ECCOMAS Congress 2016
VII European Congress on Computational Methods in Applied Sciences and Engineering
M. Papadrakakis, V. Papadopoulos, G. Stefanou, V. Plevris (eds.)
Crete Island, Greece, 5–10 June 2016

ROBUST INTEGRAL COMPOSITE AIRCRAFT STRUCTURES

Tamas Havar[1]

[1] Airbus Group Innovations
Willi Messerschmitt Str. 1, 82024 Taufkirchen
e-mail: tamas.havar@airbus.com

Keywords: Composite, Design, Sizing Aircraft, Load Introduction, Robust.

Abstract. *In several research projects highly integrated composite aircraft structures have been design, with a strong emphasis on low cost manufacturing. At the same time the robustness of the part had to be increased in order to lower direct maintenance costs for the end customers. Several integral aircraft part designs are shown, which allow the usage of low cost composite manufacturing procedures, but at the same time guarantee sufficient performance against the occurring loads and external damages. The focus is on the integral composite load introductions that withstand high loadings, even when small cracks have occurred due to external damages. The cracks can be stopped in areas with smaller internal strains or by specific ply drops and junctions. This has been shown by extensive analysis of the critical areas as well as the whole part and proven by coupon, subcomponent and component tests. This allows a light weight but also robust design in combination with low manufacturing and assembly.*

1 INTRODUCTION

Current Aircraft Structures are being made more and more of composite materials. These composite materials are very light combined with high strength and have very good fatigue characteristics. On the contrary their damage behavior is critical leading to low damage allowable for the material. This limits the weight potential and leads to additional higher manufacturing costs by adding toughening interleave materials are thicker structures. The aim is to reduce manufacturing and assembly costs for future design by using out of autoclave processes and a higher integration of subparts in the large structure. For these highly integrated part designs even with included load introduction, the phenomena of crack propagation becomes even more critical, since a small crack can propagate through the whole structure leading to an early failure of the complete structure. Therefore new designs of integral load introduction in combination with sizing methods were developed to provide low cost, low weight but robust structures for future aircrafts.

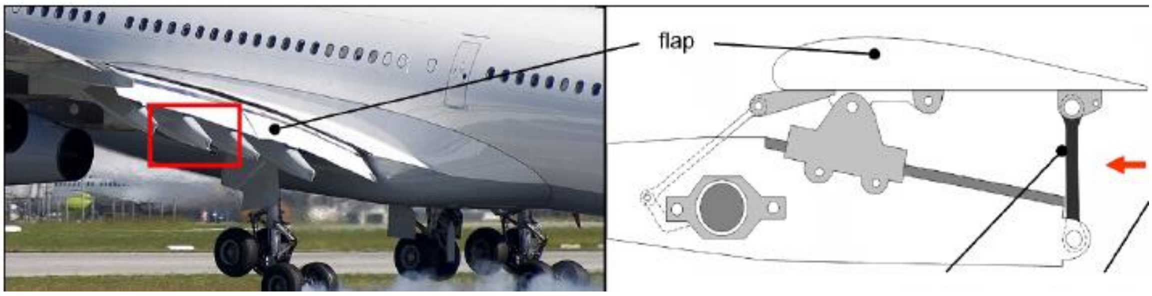

Figure 1: High Lift System of Commercial Aircraft

2 MODULAR COMPOSITE LOAD INTRODUCTION

In cooperation between different AIRBUS divisions, a new advanced composite load introduction rib for high lift devices of future long range aircraft has been developed to minimize weight and manufacturing costs.

