Presented by

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Fatigue and Damage Tolerance, Airbus

Hybrid structure solution for the A400M wing attachment frames

From concept study to structural justification

Contents

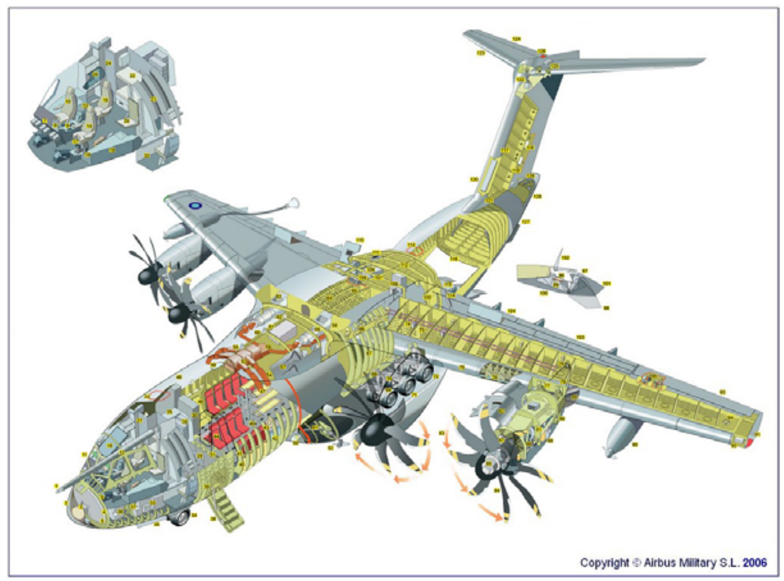
A400M – General

A400M General Configuration

Typical for A400M and deviating from common Airbus A/C:

- Turboprop engines
- High wing
- T-tail
- MLG configuration
- Cargo Ramp & Door
- Militairy Systems:

    Cargo Handling system, AAR



A400M – General

- Comparison to other militairy airlifters

	A400M	***C160 Transall***	***C130J Hercules***
Payload	37 t	16 t	22 t
MTOW	130 t	50 t	70 t
Range	6 500 km	1 800 km	4 500 km

A400M – General

- Comparison to „other airlifters“

	A400M	*C160 Transall*	*C130J Hercules*	***A330-200F***
Payload	37 t	16 t	22 t	69 t
MTOW	130 t	50 t	70 t	228 t
Range	6 500 km	1 800 km	4 500 km	7 400 km

length [m]	45		59
wingspan [m]	42		60
height [m]	15		17

A400M – General

- **Strategic airlift mission capability:**
  - Long range (to allow deployment flexibility),
  - High cruise speed,
  - Large cargo hold dimension and volume combined with.
  - High payload (to match the whole range of modern military vehicles, helicopters, containers and heavy engineering equipment),
  - Flexible cargo handling system (to allow rapid internal configuration changes for different types of loads) and the possibility of.
  - In-flight refueling;
- **Tactical airlift mission capability:**
  - Low speed characteristics (for airdrop and tactical flight).
  - Short soft field performance,
  - Autonomous ground operation, aerial delivery of paratroops and cargo loads and.
  - High survivability (damage-tolerant design of airframe and systems);
- **Aerial tanker mission capability:**
  - 2 or 3 point refueling system and.
  - Wide altitude/speed flight envelope (allowing refueling of both helicopters and fighter aircrafts).

A400M – General

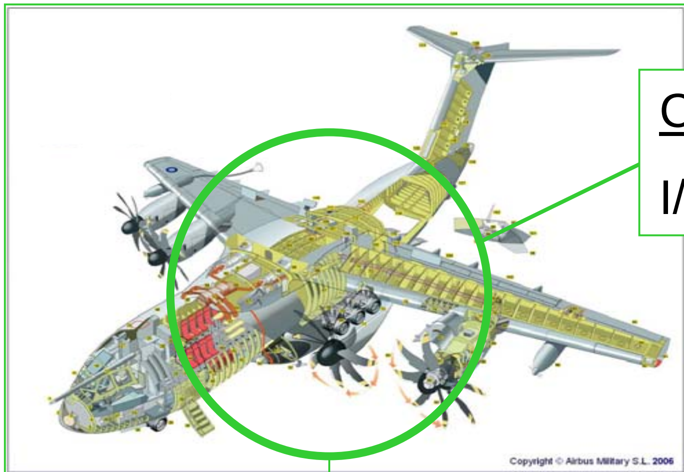
- Aircraft Target Operational Usage

Mission Profile	Average Flight Time (h) Hi / Lo	Flight Cycles	Pressure Cycles	Flight Hours
Long Logistic Mission	7,9 / -	2325	2325	18368 / -
Short Logistic Mission	1,25 / -	4425	4425	5531 / -
Tactical Mission	0,59 / 1,45	2000	6000	4080 / 2890
Training Mission	/ 1,69	1250	0	2110 / 2110
Total / Average	3	10000	12750	30089 / 5000

- 67% logistic - 20% tactical - 12% crew training
- Tactical mission Low Level Flight
  -> 1½ hr at 50m altitude

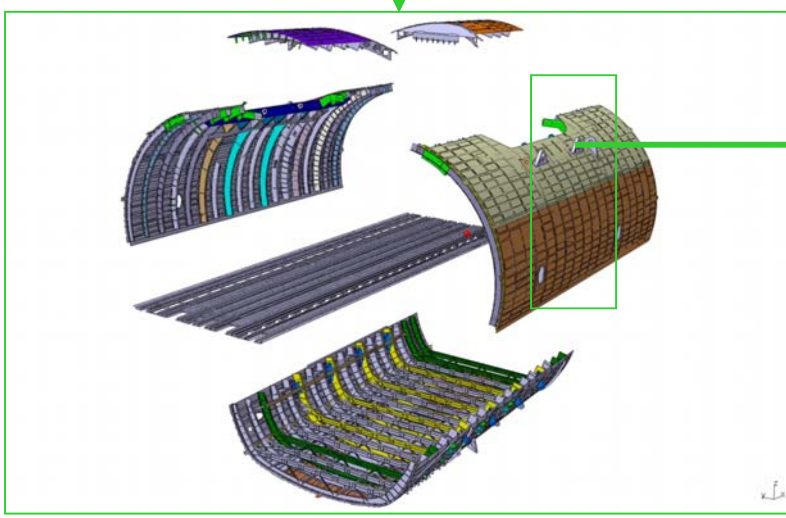
- Design Life: 10 000 FC / 30 000 FH / 30 years
- Inspection Threshold: 5 000 FC / 15 000 FH
- Inspection Interval: 2 500 FC / 7 500 FH

