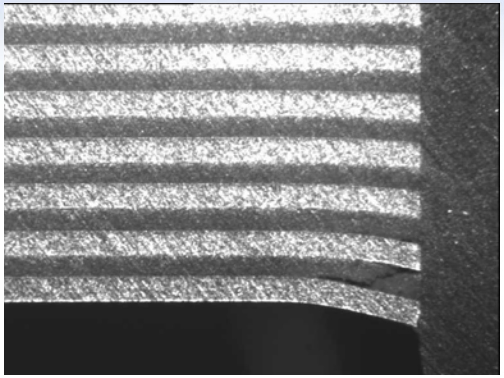
Interference fit
- **Determination permitted interference**
- **trials carried out FAE, controlled EVM**



20µm interference



40µm interference



80µm interference

Results
- **20µm → no de-lamination with anodized bolts**
- **40µm → starting de-lamination with anodized bolts**
  no de-lamination with Hi-coated bolts
- **80µm → clear de-lamination with anodized bolts**

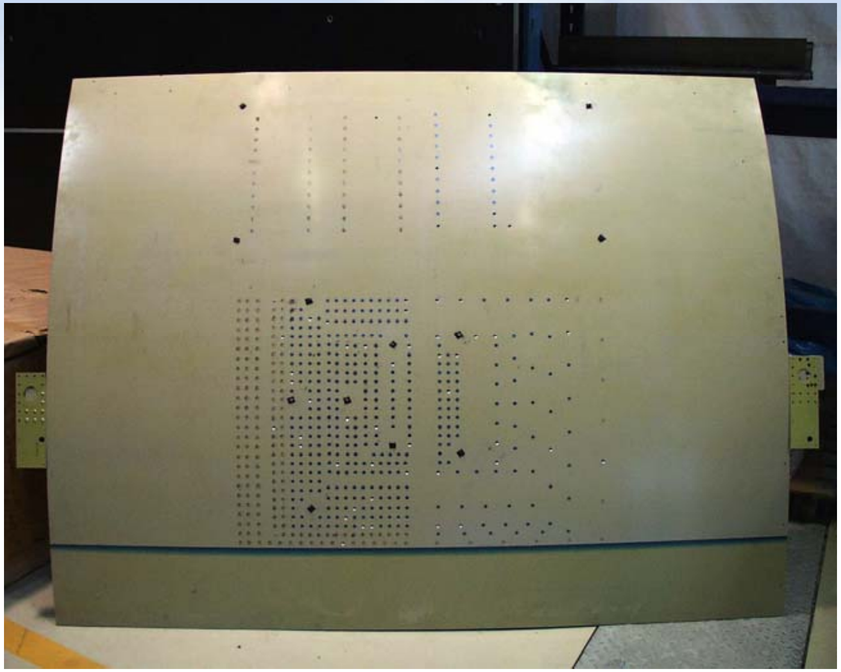
GLARE®, Qualification Material & Machining

Panel on automatic riveting machine in Nordenham

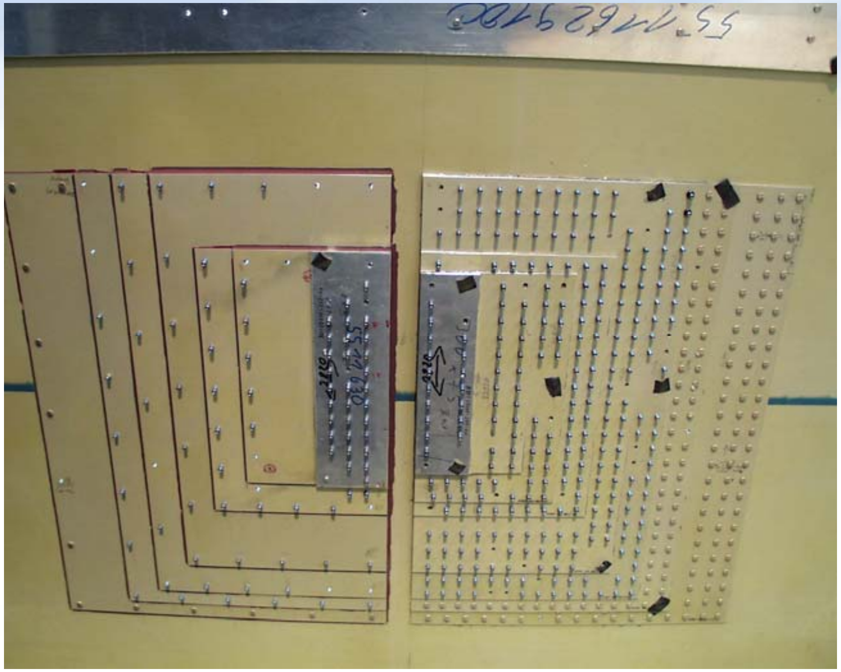
Door-frame panel on automatic riveter

Automatic riveting operations

Door-frame panel



Typical riveted door-frame (outside)



Typical riveted door-frame (inside)

GLARE® status qualification (01.01.2003)

- **Documents:** **127 Documents involved**

51 R-, P-, Q-reports
17 QCS
12 AIMS, 2 AIPS, 2 AITM,
3 ABS
9 IPS
9 MARS
17 80-T
5 QVA

FML Certification Tasks for A380

Information flow in GTP environment

GLARE Certification Group (WG3B)

Conducts working sessions with European and US AA's.
Invites specialists for support.
Directs tasks to cluster.
Presents results from cluster.

GTP Working Groups

- M&P Qualification
- Material Properties
- Durability
- Methods Static
- Methods F&DT
- Design Guidelines
- Industrial Manufacturing
- NDI
- Repairs & SRM
- Specialties

Cluster conduct technical tasks according to A380-800 milestone planing. Task results required for aircraft sizing and design,strength justification and aircraft certification.

A380 stressmen, designers and manufacturing specialists define tasks for cluster and use cluster know-how for aircraft strength justification and aircraft structural certification.

Fuselage Panel Production Steps

Decoiling and cutting of alu-minium sheets → Contour milling of sheets → Framing of sheets → Chemical treatment of sheets →

Application of bond primer → Roll up and sheet storage → Lay-up in 2-/ 3D-mould → Curing in autoclave →

Fuselage Panel Production Steps

C - scan inspec-tion of skin → Panel milling (5 axis) → Post-treatment of panel → Panel storage / expedition

- small repairs
- Alodine application on cut edges
- painting with basic primer

if internal doublers and/or stringers need to be bonded:

=> return of skin to lay-up station and autoclave for a second bond cycle

=> quality control of metal bonding by using Fokker bondtest technique

Fuselage Panel Production Steps

To enable access also to the center of the bond mould, a special portal vehicle has been developed which transports a person over the mould who positions the prepreg and the alu sheets.

Under investigation: Automated lay-up.

FML Certification Tasks for A380

Information flow in GTP environment

GLARE Certification Group (WG3B)

Conducts working sessions with European and US AA‘s.
Invites specialists for support.
Directs tasks to cluster.
Presents results from cluster.

GTP Working Groups

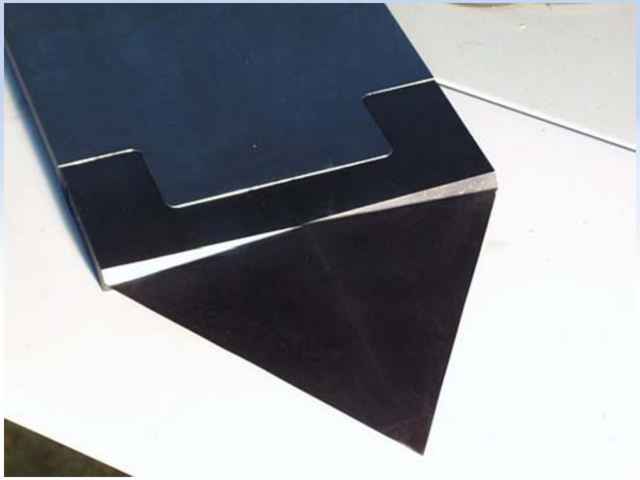
- M&P Qualification
- Material Properties
- Durability
- Methods Static
- Methods F&DT
- Design Guidelines
- Industrial Manufacturing
- NDI
- Repairs & SRM
- Specialties

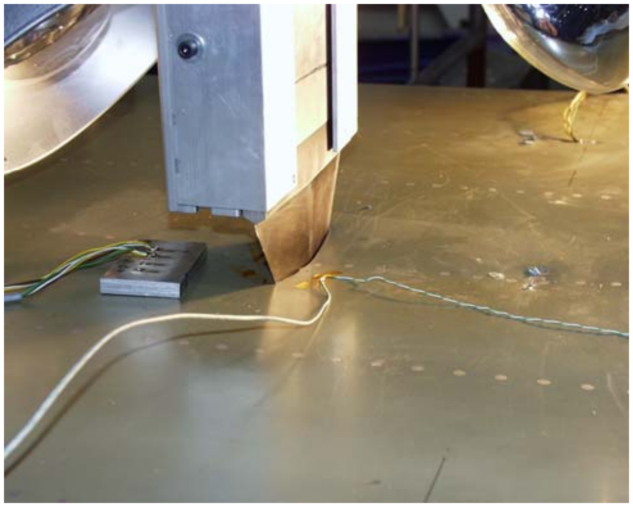
Cluster conduct technical tasks according to A380-800 milestone planing. Task results required for aircraft sizing and design,strength justification and aircraft certification.

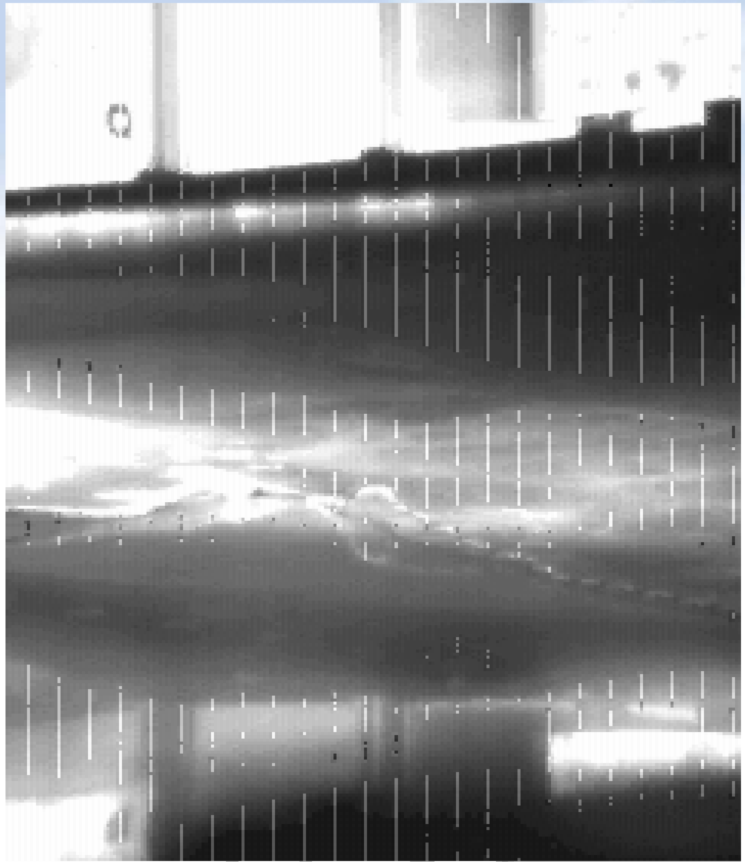
A380 stressmen, designers and manufacturing specialists define tasks for cluster and use cluster know-how for aircraft strength justification and aircraft structural certification.