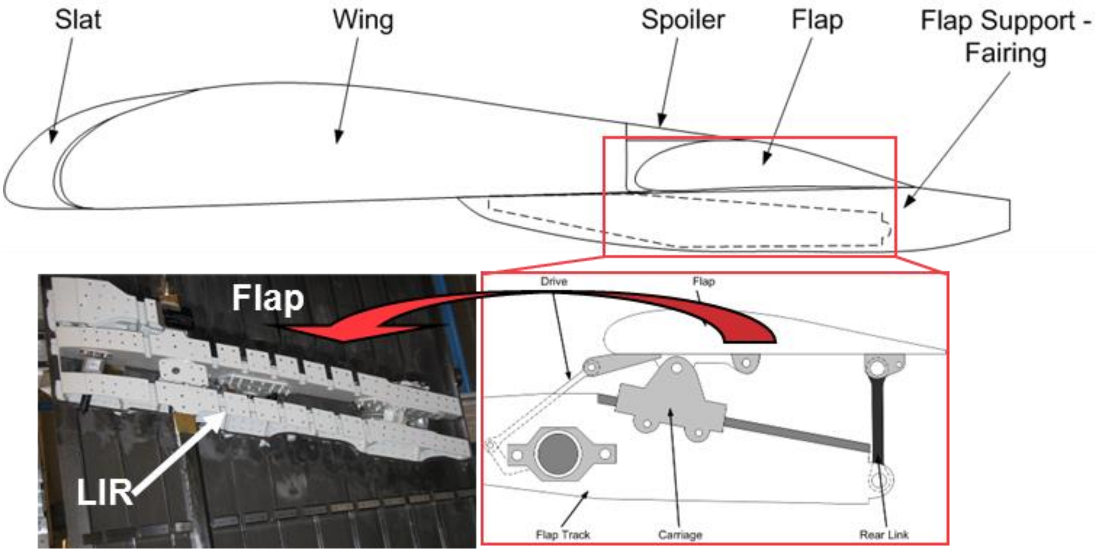

Figure 2: Typical wing cross section with flap and load introduction rib

The focus of the new integrated design of the load introduction rib is on the reduction of the complexity and to simplify the preform manufacturing and therefore the cost. The complex loading of the load introduction structure requires a detailed numeric analysis for an accurate calculation of all critical stresses. The static analysis of the new composite load introduction rib and drive fittings show sufficient strength. Based on prior investigations, the composite lugs show satisfying damage tolerance behavior leading to the conclusion that a second load path is not necessary.

