First International Conference on Damage Tolerance of Aircraft Structures
R. Benedictus, J. Schijve, R.C. Alderliesten, J.J. Homan (Eds.)

Can welded fuselage structures fulfil future A/C damage tolerance requirements?

- Lessons learned and new concepts derived from 10 years of research in fatigues crack growth and residual strength -

Frank Palm
EADS Innovation Works
81663 Munich
e-mail: frank.palm@eads.net

ABSTRACT

Aircraft design has made tremendous progress over the last 50 years. Safety and reliability could be improved significantly although market competition, environmental constraints and permanently increased request for comfort create a big pressure in terms of money and in service quality.

Beside established metallic designs and manufacturing concepts using mechanical fastening/riveting and/or bonding CFRP material solutions gain more and more particular interest of the large aircraft designer. Thus future civil commercial air transport is confronted with a paradigm chance where both competitors (Boeing and Airbus) are looking each other how each of them is solving these challenges.

Laser beam welding (LBW) of lower fuselage panels in the pressurized airframe of the Airbus planes A318, A380 and A340-600 has been a success story.

Ongoing shared research work at EADS on welded structure design principals, always coupled with manufacturing issues and constraints concerning (Al)material availability, weldability and material costs as well, has meanwhile culminated into a broad understanding of what is necessary to build up a competitive welded DT structure.

The presentation will show that a selective approach differentiating between materials of the skin, stringer, frames and other fuselage elements, their properties in terms of static strength, fatigue, fatigue crack growth (FCGR), R-curve and/or notch toughness, the local and global geometry and their local capabilities in a (fusion) welded joint configuration are determining the achievable progress for structural application or even causing a undesired step back.

Taking this into account, combined with an understanding of very complex interferences in a welded structure, a tailoring of the shell structure becomes possible without sacrificing important issues like manufacturing costs and risks. Step by step tests on welded components demonstrates the progress which was achieved over the last years resulting meanwhile in the feasibility of LBW structure application at both (lower and upper) fuselage locations.

In areas where the weld joint is the most limiting property parameter, thanks to appropriate material-geometry-welding selection, the important DT value “residual strength” could be improved by about 50%, now exceeding established riveted or bonded designs in those configurations by 15-20%. FCGR could be enhanced 2-3 fold and corrosion insensitive AlMgSc type materials together with a “new” (actually old) design will allow significantly (20-30%) higher compression (shear) loads enabling extreme a light weight design especially in very thin structures where CFRP solutions are faced with fundamental thickness problems (due to multi-directional layering of C-fibers).

Al data are derived from “traditional” destructive testing and not from assumptions derived from computer modelling and simulation.

1 INTRODUCTION

The availability of thick Al aerospace plate material (> 250 mm) on one hand and the, since many years permanently growing, machining capabilities of new CNC milling machines on the other hand are fostering the development of unitized structure design and manufacturing. Campaigns like *Metals Affordability Initiative* (MAI)[4] or the ALCOA *Advanced Aluminum Aero structures Initiative* (A^3I)[5] have demonstrated that integral design solutions with a reduced number of parts combined with multi functionality can accomplish significant weight savings coupled with improved durability and all over reduced manufacturing (machining & assembly) costs.
NASA studies like the *Integral Airframe Structures* (IAS)[2] describe very good the actual situation of machined components subjected to static and dynamics loads. It is undisputed that unitized components have several advantages:

- Significantly improved long term corrosion behavior
- Enhanced durability (fatigue => crack initiation) ⇔ lower number of fastener
- Cost advantages compared to assembled components depending on part geometry

But damage tolerance (DT) of integral machined parts i.e. fuselage panels is an ongoing issue (if no “additional belts” like bonded or riveted tear straps are employed). The investigations over the last 30 years revealed some interesting as well surprising relations (s. figure 1).