Large Impacts in Standard-GLARE

Ductile Material Behaviour



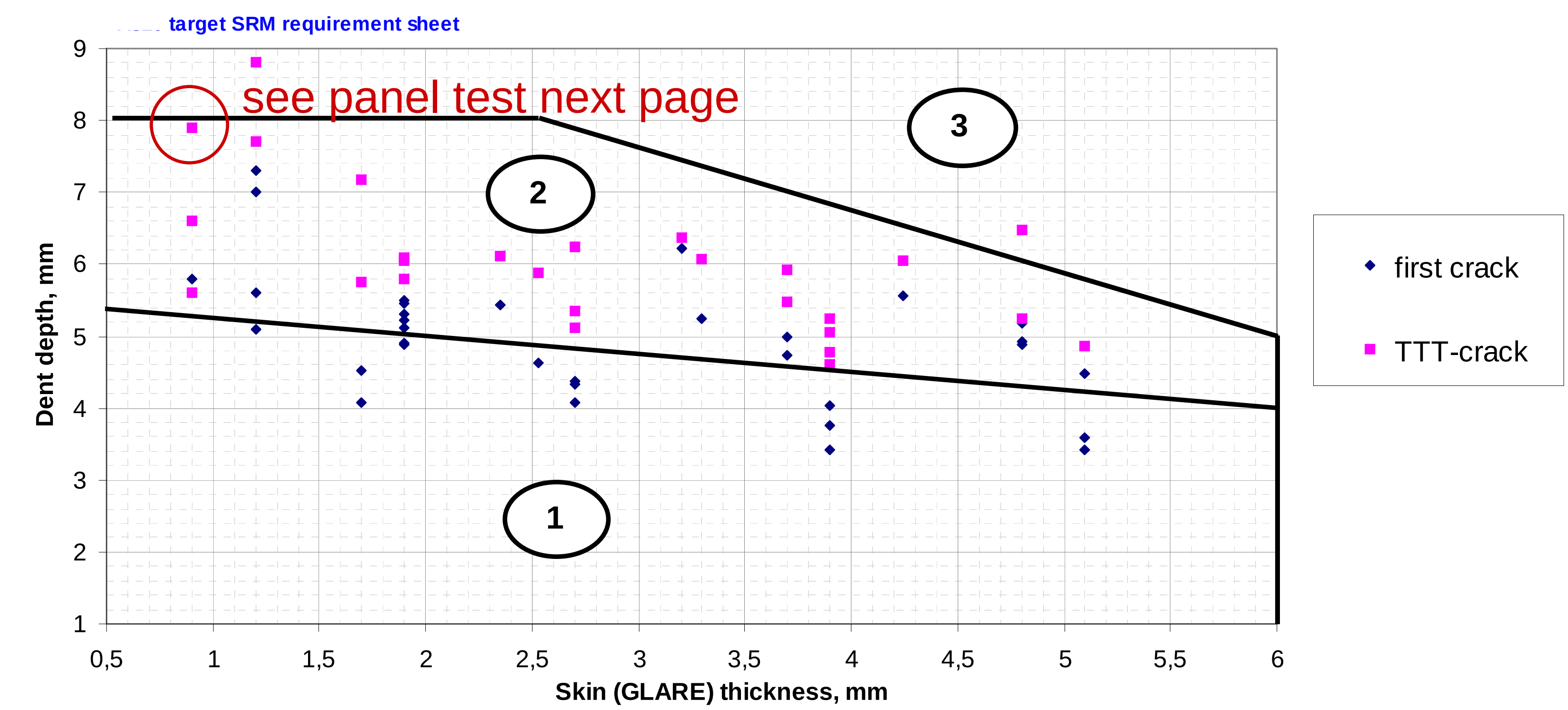




19.07.02 12:01:35 1700 -0171,0[ms] CAM
profile_4 (1000 Hz)

Evaluation of Impact Test Results

Standard-GLARE, undisturbed structure, target SRM sheet:



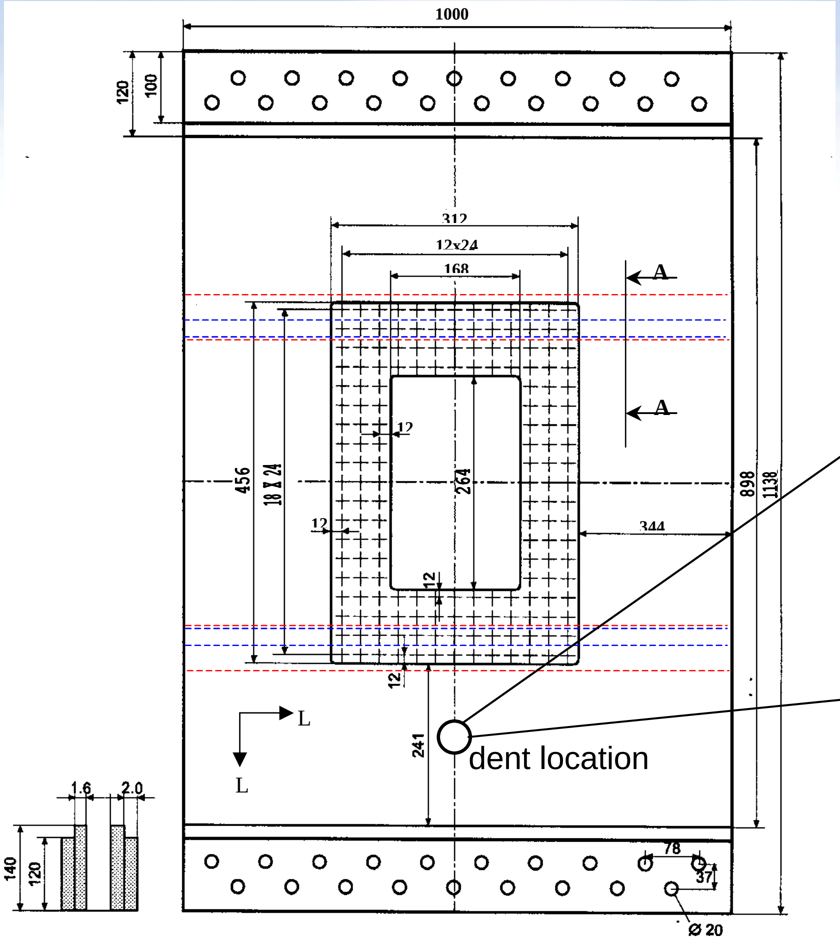
1: check damage by detail visual inspection from external. If crack found contact Airbus or repair before next flight.
If no cracks found, inspect this damage within **8000 FC** from internal and external with NTM to confirm no cracks.
If no cracks detected, no further action is required. If cracks detected contact Airbus or repair before next flight.

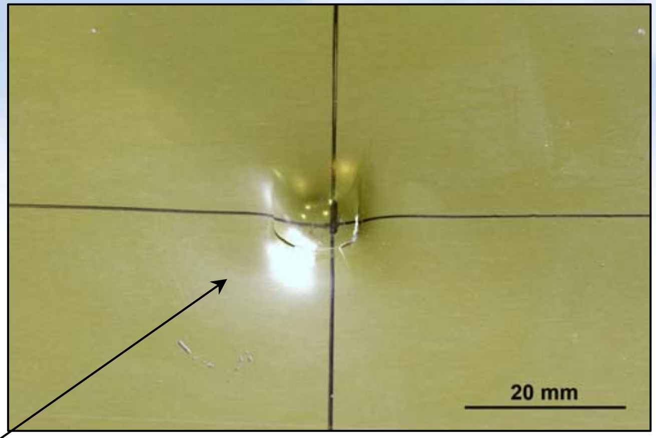
2: check damage by detail visual inspection from internal and external. If cracks found contact Airbus or repair before next flight.
If no cracks detected, repair within **1000 FC**

3: contact Airbus or repair before next flight

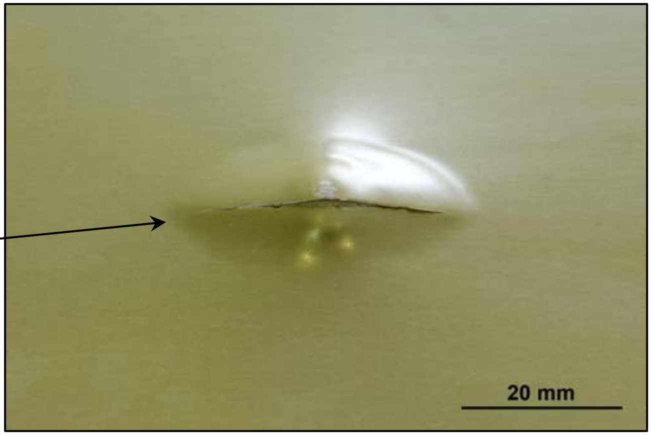
Evaluation of test results / tensile panel test

In order to validate the structural reserves of the GLARE laminate, a severe dent has been impacted in the 0,85mm area of the basic panel, ultimate load has been exceeded, failure at dent.