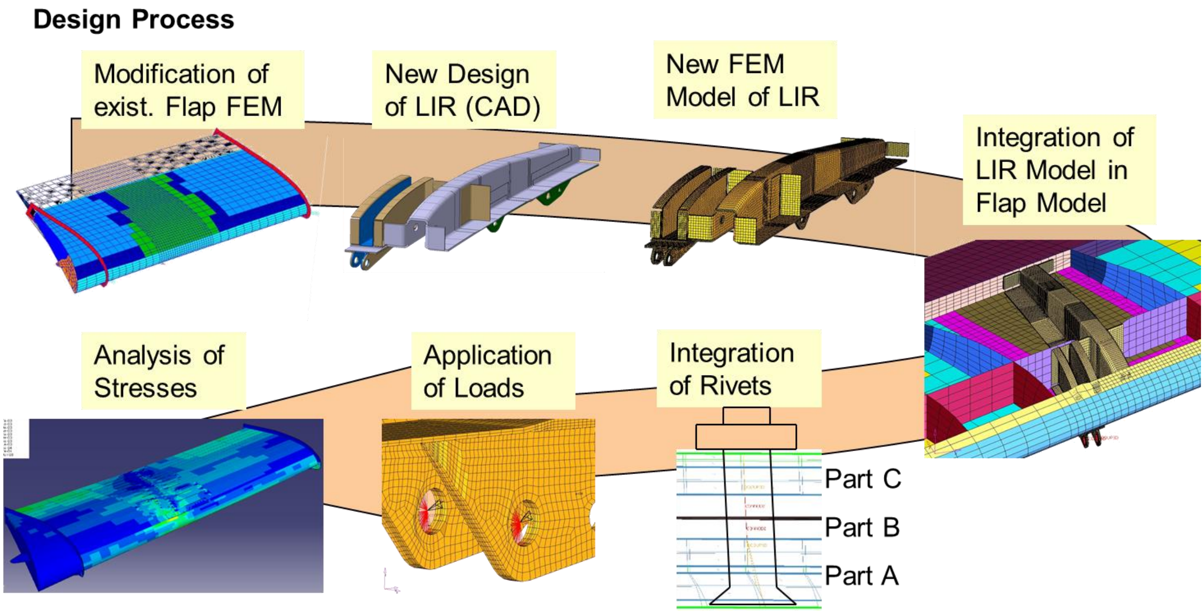

Figure 3: Design process for new composite load introduction rib

The design was verified by subcomponent and component manufacturing by Airbus Helicopters. Knowledge from the prototyping went back into the design to improve the design and to verify to low cost approach. Afterwards the load introduction rib was assembled into an existing high lift device and validated in a full scale component test.

Figure 4: Design process for new composite load introduction rib

3 GENERAL LOAD INTRODUCTION PROBLEM

The partly integral high lift load introduction has shown that current metallic brackets and fittings used for introducing external forces into large structures can be done with composite design. For future aircraft a more integral design is favorable reducing assembly time and effort. This is especially critical for high production rates for singe aisle aircrafts.

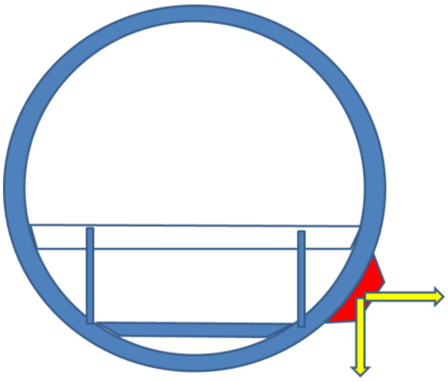

Figure 5: Complete Integral load introductions at aircraft fuselage

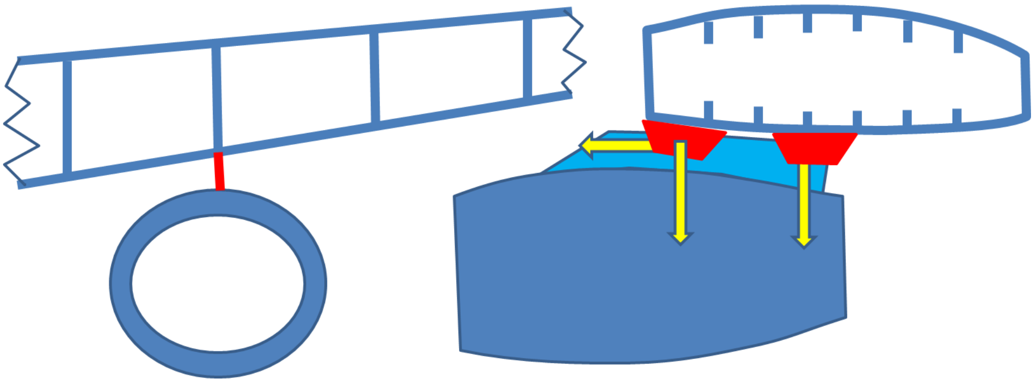

Figure 6: Complete Integral load introductions at aircraft wing/engine junction

For composite structures this is even more difficult than for metallic parts. New integral load introduction designs for composite structures were developed. Usually high bypass loads in the skins/panels have be transferred, while out of plane loads are need to be introduced, best done into frames and stiffeners on the inside.

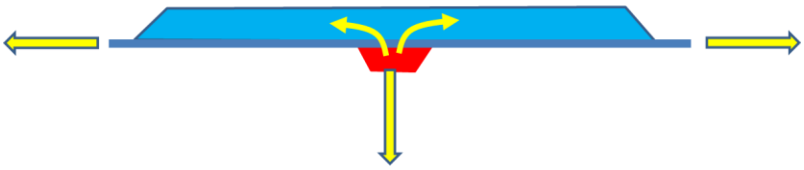

Figure 7: Panel/skin junction with external load bracket

This is also referred as X cross section problem at composite structures. Some composite designs are on the market (3D weaves, Crucify Forms…), but either with very limited performance or difficult manufacturing processes.