Wing attachment frames

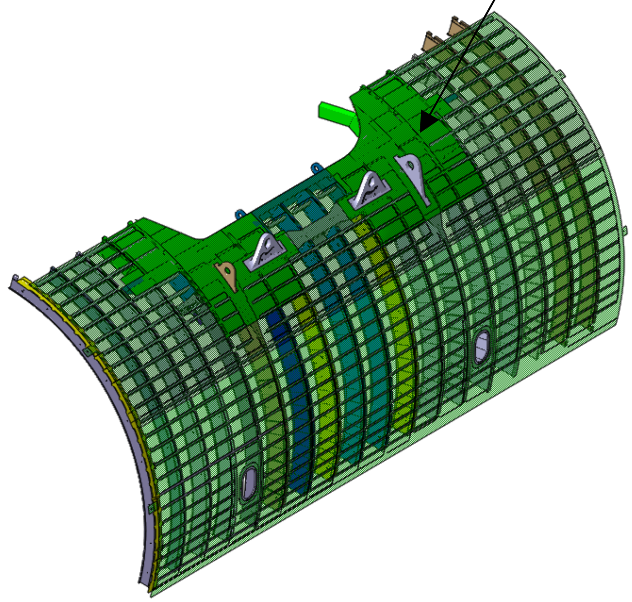


<u>Center Fuselage</u>:

I/F with wing and MLG

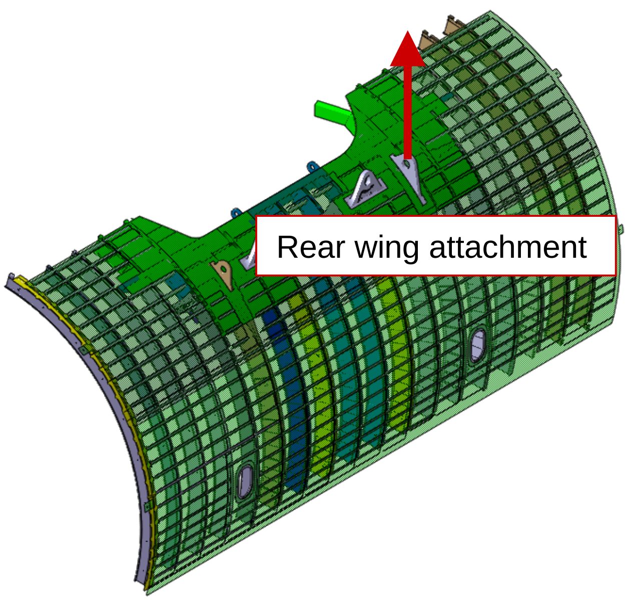


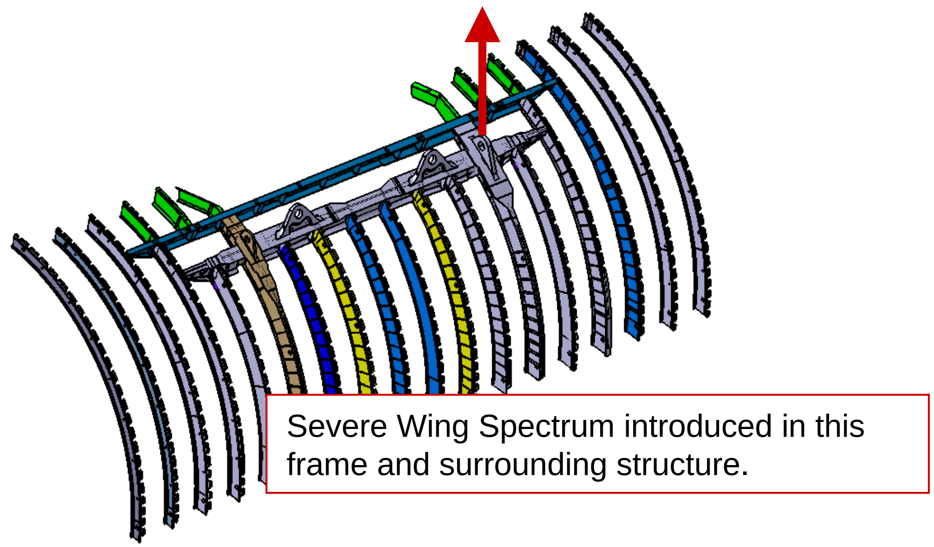
Wing attachment frames



Problem description

- Problem description:





- Investigation showed that main frame under rear wing attachment is SLP structure instead of MLP.
- Hence, frame had to be inspected on small cracks, instead of failed part. Design criterium had to be stricter, resulting in low allowable DT-stresses to ensure slow crack growth
- Design had to be improved => severe weight impact when concept of integral frame would have been kept.

Problem description

- Wing spectrum caused in frame inner flange below rear wing attachment:
  1. High Fatigue Stresses in inner flange
  2. High tensional static loads
- Resulting in:
  1. To meet inspection interval detecable crack length 1-2 mm
     – Risk due to low probability of detection
  2. Critical crack length is extremely small (enhanced by brittle alloy)

- Risk on Multiple Element Damage (MED) due to similar high stress level in neighbouring frames

Concept study

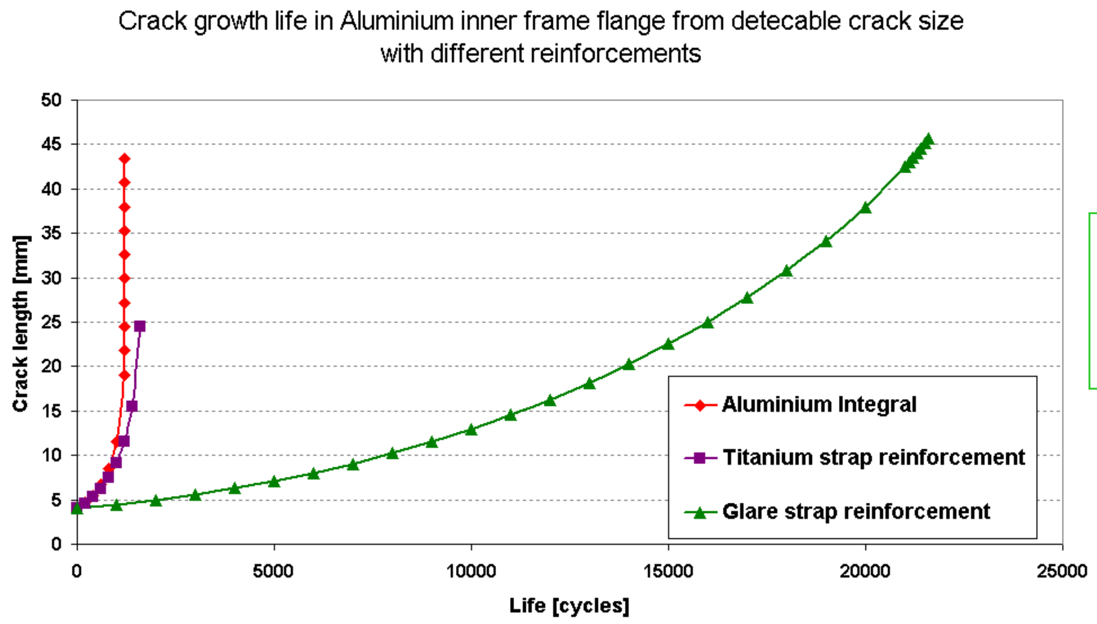
- Study was carried out on improvement of the main frame looking at:
  - Safety (Inspectibility, DT-behaviour)
  - Weight
  - Cost