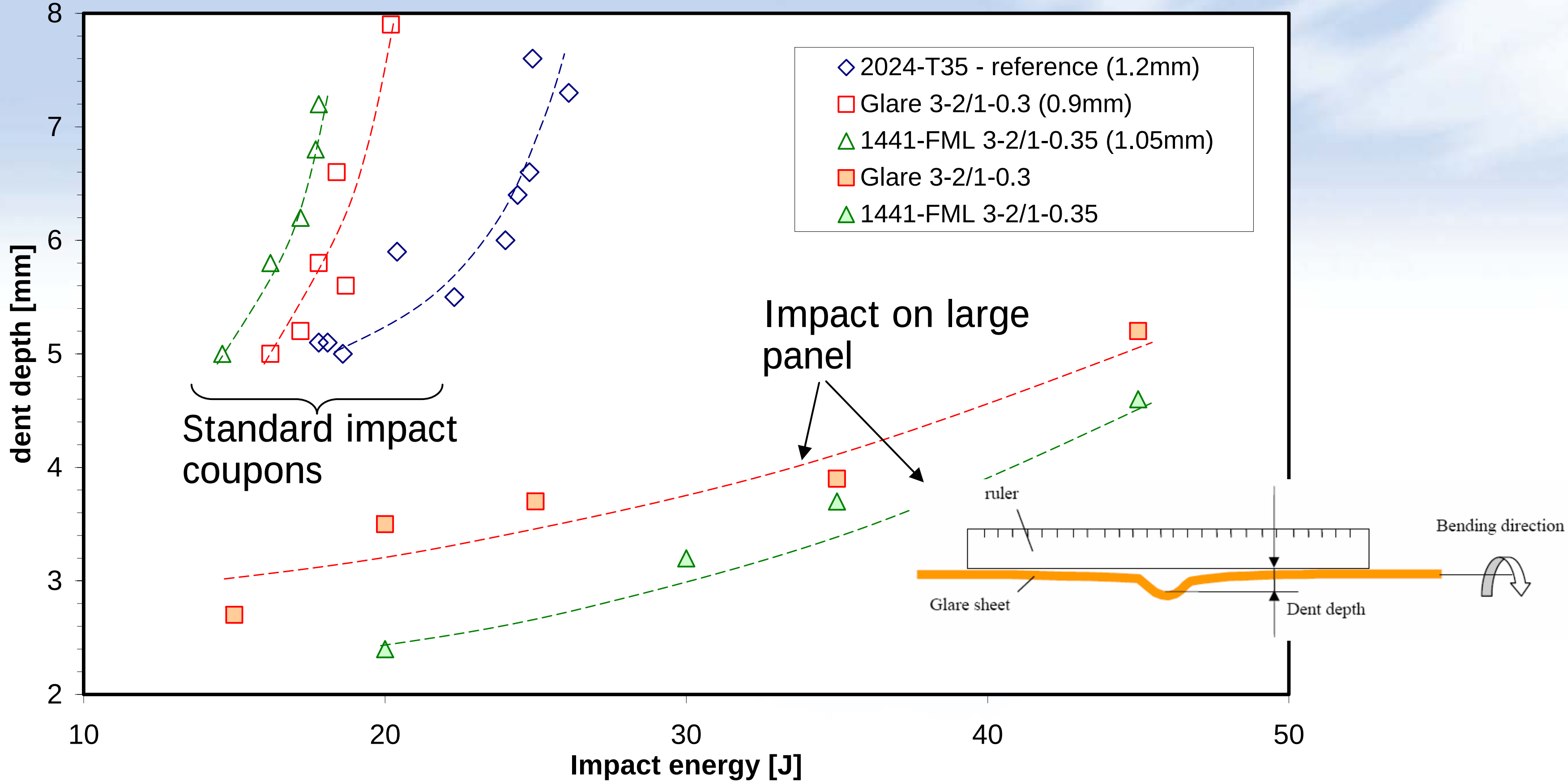
impact side



rear side

Evaluation of Impact Test Results

Caution: Correlation with impact tests on sub-component panel !



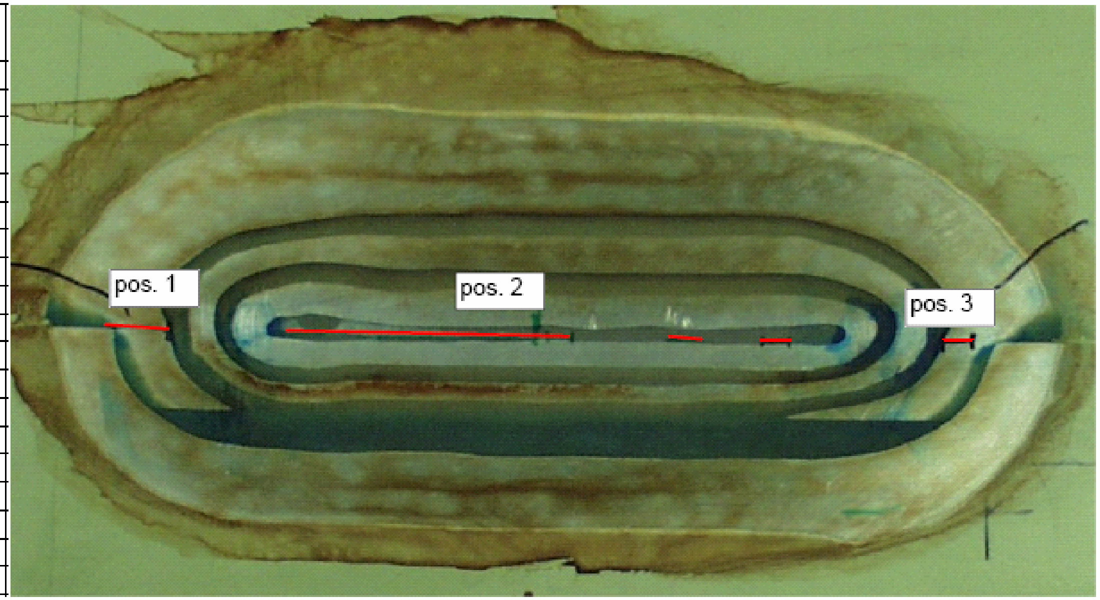
Source: Recent advancements in FML technology for aerospace fuselage and wing applications, Dr. R. Alderliesten, Prof. Dr. R. Benedictus, 10th BIWUS Conference, San Antonio, 2008

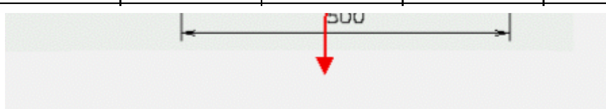
SRM support, i.e. scratches

GLARE3-5/4-.4, scratch & rework at splice location

F_o [N]	F_u [N]	F_m [N]	F_a [N]	σ_o [MPa]	R [-]
100000	5000	52500	47500	89,9	0,05

Load cycles	indication		
	pos. 1 [mm]	pos. 2 [mm]	pos. 3 [mm]
40000	n.f.	n.f.	n.f.
60000	n.f.	n.f.	n.f.
75000	n.f.	n.f.	n.f.
90000	n.f.	n.f.	n.f.
100000	n.f.	n.f.	n.f.
120000	?	?	?
140000	11	sum 60	5





Damage depth: 55%

The FML DT behaviour supports the application of bonded repairs.

FML Certification Tasks for A380

Information flow in GTP environment

GLARE Certification Group (WG3B)

Conducts working sessions with European and US AA's.
Invites specialists for support.
Directs tasks to cluster.
Presents results from cluster.

GTP Working Groups

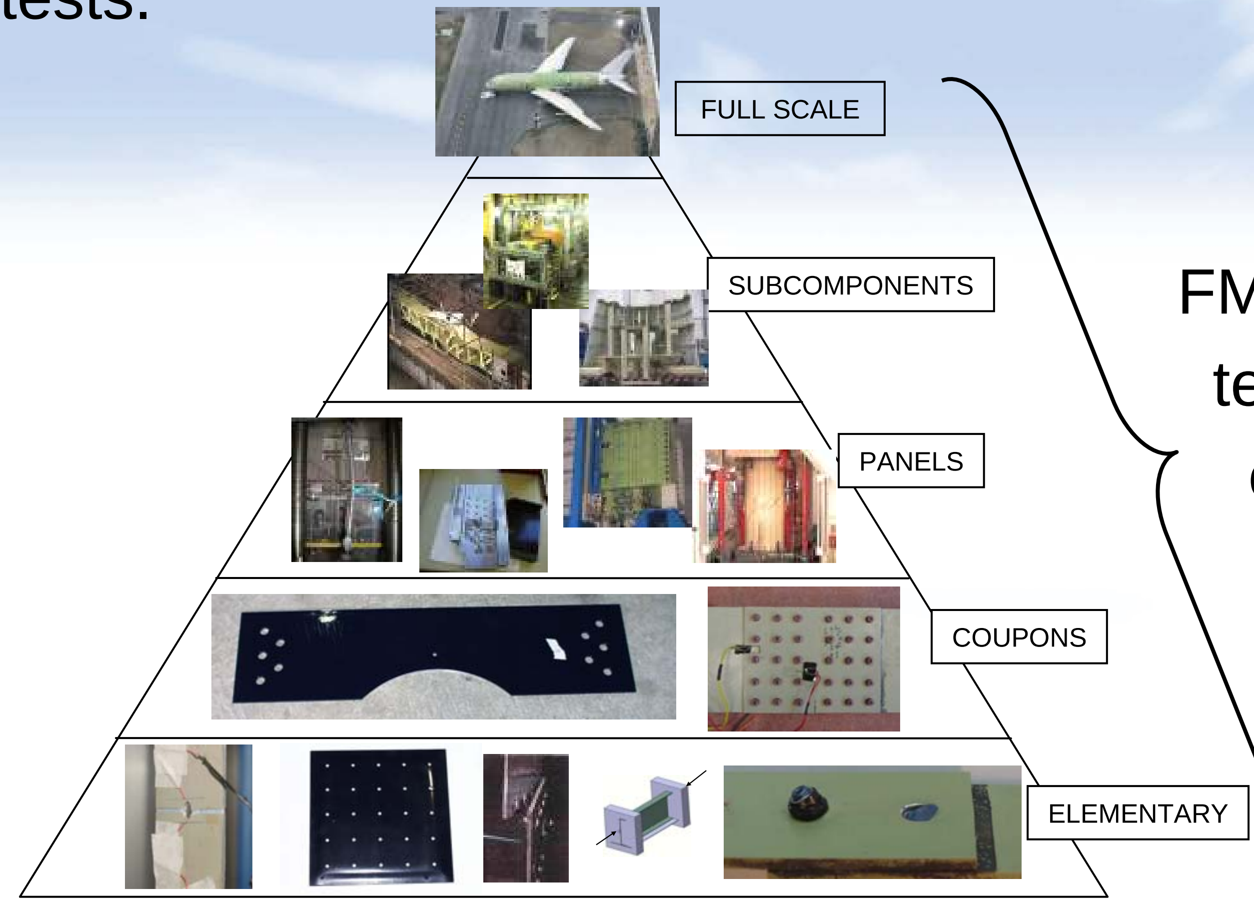
- M&P Qualification
- Material Properties
- Durability
- Methods Static
- Methods F&DT
- Design Guidelines
- Industrial Manufacturing
- NDI
- Repairs & SRM
- Specialties

Cluster conduct technical tasks according to A380-800 milestone planing. Task results required for aircraft sizing and design,strength justification and aircraft certification.