4 INTEGRATED LOAD INTRODUCTION

4.1 Composite Cross Section Design

Several composite cross section designs have been developed. In order to mount external load introduction, so called fins were developed. In general a cut in the lower skin has be made in order to penetrate with the fin, which is positioned interleave between the frames/stiffeners on the inside. Just to mount the fin to the skin/panel would lead to very high our of plane loads on the skin, leading to poor performance. This design allows transferring very high loads through the skin into the backing stiffening structures.

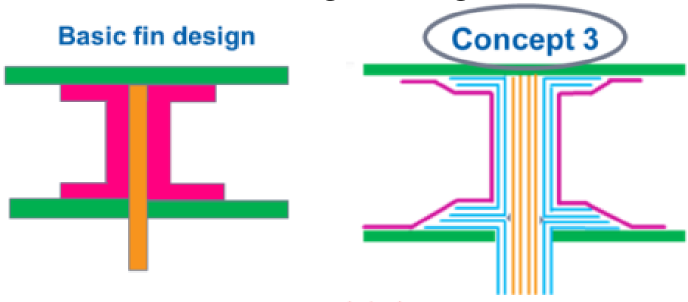

Figure 8: Basic cross section (fin) design

The different concepts were roughly sized with FEA, but only 1 showed high performance and good damage tolerant capability. A high damage tolerance capability is very important to highly integrated structures, hence cracks/delamination caused by external impacts, could grow rapidly leading to early failure of the integral load introduction. Therefore design with no growths or slow growths for damages were chosen

4.2 Detailed FE Analysis

The most promising design shown in Fig. 8, was analysed with non linear effects to determine the maximum load carrying capability. A representative cross section was chosen with a 3 point bending load case. The edges of the skin/panel were fixed, while the fin (load introduction) was loaded perpendicular to the skin with tension and compression. The stiffening back up structure of the skin/panel, which are usually frames, spars and ribs, were also included. These usually carry the out of plane loads of the skin and here the external loads on the fin.