- 3 options were investigated:
  1. Thickening of the aluminium inner flange to reach an acceptable stress level.
  2. Riveted Titanium strap attached to the inner flange.
  3. FML strap adhesively bonded to the inner flange.

Concept study

- Coupon test program performed to investigate crack growth behaviour of FML reinforced inner flange.
- The test results showed a constant crack growth rate for a wide range of crack lengths. This is due to the „crack bridging“ effect.

  With metal isotropic material an increasing crack growth rate will be found for longer cracks.

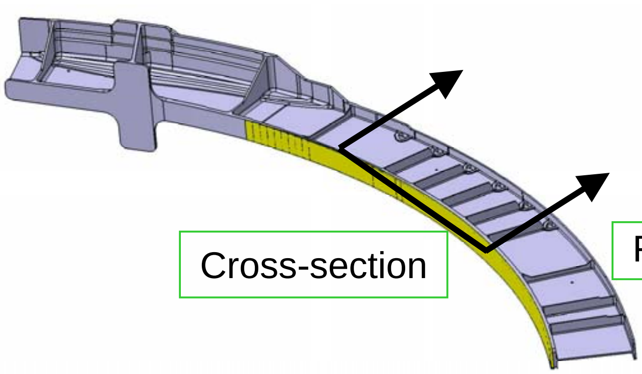


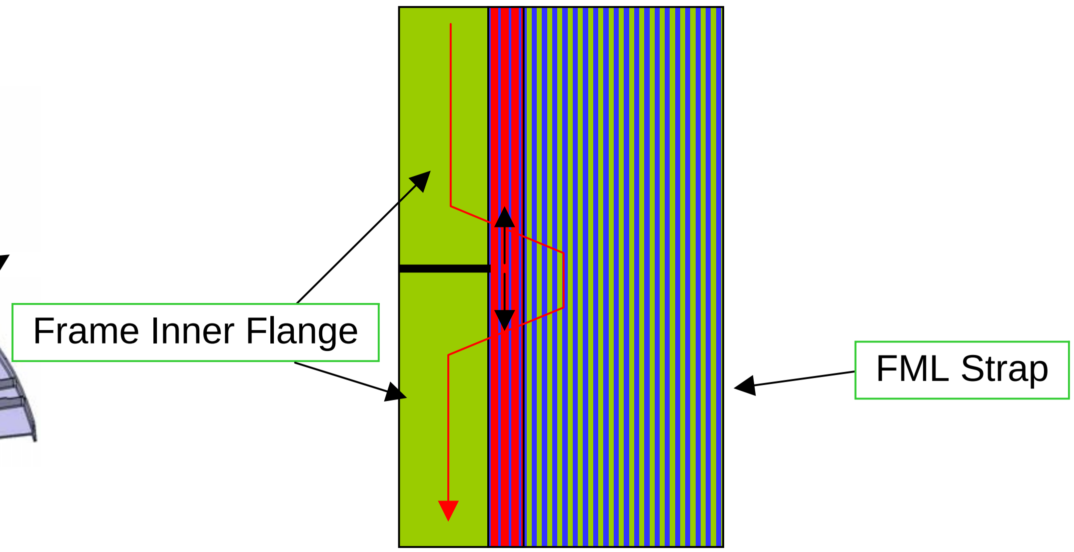
At same stress level only FML strap can meet the inspection requirement.

Concept study - FML strap

Concept of FML Reinforcement:

- The aim of the bonded FML-strap is to control both the fatigue crack growth behaviour of the frame and the residual strength capability of the hybrid design.
- The FML strap will retard or stop any potential fatigue crack in the frame.





„Crack Bridging“ effect analogue to GLARE

Concept study - Conclusions

Results of concept study:

- FML reinforcement was favourised:
  - Lowest weight
  - Meeting best all DT requirements. Static requirements were fulfilled as well.
  - Relatively low costs per lost kg per A/C.
- Titanium reinforcement:
  - Heavier compared to FML strap solution
  - Could not satisfy with meeting all DT-requirements
- Integral frame:
  - Could not meet DT requirements with acceptable weight.

Concept study - Conclusions

Option	Weight opportunity	Effort to detect cracks
Integral Aluminium	-	-
Titanium Strap	+	--
FML Strap	++	++