A380 stressmen, designers and manufacturing specialists define tasks for cluster and use cluster know-how for aircraft strength justification and aircraft structural certification.

MoC / Analysis Support by Structural Testing

Compliance demonstration to structure requirements based on analysis and supported by a comprehensive pyramid of tests.



FML structure related tests have been conducted at all levels where feasible

MoC / Analysis Support by Structural Testing

Concerning FML Structures special attention throughout the entire pyramid was paid to:

- potential environmental influences on the FML material.
- potential influence of various temperatures on structure.
- potential interactions at hybrid joints Metal/FML or Composite/FML.

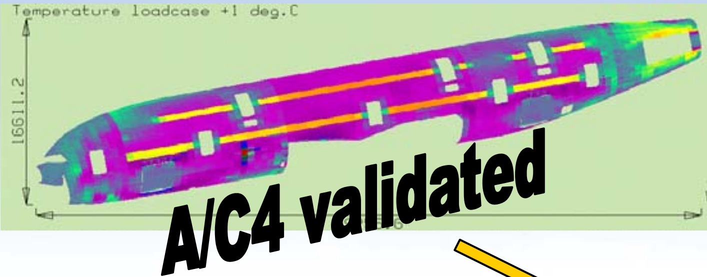
Note for material qualification:

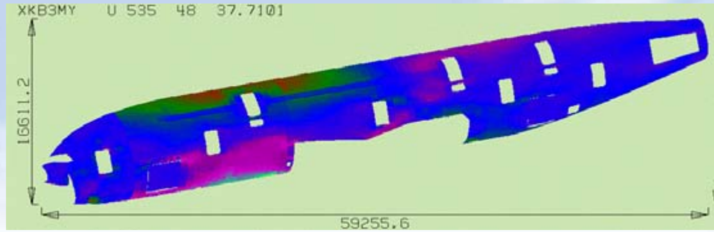
- The entire generation of material properties has been conducted at +80°C, RT, -30°C (for fatigue) and -55°C (for static strength).
- Potential ageing influences are covered by a knock down matrix for the various laminates and strength data.

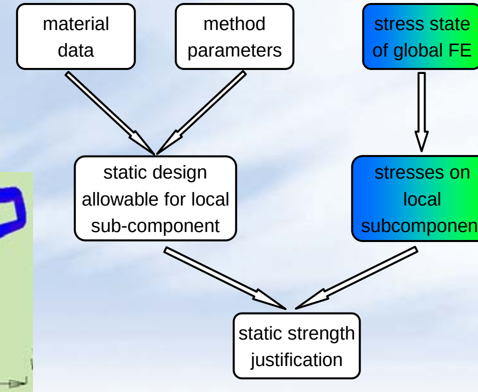
Example Thermal Stress – from Global to Local

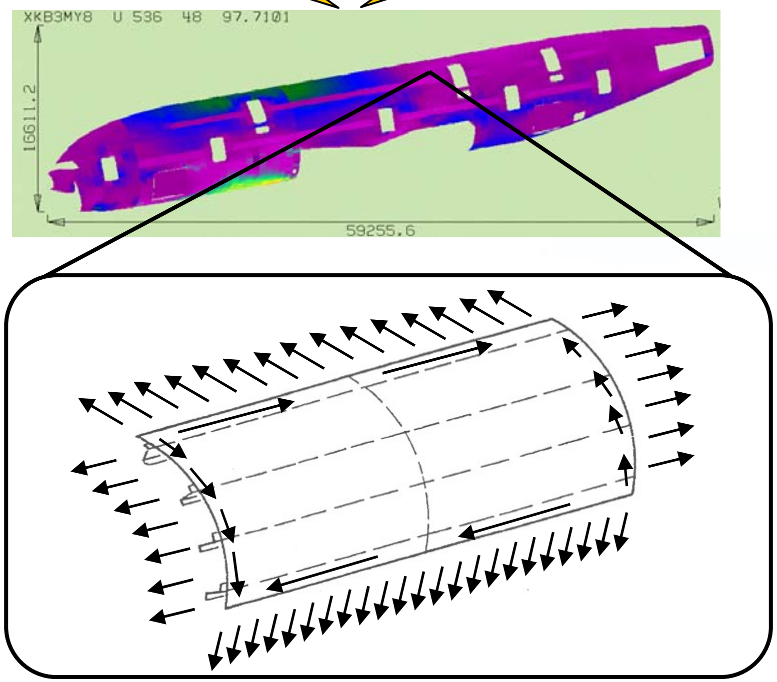
Stresses from temperature load

Stresses from mech-anical load case









Stresses from combined load case

Stresses/loads in local analysis environment

Example Elementary Tests: Rivet Strength

- Because of the significant number of joint variables it has been required to support the calibration of a reliable strength prediction method with >>1000 tests acc. to NASM1312-4 (lap joint shear test).

- Static joint allowable test program variables:
  - GLARE® types: 2,3,4
  - solid rivets and titanium bolts
  - test directions: L; LT; 45°
  - various thicknesses
  - exposure and different temperatures
  - evaluation of test results according to MIL-HBK-5J

- Conservative adaptation of allowables according to MMPDS –01

Example Elementary Tests for Fatigue Support

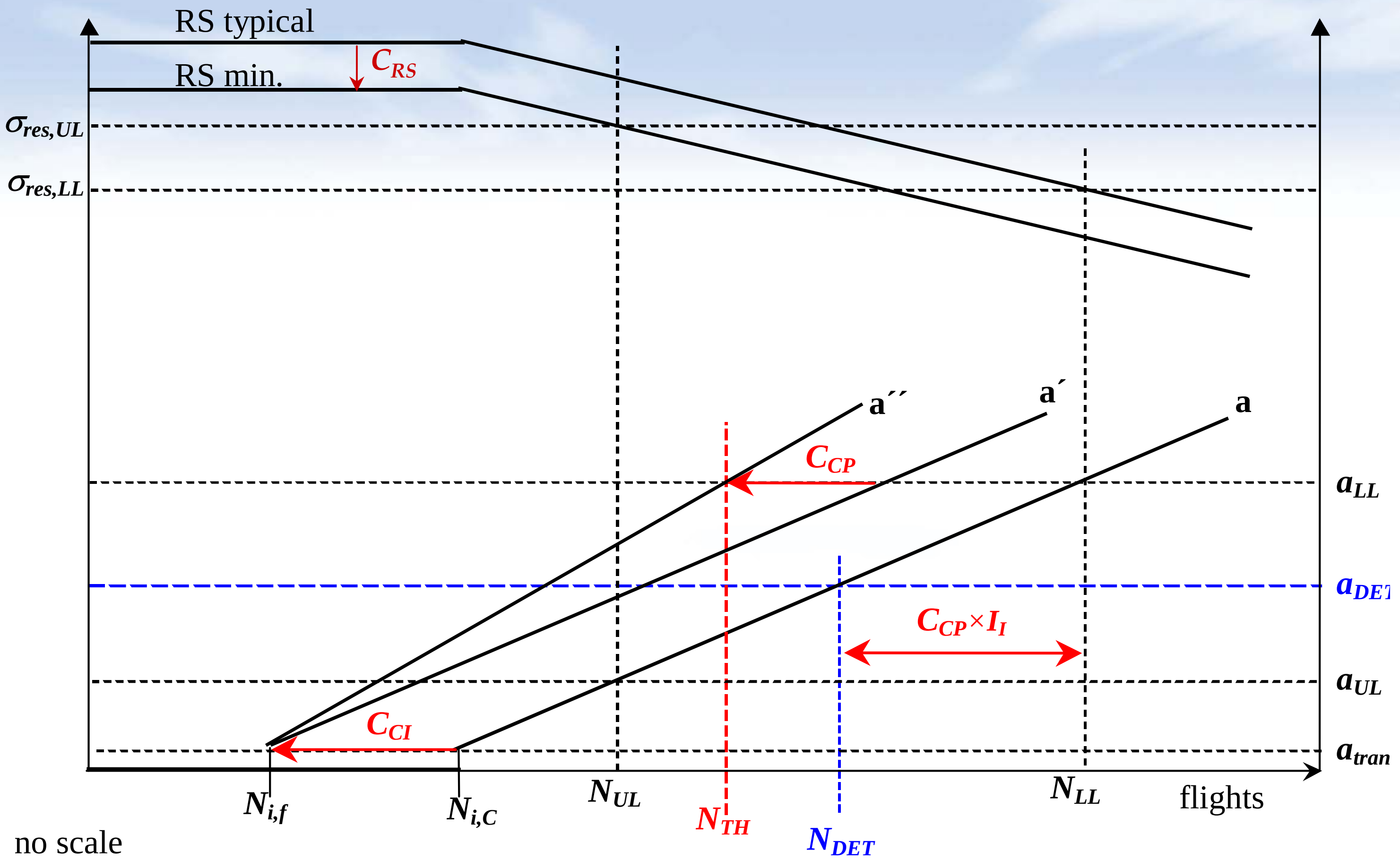
For fatigue, especially fatigue at riveted locations, a design philosophy has been established with special regard to FAR 25.571 and FAR 25.1529.

Crack Initiation (CI), Crack Propagation (CP), Residual Strength (RS) methods justified by test for:

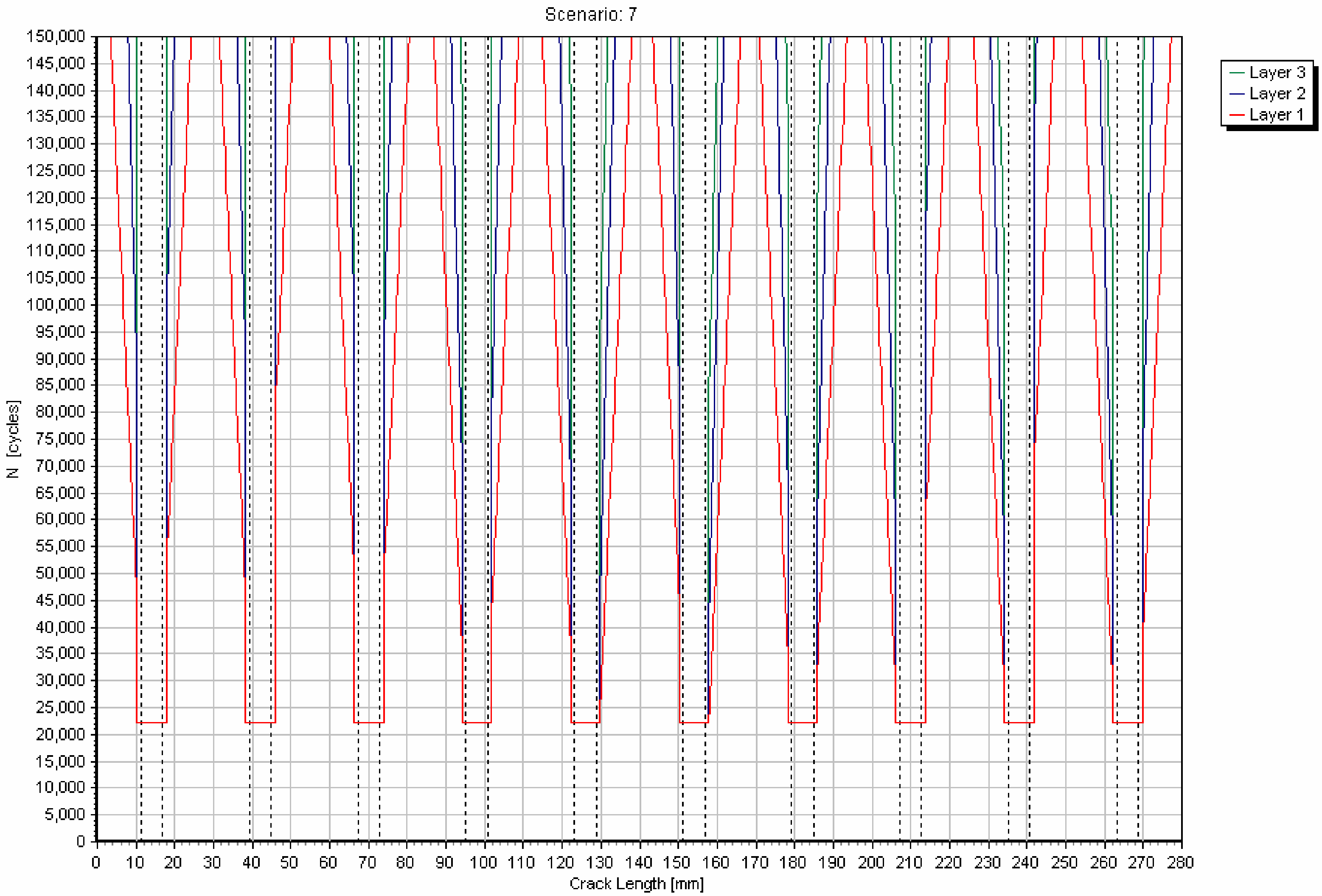
- potential temperature influences, tests at constant temperature (CT) and variable temperature (VT)
- potential environmental influences - tests dry, after accelerated- and outdoor exposure
- scatter
- (check of frequency influence on CI/CP)

F&DT Justification

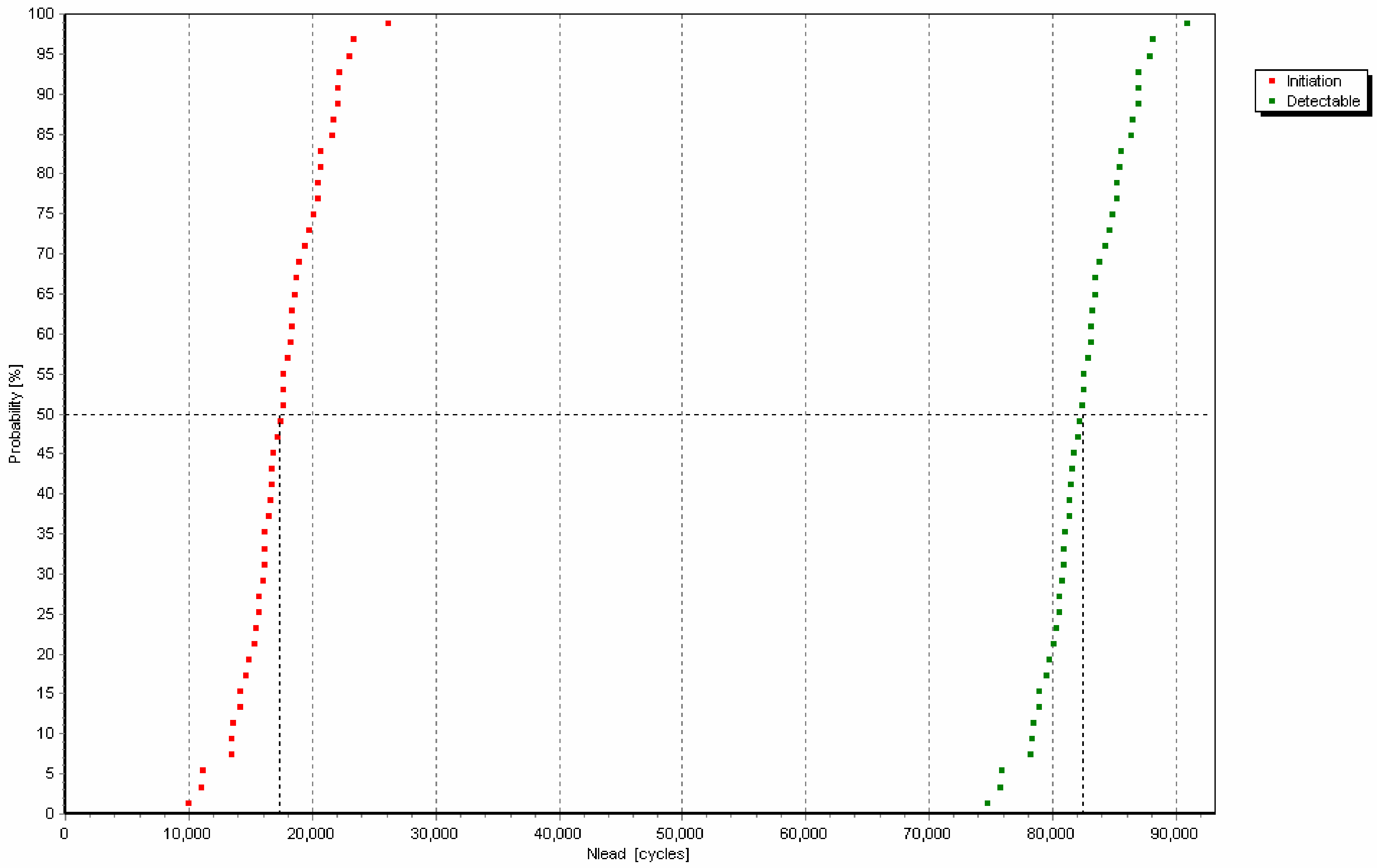
- Example for <u>one crack</u> in frame of riveted joint justification



FML Toolbox Example, Riveted Joint



FML Toolbox Example, Riveted Joint



Example Factors for Fatigue of Riveted Joints

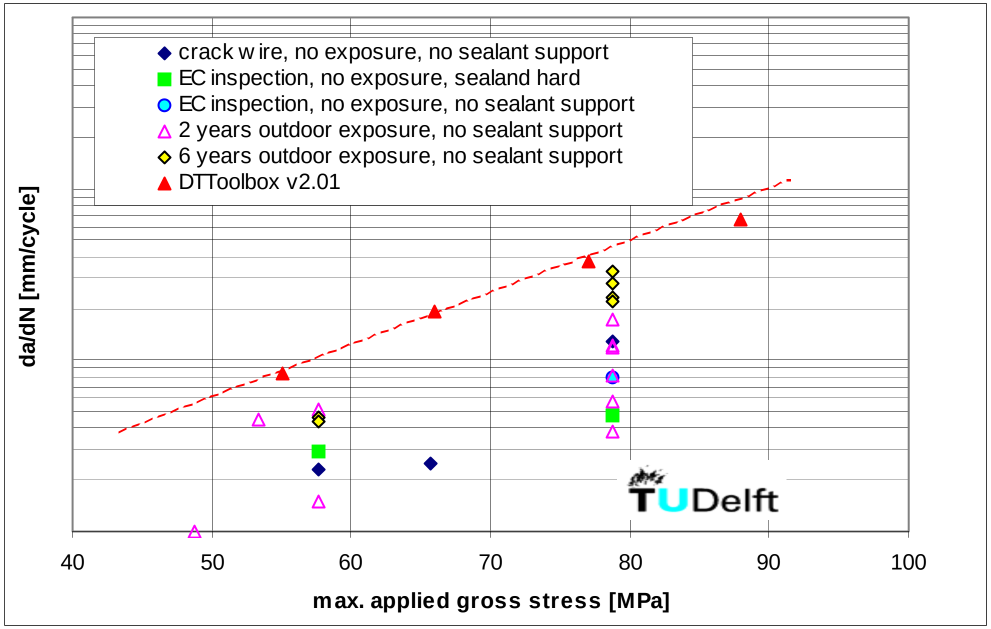
$$C_{CP} = C_{CP,E} \times C_{CP,T}$$

- $C_{CP,T}$ → Temperature factor on CP, VT-tests with riveted joints conducted
- $C_{CP,E}$ → Environmental factor on CP, outdoor exposure tests conducted

Practical problem for crack propagation monitoring in mating surfaces of <u>riveted joints</u>: <u>any</u> measurement procedure influences test result

→ significant scatter.

Airbus / TU Delft F&DT tool conservative & validated.



Example Coupon Test: Door Corner

Consider that 10 door cutouts are located in the GLARE® sections and that cut-outs in FML provide significant weight saving.