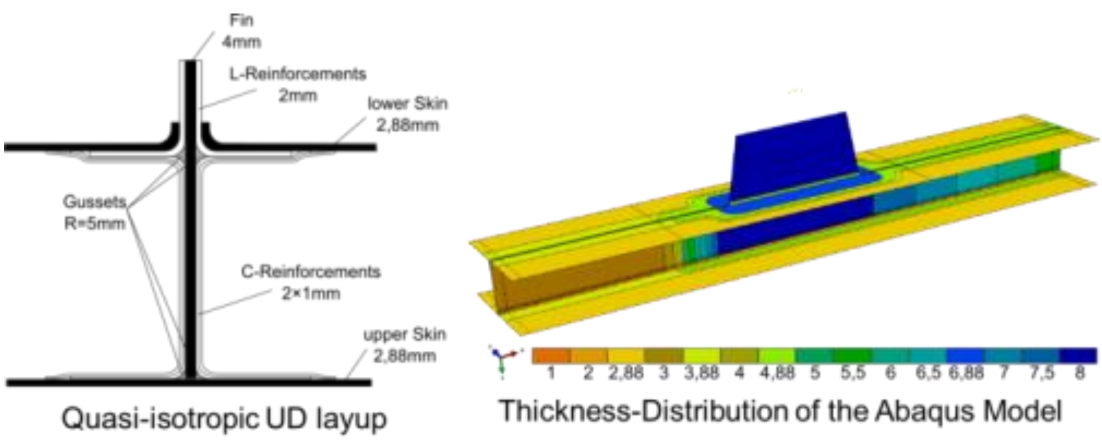

Figure 9: Representative fin analysis with non linear FEA

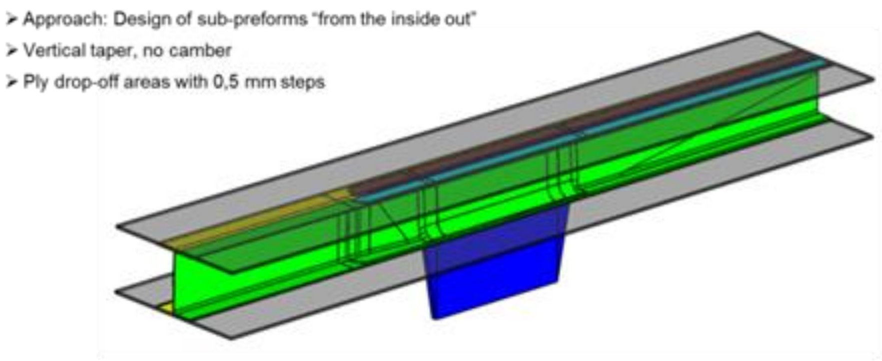

Figure 10: Representative composite skin cross section design with integral fin

At the non linear FE analysis, the transfer loads of the fin to the stiffening elements (transversal interlaminar shear) were of most interest. These are usually tested with Mode I and Mode II test for different materials to determine the interlaminar material allowable. These allowable values were used to determine the reserve factors against the maximum static loads occurring at the cross sections. The FEA has shown that are these stresses are not very critical due to a large connection area between the fin and the backup structures (frame, ribs, spars…).

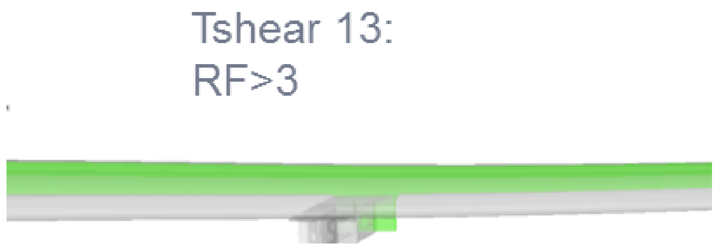

Figure 11: Transversal shear stresses in fin to frame junction

5 VERIFICATION AND VALIDATION

5.1 Verification

In order achieve the high cost reduction goals, out of autoclave manufacturing materials and processes were used as basis. The representative fin design was manufactured CFRP non crimped fabric and an out of autoclave VAP® process.

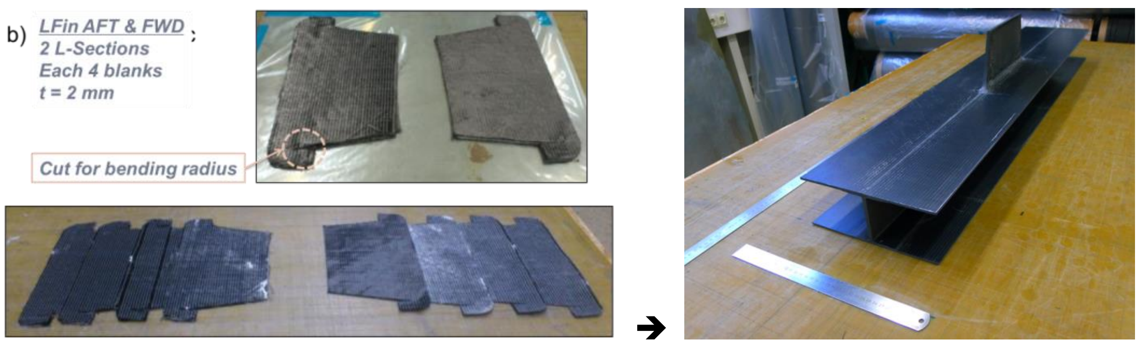

Figure 12: Manufacturing of representative composite skin cross section design with integral fin

Afterwards several prototypes were statically and fatigue tested. During the test, buckling of the skin was visible at the maximum static load, which is usual for very high loaded structures. This was later on reduced with additional stiffeners on the side.