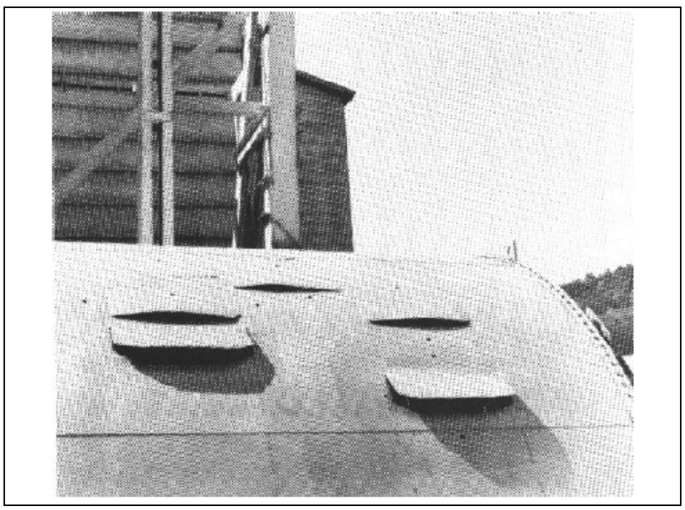

Figure 1: Crack turning and flapping in Boeing 707 test panel [1]

The better understanding of these interactions could generate some improvements (like eased crack turning in integrally machined shells panels) but most of those rely on 2- or 3-dimensional (multi-axial) loading strongly stimulated by the internal pressure of a pressurized fuselage. Thus crack turning can be enhanced by a geometrical reorganization of stiffeners forcing crack deviation (s. figure 3) and pushing limit load capabilities towards higher values. “Orthogrid” and “Isogrid” structures have been proposed but its suitability is discussed often controversially due to complex and costly machining as well as difficult 3-D shaping [2].

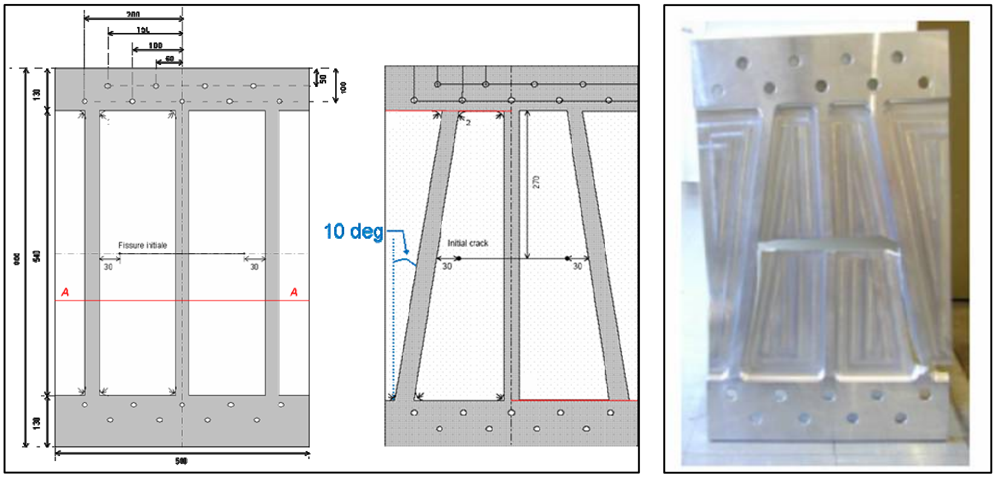

Figure 3: Enhanced residual strength in machined panels by crack branching due to tilted stiffeners [6]