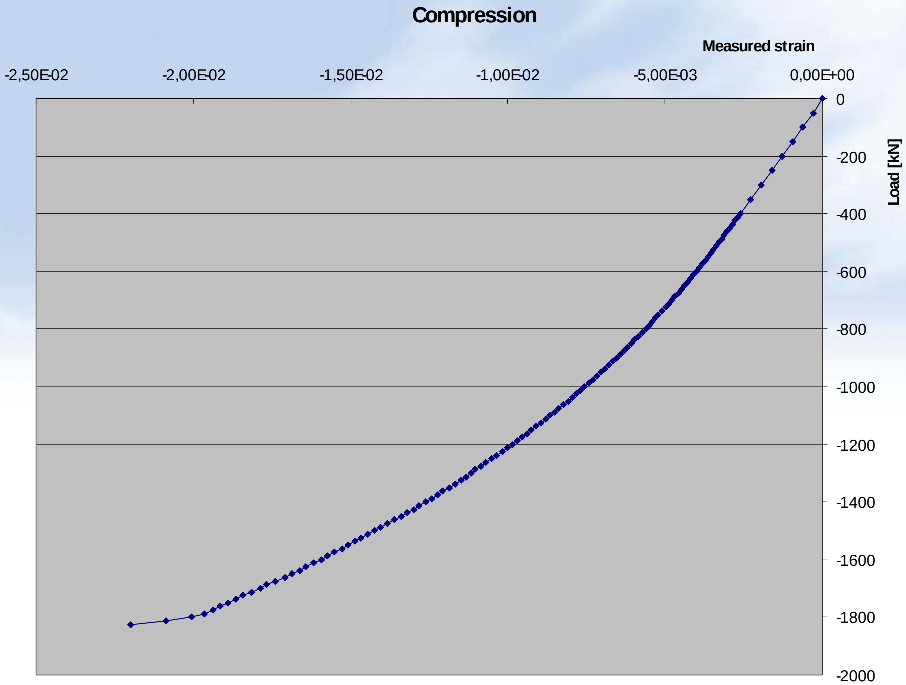
- Tensile test set up

- Compression test set up (with anti buckling guide)

- 15 tests performed:
  - 6 tensile tests
  - 6 compression tests
  - 3 compression tests at elevated temperatures

- Tested lay-ups taken from A380 MSN1 and MSN7 configurations
- Selection criteria:
  - Lowest RFs, thickness range, stiffness range

Example Coupon Test: Door Corner

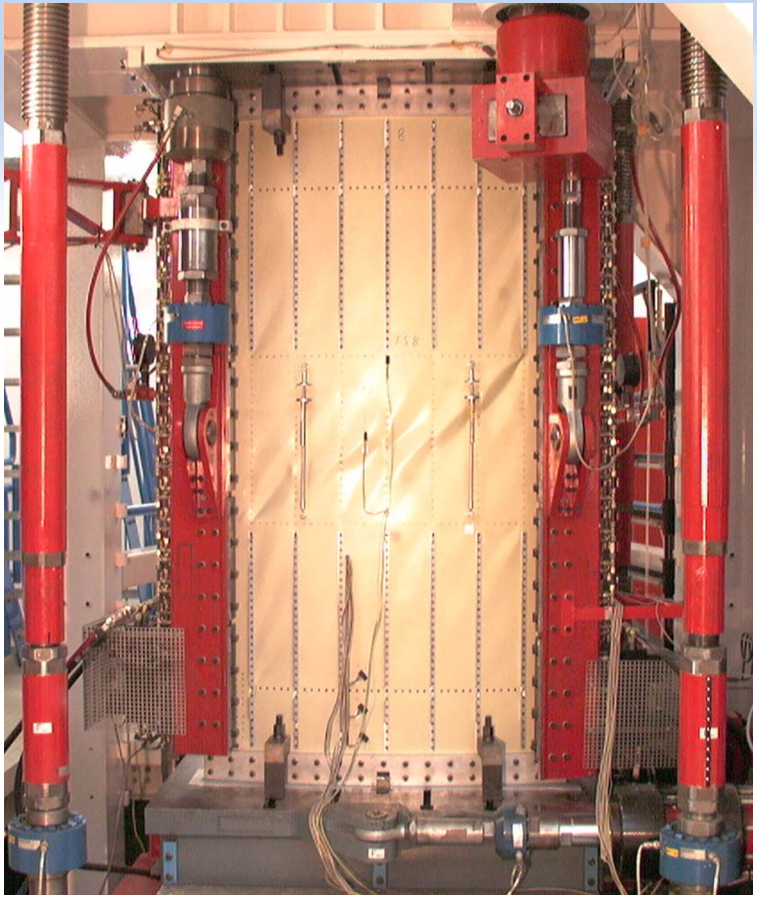


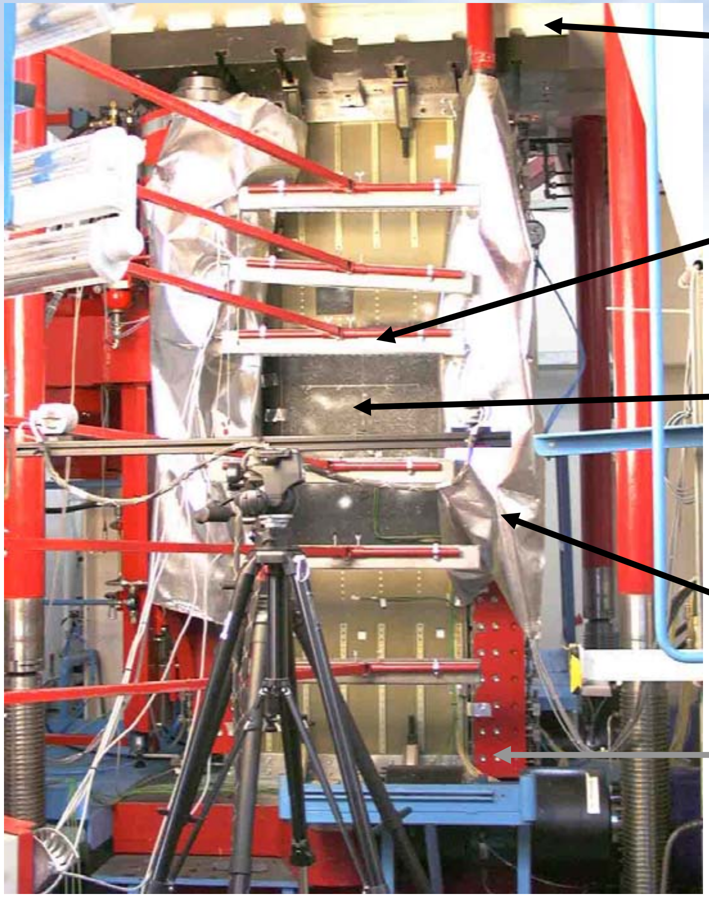
Load reached at failure corresponds to:

A340-200 at MTOW hanging on 440mm wide GLARE door corner specimen

Example Panel Tests: Comp./Shear Buckling

- Tests to support analysis have been performed at RT, 55°C or 80°C, depending on the relevant load case (total: 18 specimen, incl. AD)

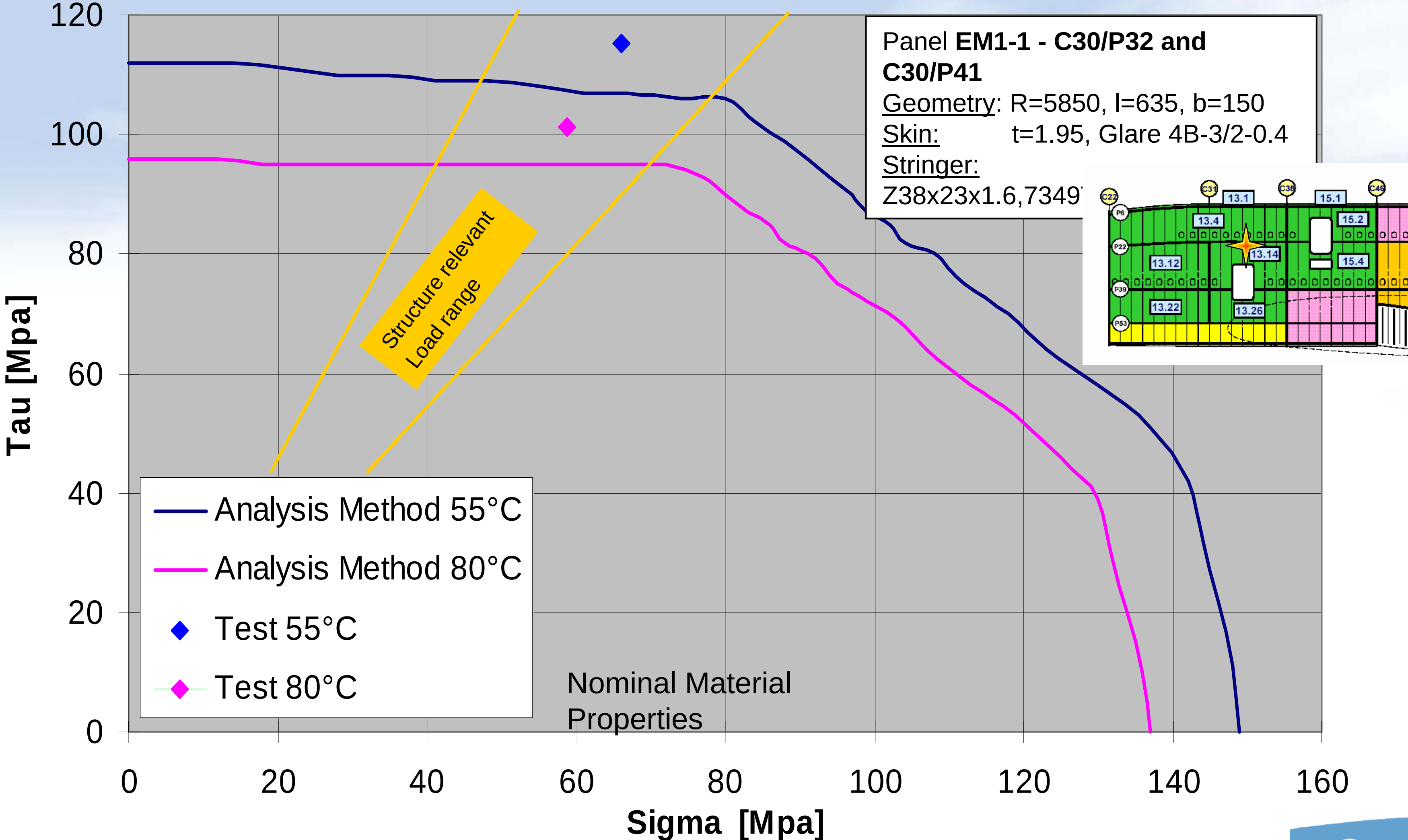




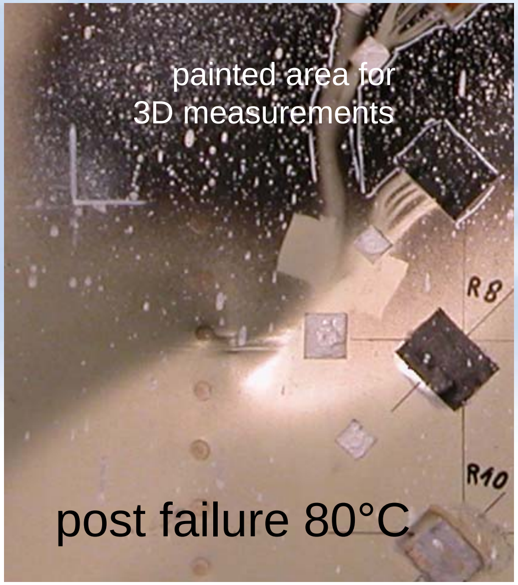
AIRBUS

Example Panel Tests: Comp./Shear Buckling

GLARE4B Shell at position C30/P32 and C30/P41 (EM1-1)
Comparison of test results to analysis method results



Example Panel Tests: Comp./Shear Buckling



- Panel failure mode in any case: stringer failure
- Secondary failure in case of riveted stringer: interrivet buckling
- Analysis method takes interrivet buckling into account
- Temperature influence on static strength allowables is taken into account by analysis method which is validated by test results