Figure 13: Testing of representative composite skin cross section design with integral fin

In order to visualize the critical fin run out area, where cracks could occure, additional white paint was applied. At maximum static load small cracks did occur at the run out area. This was party caused by manufacturing effects (resin rich areas) and by the high corner loading. This did not lead to failure, though; since the cracks were only at the surface. Fracture did finally occur at the backup stiffener structure were it was not reinforced close to clamping. Here an in plane shear fracture could be seen (Fig. 14). Therefore the fin has proven itself to be very damage tolerant even with cracks at the surface, the fin did not fracture, but rather the skin/frame backup structure outside of the load introduction area.

Figure 14: Fracture of representative composite skin cross section design with integral fin

5.2 Validation

The successful testing of the load introduction elements (fins) was analyzed with nonlinear FEA. Here the buckling phenomena could also be shown. In the post buckling analysis an increased in plane loading of the stiffening backup structure could be shown, which lead to the final fracture above ultimate load. The FEA showed very good conformance with the strain gauges in the test [Fig. 15]. Therefore the design was successfully verified in the test with very good validation to the non linear FEA.

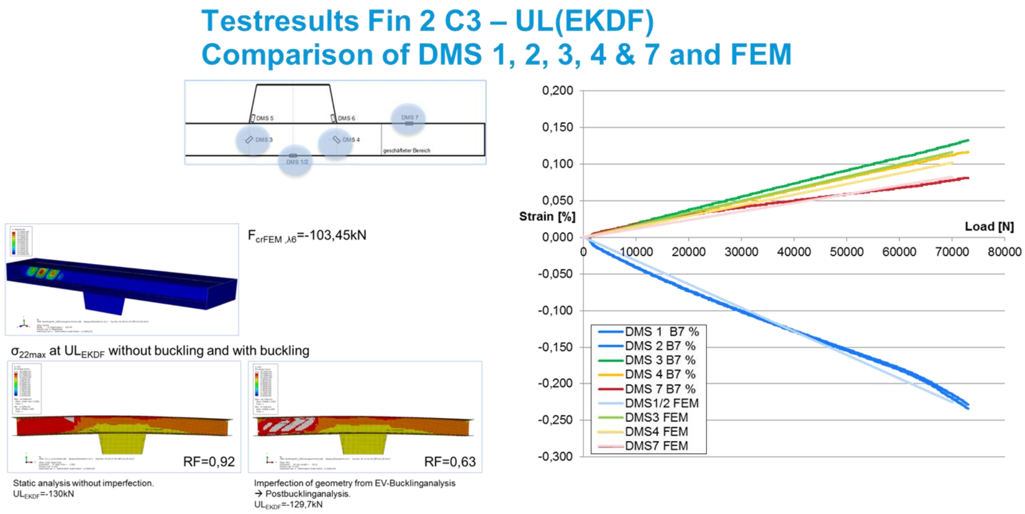

Figure 15: Validation of representative composite skin cross section design with integral fin

6 CONCLUSIONS

This papers shows the design, verification and validation of partly integral and fully integral composite load introduction for future aircraft. Both design have been proven to be very damage tolerant, leading to a robust design and therefore low maintenance costs for the airliners. The manufacturing of the load introduction design has proven the high cost reduction potential of over 20% in regard to current bolted design. A weight reduction of over 10% could also be achieved for the new load introductions.

7 REFERENCES

[1] S. Heimbs, H. Lang, T. Havar, *Central European Journal of Engineering*, *Vol. 2, 4th Edition*. Springer, 2012.

[2] Havar, T. Werchner C.; Analysis of Innovative Composite Aircraft Structures, ECCOMAS Conference 2012.