It is all over accepted that in a built up (differential) design a crack, located in the skin perpendicular to the stringer, can tolerate much higher loads than in the integral design because the ("untouched") stringer close to the crack relieves the skin very effectively, hence reducing crack tip stress intensity by far better (the stress in the stringer might reach nearly base material tensile strength) than the fracture mechanically "trapped" stiffener in a bulk material solution.
As integral aerospace plate products are made from high strength Al alloys their intrinsic fracture toughness is comparably low and related notch sensitivity is pretty high. This propensity fosters premature failures at low stress levels in high strength integral component.
Considering pure uni-axial loading scenarios, especially the residual strength capability of an integrally stiffened shell element remains unsatisfactory mirrored against built up structures. A comparison (s. figure 4) prepared and presented by ALCOA at AEROMAT 2007 [9] showed the actual gap between leading edge built up structures used in A380 (baseline 2) and B777 (baseline 1) and an integral profile solution respectively.
Even the application of new high strength AlCuLi alloys (like 2099 in the chart below) cannot bypass the principal problem (low residual strength) of the integral design here used for comparison reasons and confronted with built up serial solutions (A380 and B777) and some new, highly sophisticated proprietary ALCOA concepts where smart applications of metal laminates + fiber reinforcements (ALCOA calls it CentrAl™)[7] enable pretty high limit load capabilities. In this particular investigation where a lower wing design is anticipated one can recognize a shortfall in residual strength of the integral solution versus established built up technologies of about 30%.
Welded structures are also belonging to the group of integral design solutions. For the time being, when semi material costs are stressing the developing budgets, welding can count economically by an improved ***buy to fly ratio*** compared to thick plate machining. Even more it allows a certain degree of (DT) tailoring to skin and stiffener properties (high strength)

provided weldability related issues are solved.

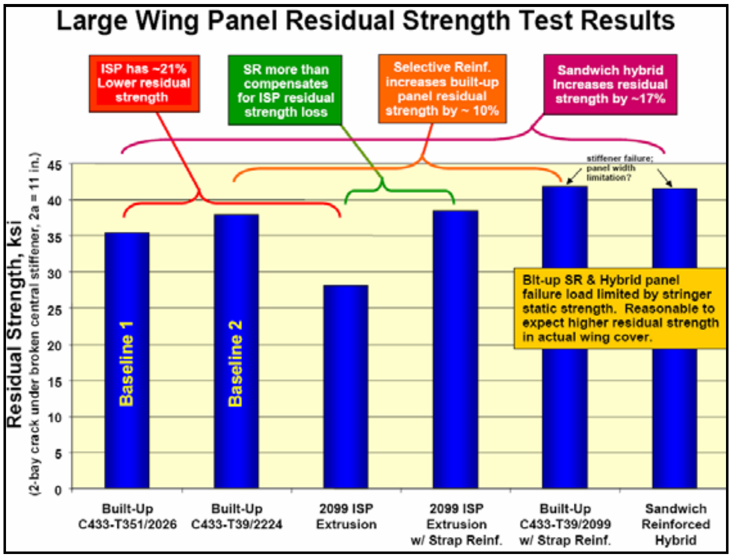

Figure 4: Comparison of residual strength in integral and built up 5 stringer test panels [7]

Welding in primary aerospace structures is well accepted nevertheless not widespread in use, in particular there, where load path and weld seam location cannot be separated to a desired extent. It was a long lasting developing work for EADS (AIRBUS) to establish laser beam welding (LBW) in pressurized fuselage manufacturing (s. figure 5[3].

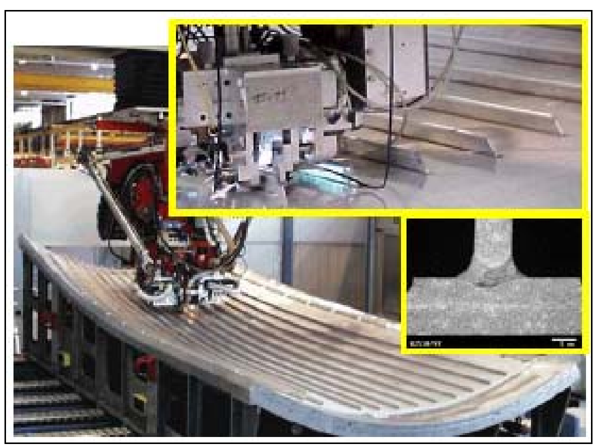

Figure 5: Laser beam welding of stringer to skin in spherical shaped shells for Airbus A318 [3]