Concept study - Conclusions

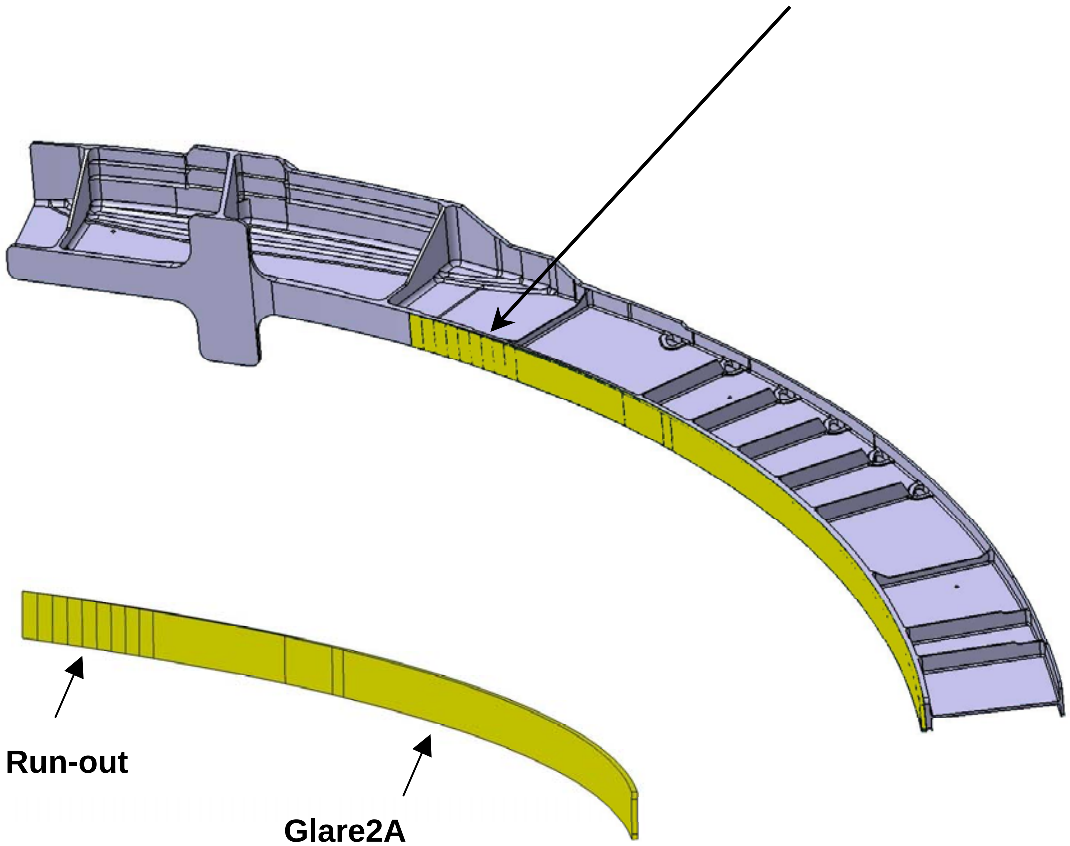
- In general the FML reinforcement bonded application is a solution for structural parts that are highly loaded under tension.

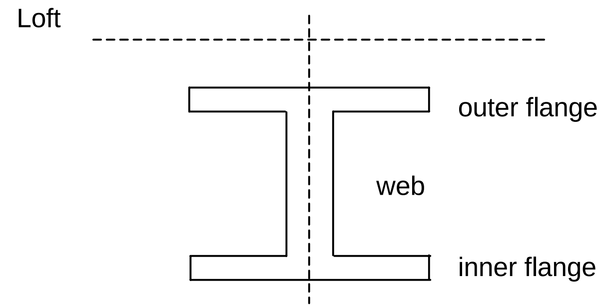
  Without FML-reinforcement this structural part would be a SLP or a structure with poor damage containment feature at the most.

- Bonded FML-reinforcement is normally optimal for SLP frames, regarding:
  1. Safety -> larger critical crack length, reducing risk of MED.
  2. Weight -> Higher Allowable Stresses for DT
  3. Cost -> Less inspection with lower inspection level

Implementation - Design & Material

- The FML-Strap is bonded to the inner frame flange in an area which is fatigue design-driven.
- The upper end run-out is not a fatigue-driven location.





•Thickness ratio inner flange to FML strap is 1:2

•Glass-Fibres are unidirectional in hoop direction (GLARE2A)

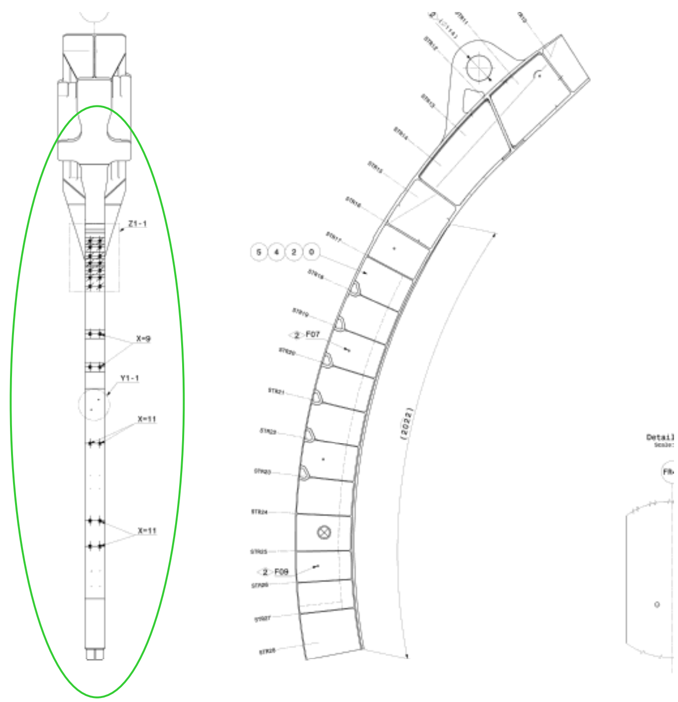
•Strap Lay-up according to A380 Principles

AIRBUS

Implementation - Design & Material

- Anti-peeling fastener
  - Not load transfering rivet
  - Reducing net-section
  - Introduces fatigue sensible locations
  - Request based on CS23.573(a) (although applicable to smaller aircraft and subparagraphe for composite material)

Bonded strap with anti-peeling fasteners



Implementation - Design & Material

CS23.573 (a) (5)

„(5) For any bonded joint, the failure of which would result in catastrophic loss of the aeroplane, the limit load capacity must be substantiated by one of the following methods:-

(i) The maximum disbonds of each bonded joint consistent with the capability to withstand the loads in subparagraph (a)(3) must be determined by analysis, test, or both. **Disbonds of each bonded joint greater than this must be prevented by design features**; or

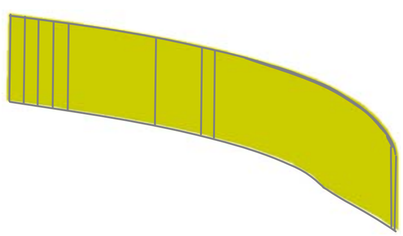
(ii) Proof testing must be conducted on each production article that will apply the critical limit design load to each critical bonded joint; or

(iii) Repeatable and reliable nondestructive inspection techniques must be established that ensure the strength of each joint.“

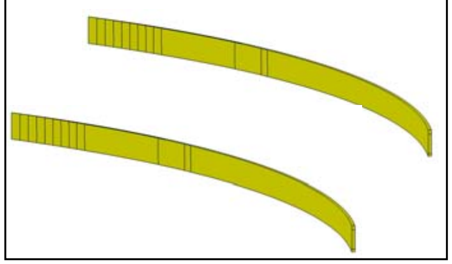
(i)	-> Possible
(ii)	-> Not practical/economical
(iii)	-> Not feasible