Top of the Pyramid: Full Scale Tests

Purpose of the full-scale A380 static test (ES):

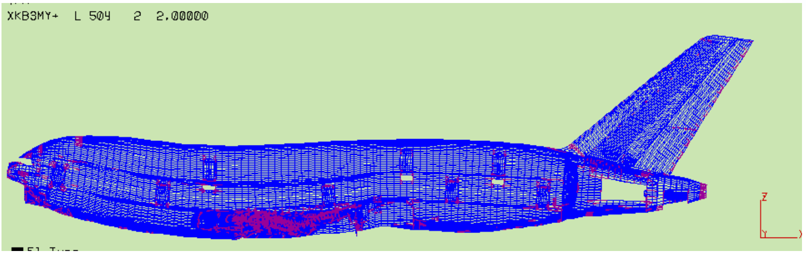
- Support static analysis (global equilibrium, internal loads distribution, validation of FEM and analysis methods used for compliance demonstration).
- Contribute to proof of structure demonstration as requested by FAR/JAR 25.307 Proof of structure, SC C-14, JAR 25.651 Proof of strength.
- Support residual strength analysis under limit loads for the failure conditions selected to comply with FAR/JAR 25.571 (b) Damage tolerance and fatigue evaluation of the structure.
- Demonstrate functioning of flight controls under deflected shape of structure as requested by FAR/JAR 25-683 Operation tests.
- Show Compliance with FAR/JAR 25.843 (a) Test for pressurised cabins and FAR/JAR 25.965 (a) Fuel tank tests.
- Confirm strength margins of the specimen up to failure.
(Internal Airbus objective)

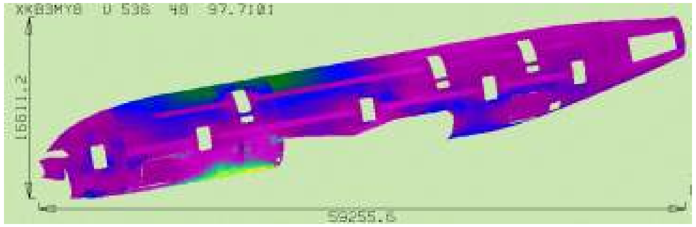
AIRBUS

Full Scale Static Test (ES)

Achieved load cases (fuselage relevant)	
Date	**Load case / applied load level**
9. Jun. 05	UL§11: BLG and WLG turning cases
27. Jun. 05	UL§12: NLG dynamic braking and max torsion between HTTP pivots
8. Jul. 05	UL§18: BLG braking (16 braked wheels), forward NLG towing
28. Jul. 05	UL§14: max shear on HTTP
22. Aug. 05	UL§16: rear fuselage max lateral bending with internal pressure
5. Sep. 05	UL§15: rear fuselage max lateral bending without internal pressure
16. Sep. 05	UL§10: BLG turning
21. Sep. 05	UL§19: NLG rearward towing case
10. Okt. 05	UL§9: fuselage max vertical bending without pressure
30. Nov. 05	UL§6: fuselage max vertical bending with pressure
16. Dez. 05	UL§4: 2 delta p case
31. Jan. 07	Margin research: fuselage max. vertical bending with internal pressure, 1.8LL achieved: max. test rig capability

analysis / predictions





Test goals achieved without any damage in GLARE® sections.

Full Scale Fatigue Test (EF)

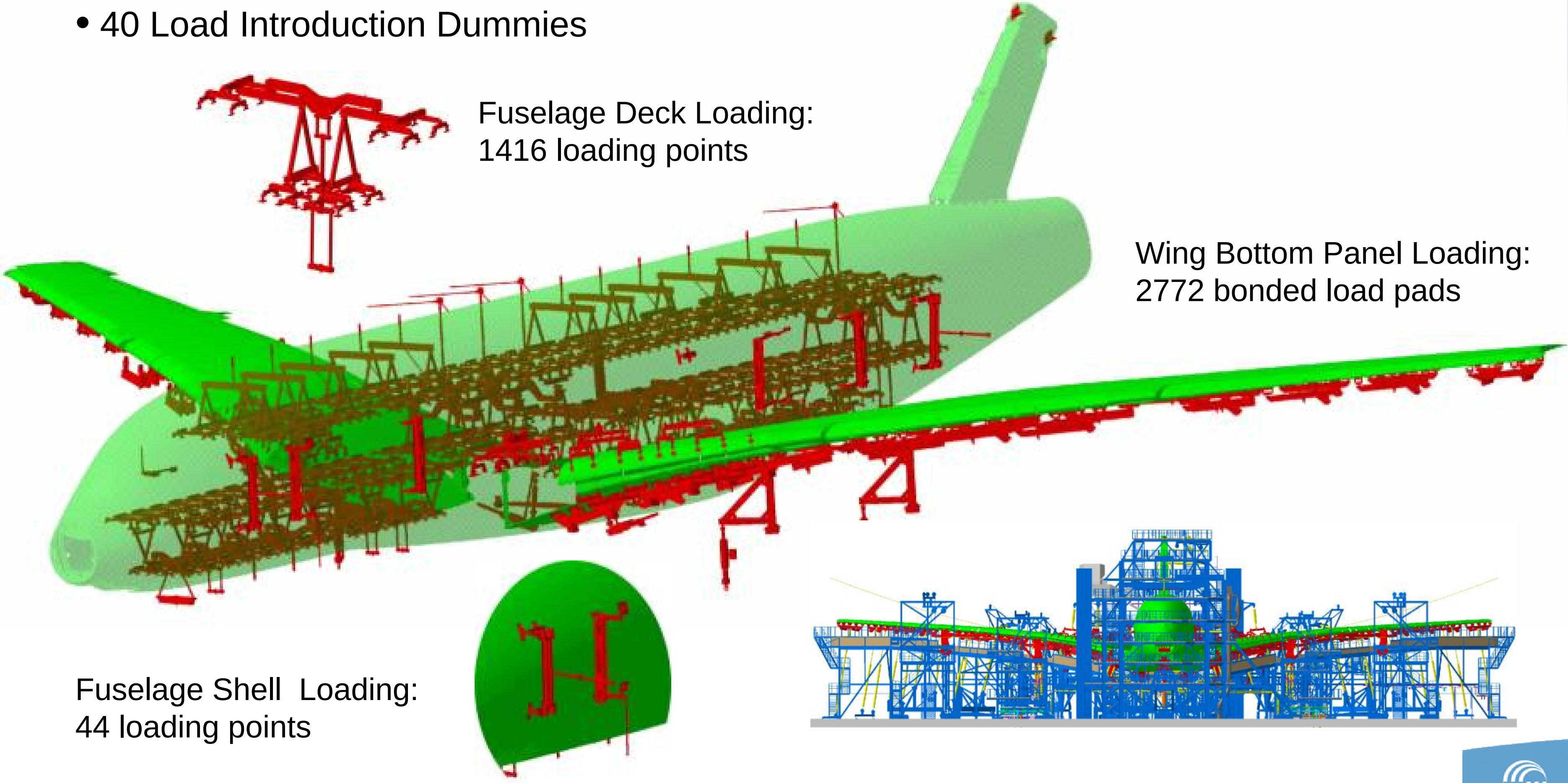
Test Plan

Test Goal (N = 2.5 * D.S.G.)	47.500	simulated flights
Fatigue Load Application (flight-by-flight, mission mix)		
Mechanical Load Introduction with 182 hydraulic actuators		
Fuselage Fatigue Pressure (Δp)	605	mbar
Load Enhancement	10%	
Repeated inspection intervals	3.800	simulated flights
Completed at TC	20.494	simulated flights
Test Start	Sept 2005	

Full Scale Fatigue Test (EF)

Mechanical Load Introduction

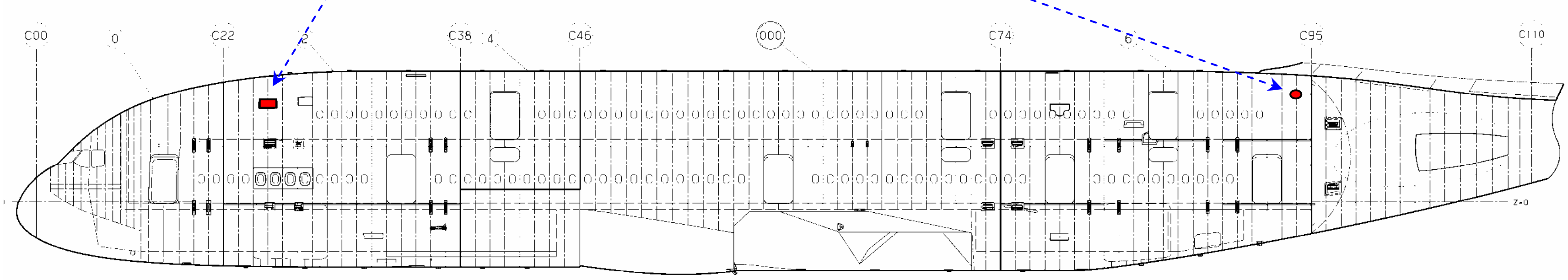
- 182 Hydraulic Actuators
- 110 loading tree systems
- 40 Load Introduction Dummies



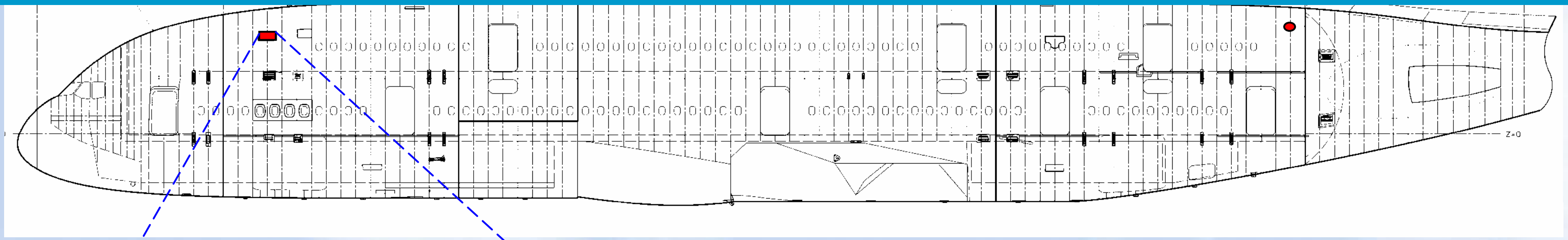
Full Scale Fatigue Test (EF)