Implementation - Production Process

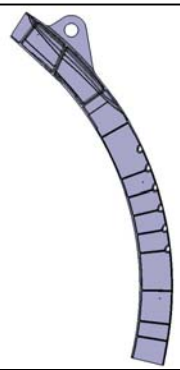
1) Production of FML-panel



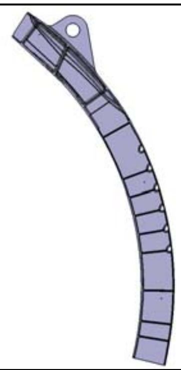
2) FML-straps milled out of panel



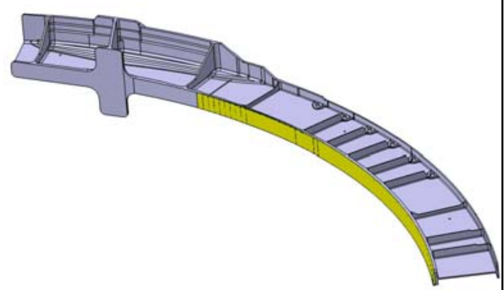
3) Frame pretreated with CAA



4) Frame primed with BR127



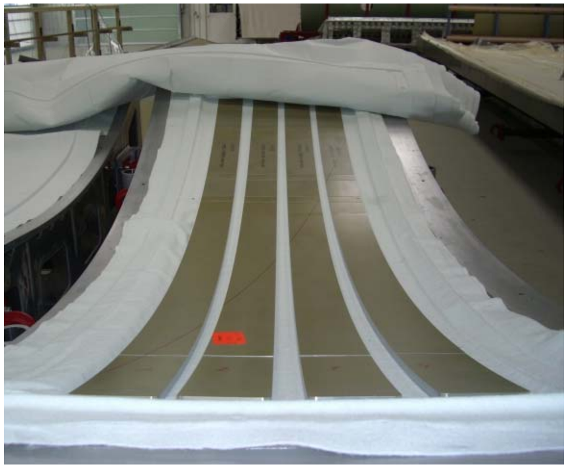
5) FML-strap bonded to frame



Distortion due to delta in CTE

First assemblies acceptable, some frames have to be shimmed on shell level assy.

Implementation - Production Process



Implementation - Quality Assurance

Inspection during manufacturing:

Step 1: Manufacturing of FML-strap laminate

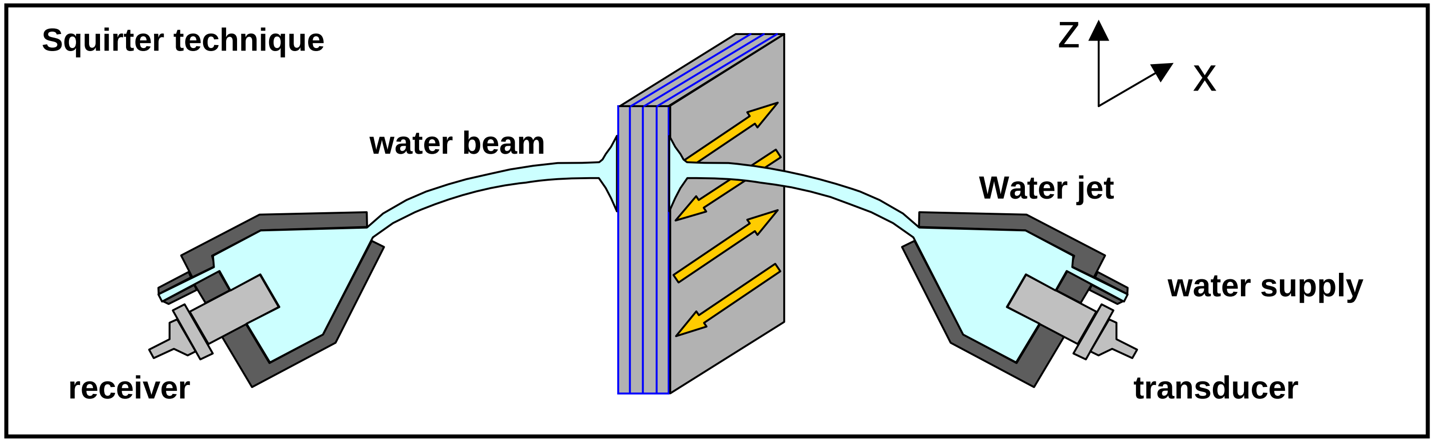
Inspection of the laminate by ultrasonic through transmission in squirter technique

Step 2: Bonding of FML-strap to Aluminium frame

Inspection of bond line by manual ultrasonic through transmission technique

Implementation - Quality Assurance

Principle of the ultrasonic through transmission method – single channel mode

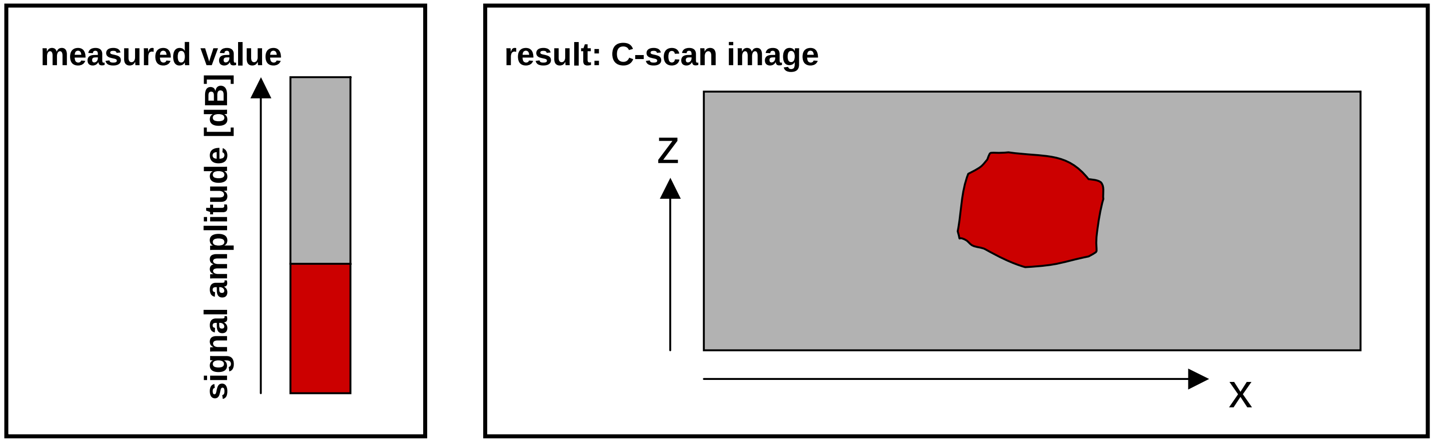


- Basic principle: ultrasonic through transmission method in squirter technique
- Both side accessibility of the inspected part required
- Complete and reproducible documentation of test data
- Display mode: C-scan (top-view)

Implementation - Quality Assurance

Principle of the ultrasonic through transmission method – single channel mode

•**Display mode: C-scan (top view)**



- Information on location and size of defect provided
- Information on defect depth not provided

Implementation - Quality Assurance

Principle of manual ultrasonic through transmission technique – single channel mode using inspection tongs (for in-production and in-service application)

- Basic principle: ultrasonic through transmission method in general comparable to through transmission method in squirter technique, manual movement of the transducers
- both-side accessibility required
- Display mode: A-scan
  - A-scan: Assessment of indications by means of sound attenuation relative to the defect-free surrounding area

Structural Qualification - Requirements

Basis for Certification

- JCRI (JAA Certification Review Item) is a selected identified item of the civil CS regulation with rules and policies established in other civil programs.
- MCRI (Military Certification Review Item) is a selected extension of the civil CS regulation with rules and policies derived from military regulations and standards.

- Note: Although A400M is a militairy transport aircraft, the basis for certification is the civil CS25 – former JAR25.
  ➔Hence CS25.571 (b) is applicable, which implies requirement of Damage Tolerant design.

Structural Qualification - Analysis

- Main Frame with FML-Strap is a Structure with Damage Containment Feature (DCF).

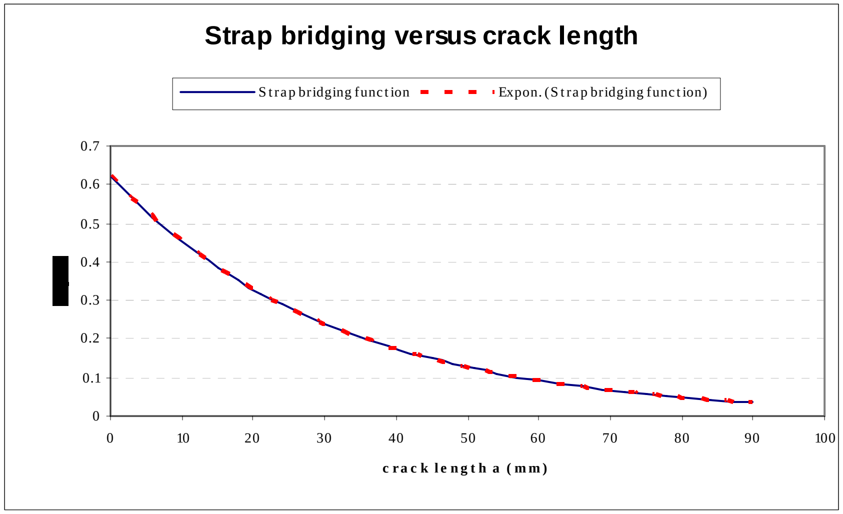
- Calculated Components
  - Justification of FML strap (run-out and highest stressed location)
  - Justification of Frame Inner Flange

- Failure Criteria
  - F&DT: Fatigue, Crack Growth, No Defect Growth, Residual Strength.
  - Static: Material Strength, Stability

Analyses supported by Test Evidence

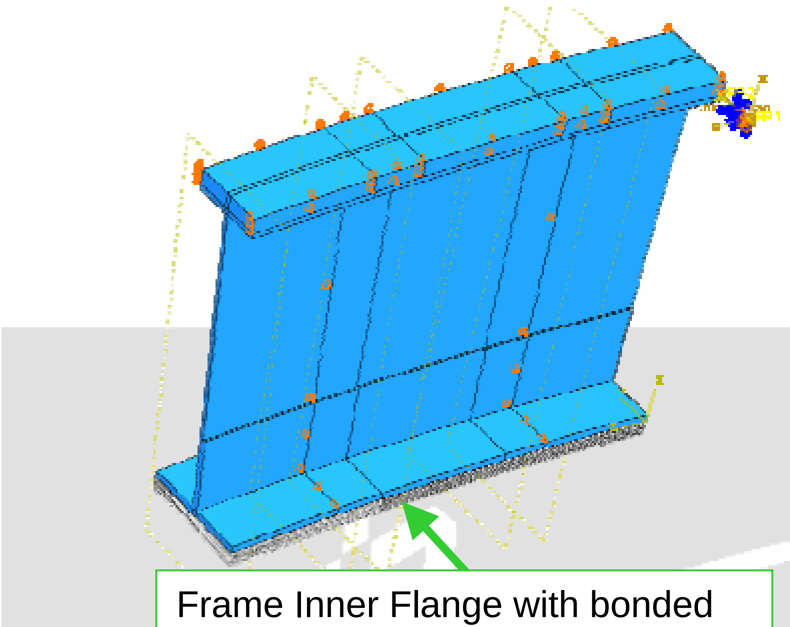
Structural Qualification - Analysis

- Fatigue crack growth:
  - Load divided between Strap and Inner flange by product of stiffness and area
  - Crack growth corrected for “crack bridging” by additional function α
  - Edge cracks from bore holes and edges calculated

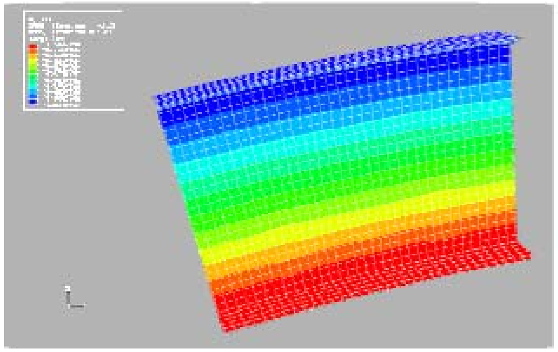


Structural Qualification - Analysis

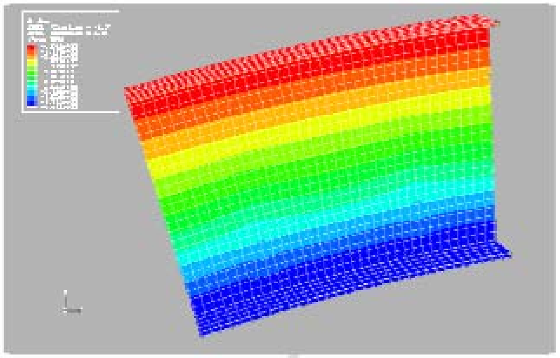
- Residual strength analysis



Frame Inner Flange with bonded reinforcement modelled.