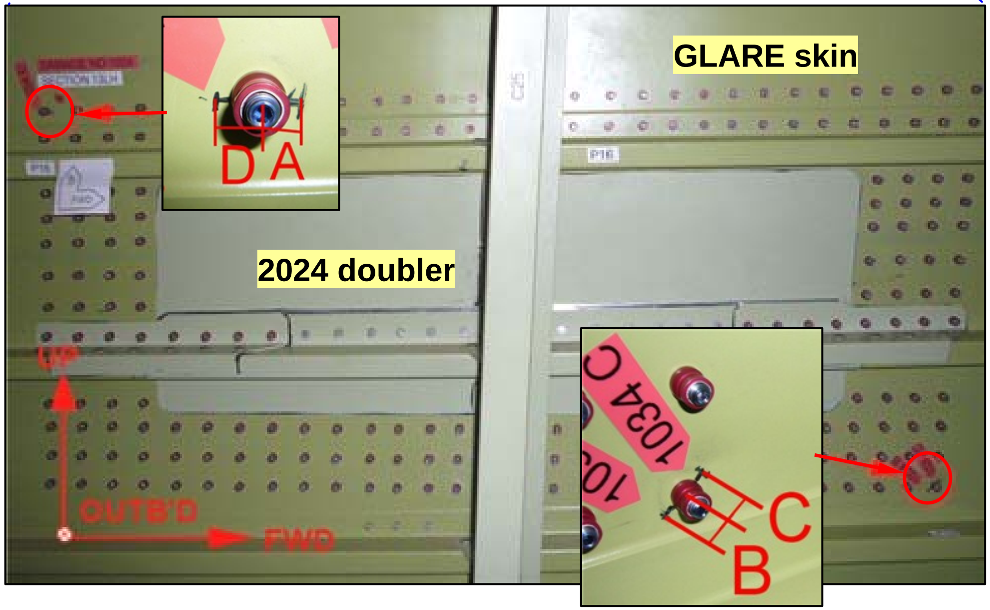
Status for GLARE® sections in August 2008

- 34700 flights achieved (with load factor 1.1)
- 120 fatigue damages detected in sections 13 and 18, 2 damage locations detected in GLARE® skin

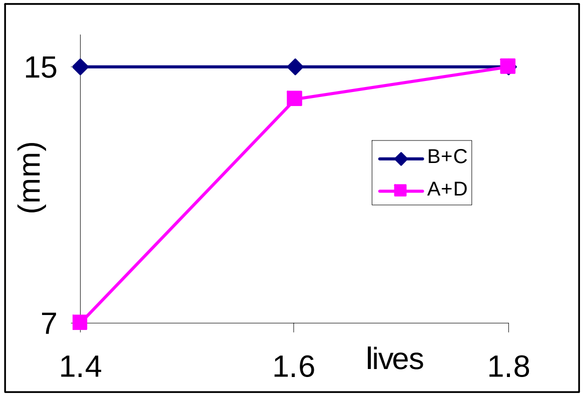


EF, Damages at Riveted Doubler

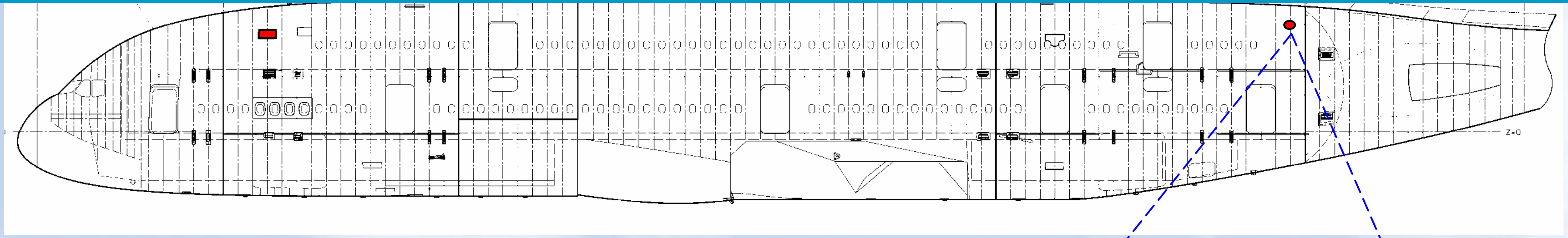




- Cracks detected after 1.4 DSG
- Cracks stopped propagation after 1.8 DSG

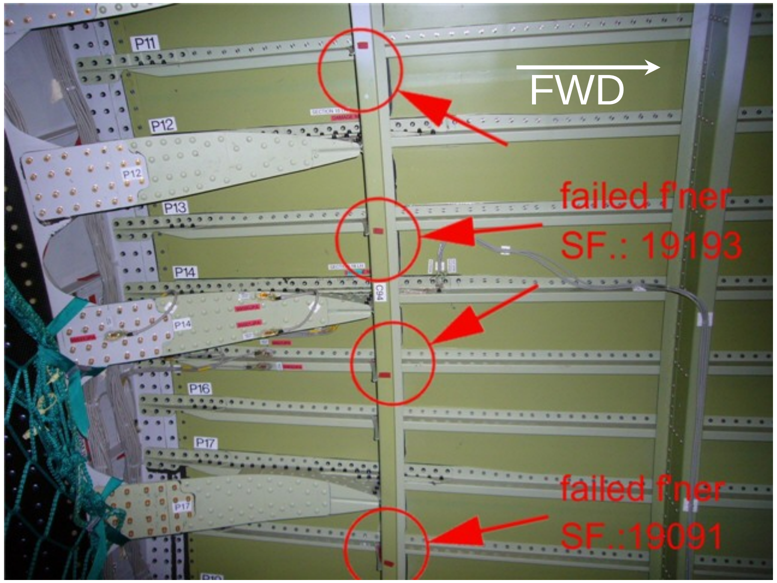


EF, Damages at Stiffness Step



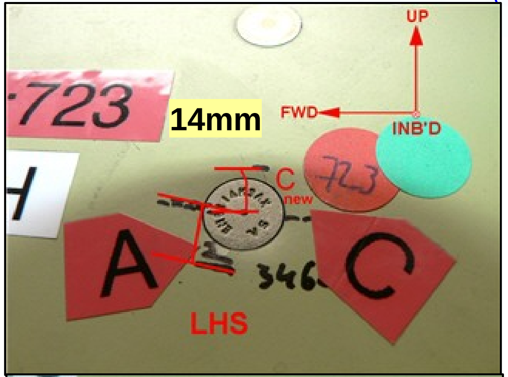
Significant thickness- and stiffness steps in front of rear pressure bulkhead

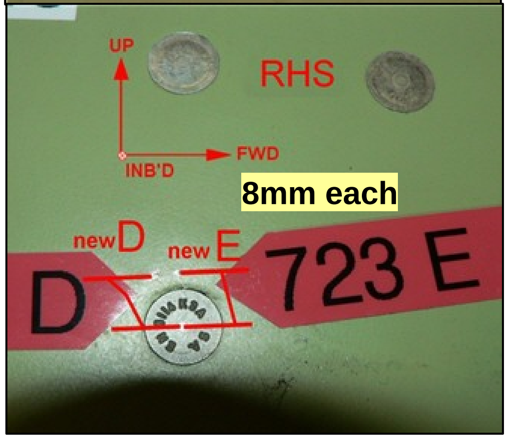
(RPB & section 19 made of CFRP)



view from inside

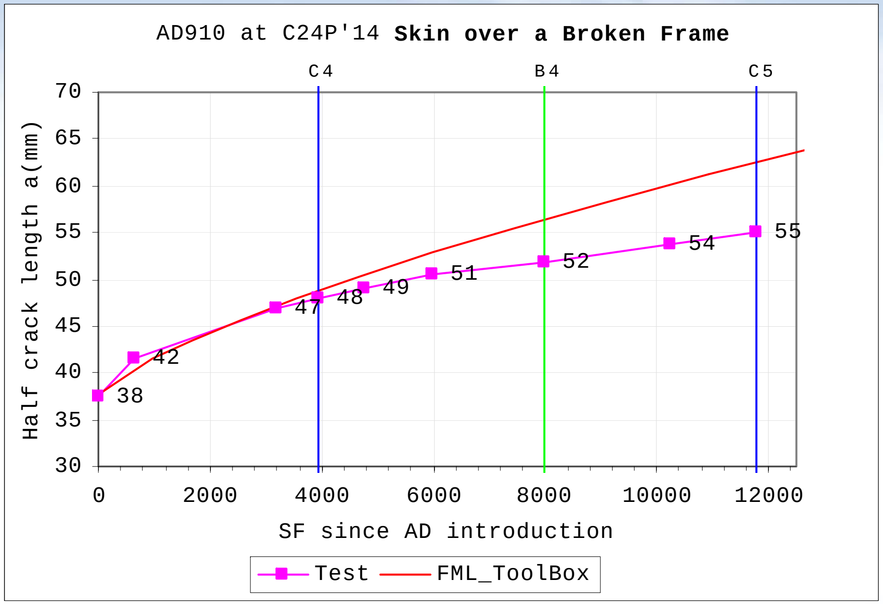
Detected at 1.75 DSG

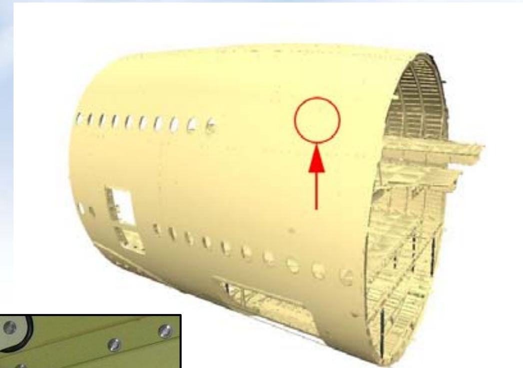


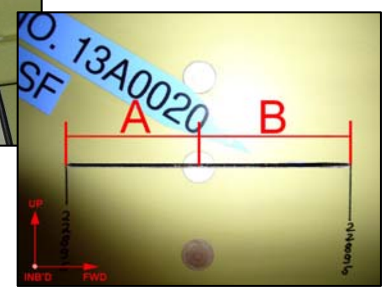


Full Scale Test Fatigue (EF)

Artificial Dam. No. 910	Title Saw cut in glare skin over a broken frame	SF at introduction 22895	Location C24 P´14 (S13 RH)







Summary and Conclusions

✓Since 1998, GLARE® material has been transferred from laboratory status into GLARE® structures of full airworthiness capability.

✓FML structure certification has been achieved under consideration of all hybrid specific aspects without a Special Condition required.

✓The weight saving targets demanded from the technology have been achieved.

✓On full scale test level no static failure and a very low amount of fatigue cracks detected. Superior damage tolerance behaviour.

✓No fatigue SSI in Maintenance Handbook for GLARE® skins.

- Development of Structural Repair Manual ongoing.

AIRBUS

AN EADS COMPANY