Frame stress distribution at ultimate negative moment



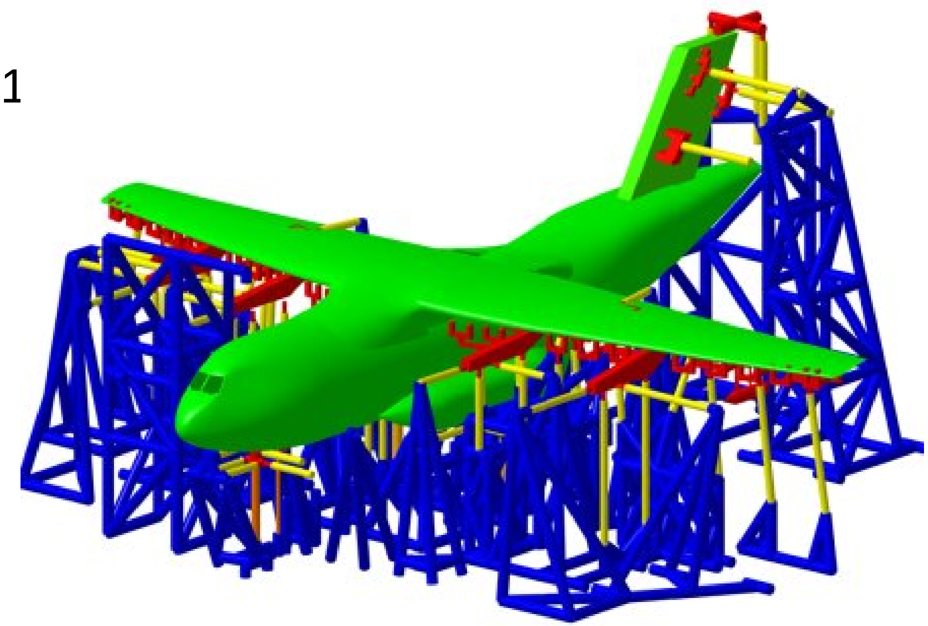
Frame stress distribution at ultimate positive moment

- Conclusion: Introducing an significant initial centred unbonded zone does not lead to delamination growth under tensile as well as compressive limit load neither. Final maximum size of acceptable delamination could not be found due to limits of the model.

➔ Based on this outcome the rivet pitch has been defined.

Structural Qualification - Test

- Full-scale Fatigue Test with MSN5001
- Frames on Left Hand (LH) and Right Hand (RH) with FML straps:
  - LH side: normal series standard
  - RH side: small artificial delaminations in frame-strap bondline and Glare
- Simulating 2.5 DSG (25.000 FC)
  - Planned for Feb. 2010- Feb. 2011

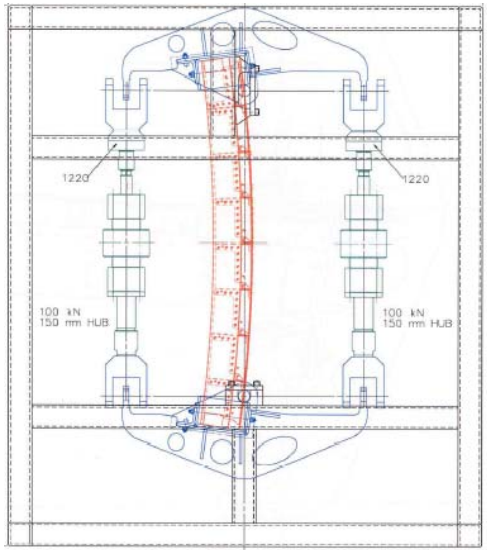


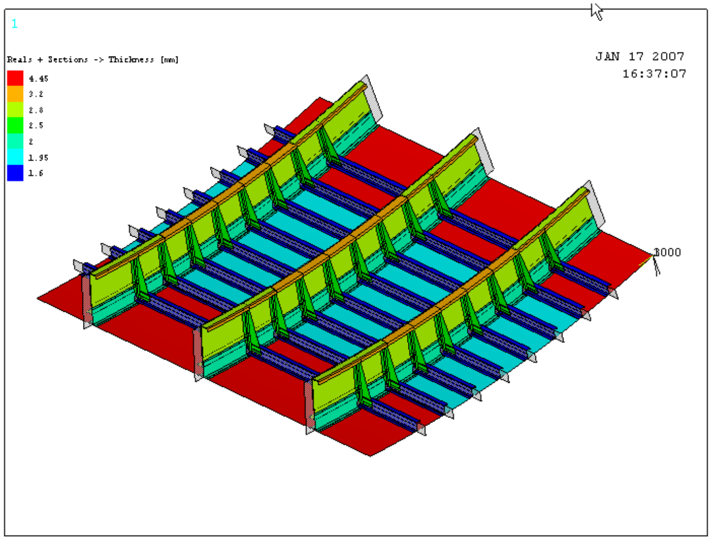
Structural Qualification - Test

Overview Static component tests (three)

Aim of the static frame bending test series is to evaluate the bonding of the FML-strap in the region of the highest stress level and at the run-outs.

1. Frame with continuous Glare strap
   - 1 specimen
   - Loaded with negative bending moment, ultimate load
   - Small artificial delaminations in frame-strap bondline





Structural Qualification - Test

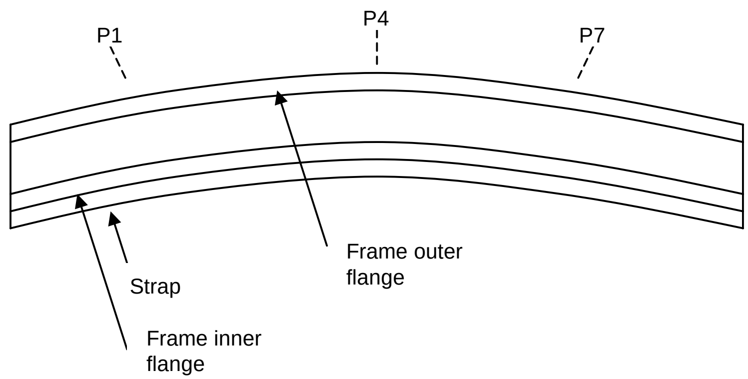
2. Frame with run-out of Glare strap,
   - 2 specimens
   - Loaded with positive/negative bending moment, ultimate load
   - Small artificial delaminations in frame-strap bondline

3. Frame with continuous Glare strap
   - 2 specimens
   - Loaded with positive/negative bending moment, limit load
   - Large artificial delamination in frame-strap bondline (determined from FE-analysis)

Structural Qualification - Test

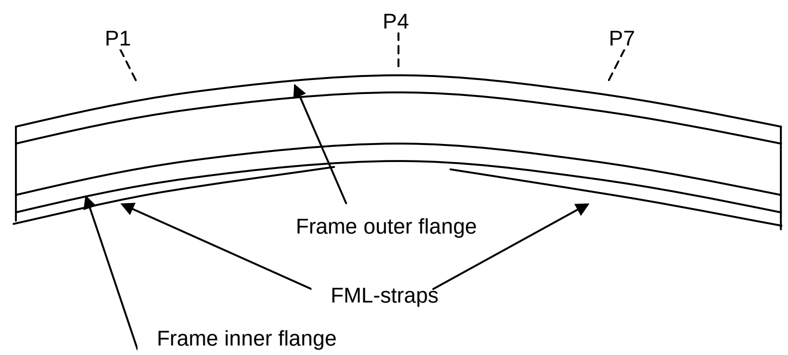
Overview F&DT component tests (two)

1. Frame with continuous Glare strap
   - 1 specimen
   - Spectrum of 3 DSG and limit load (tension+compression)
   - Initial flaws installed (1.27mm through cracks)
   - Small artificial delaminations in frame-strap bondline



Structural Qualification - Test

2. Frame with run-out of Glare strap
   - 1 specimen
   - Spectrum of 3 DSG and limit load (tension+compression)
   - No initial flaws
   - Small artificial delaminations in frame-strap bondline
   - Specimen without artificial delamination for crack initiation and crack propagation investigation



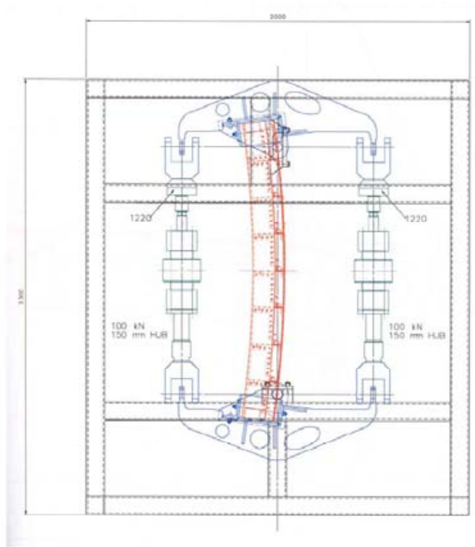


Fig 16: Frame bending test rig

Structural Qualification - Test

- Overview Coupon Tests

- Material and static coupon tests
  - Tensile test thick Glare2A
  - Compression test Glare2A
  - Blunt notch test Glare2A
  - Bearing test Glare2A

- Fatigue coupon tests
  - Bonded+riveted specimens
  - 20 specimens with/without cold worked holes

- Crack growth tests
  - Coupon tests by external company in development phase

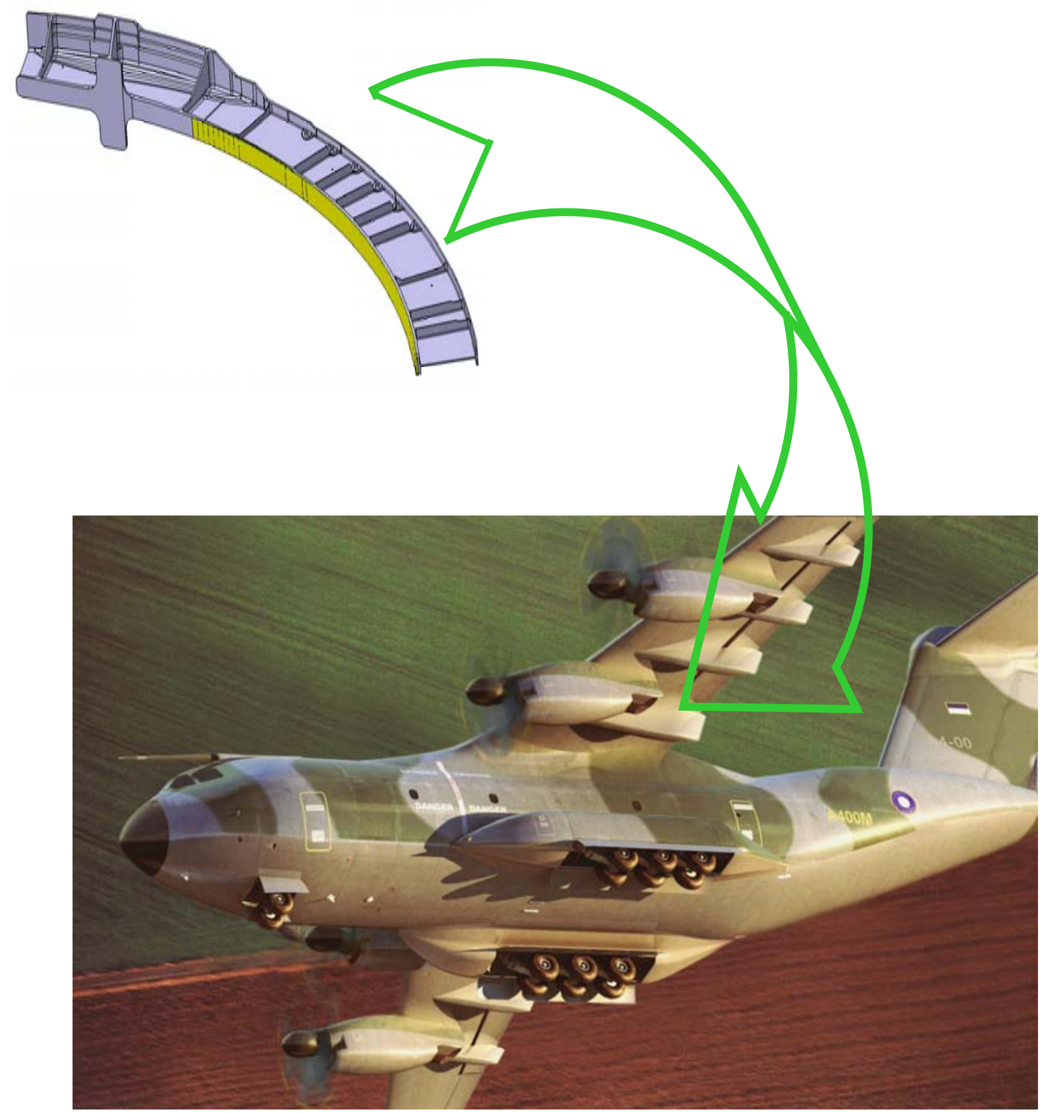
Summary

- FML strap establishes a safer, damage tolerant design of a highly loaded frame.

- The new application has been introduced with an extensive qualification program. All disciplines have to coorperate closely.
  - Structure engineering
  - Material
  - Quality Assurance
  - Process

- The first Production and Assembly has been succesfull.

Thanks for your attention/ Bedankt voor uw aandacht



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