In contrast to the successfully implemented welded lower shell design (s. Airbus A318, A380 and A340-600 HGW), however taking into account the damage tolerance load scenarios of upper fuselage applications, the analysis of fatigue crack growth and residual strength tests (made at Airbus, EADS Innovation Works as well at other locations (like ALCOA s. figure 6) revealed that the same material combination (AA6xxx skin-AA6xxx stringer used in the lower welded fuselage shells) would not generate encouraging performance/weight advantages for the upper fuselage application compared to “standard” bonded or riveted designs. In fact especially the limit load bearing capabilities (residual strength (RS)) in a circumferential upper fuselage crack scenario was weight related more or less 15 – 25% lower than a riveted state of the art solution.

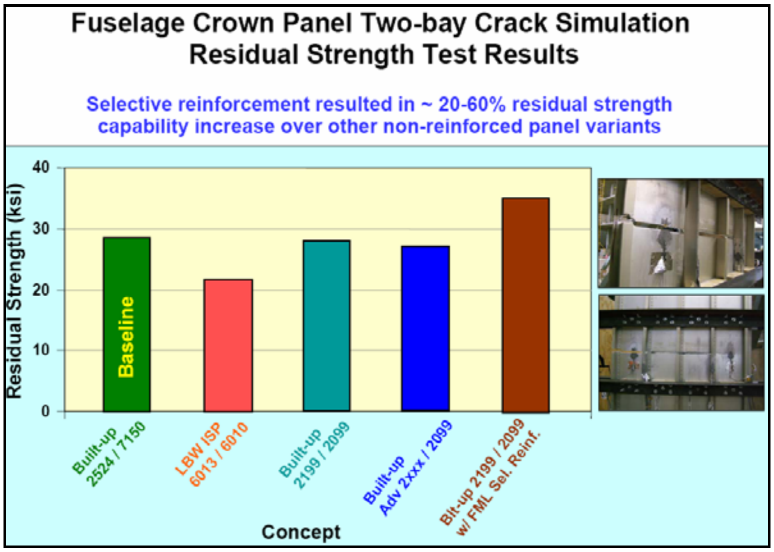

Figure 6: Comparison of residual strength in integral (laser welded) and built up 5 stringer test panels [9]

2 CHALLENGE

Albeit LBW of stringer to skin in lower fuselages in Airbus A318, A380 and A340-600 HGW has proven to be a very competitive manufacturing technology, the motivation to extend this new built up methodology to other areas of the airframe (side and upper fuselage) remains due to the above mentioned RS restrictions pretty low. In order to change this game and to step forward to cope with the challenge (to create significantly higher RS properties) there are important questions to be addressed and have to be answered comprehensively:

- Can the design of mainly DT-loaded welded skin-stringer upper shell panel structures be modified in a way that they are (in terms of RS) as good as or even better than established bonded/riveted solutions?
- What does this mean for the materials in skin, the stringer and the weld zone?
- Do we understand the failure peculiarities in welded T-joint geometries and what is the influence of the welding procedure (including the filler material)?
- To what extent can linear-elastic fracture mechanics (LEFM) and elastic-plastic fracture mechanics (EPFM) be “manipulated” to create a pseudo-differential behavior in an integral element if subjected to a ultimate loading challenge (RS test)?

A widespread common approach (or desired structural behavior) is to favor crack turning (see the sketch in figure 7 or fig. 1 [1]). This would “save” the stringer or frame and prevent premature catastrophic failure. But prediction and pre calculation of crack turning is difficult, especially if the crack is attacking purely perpendicular the 2nd load path element (no inclination between crack line and stringer).

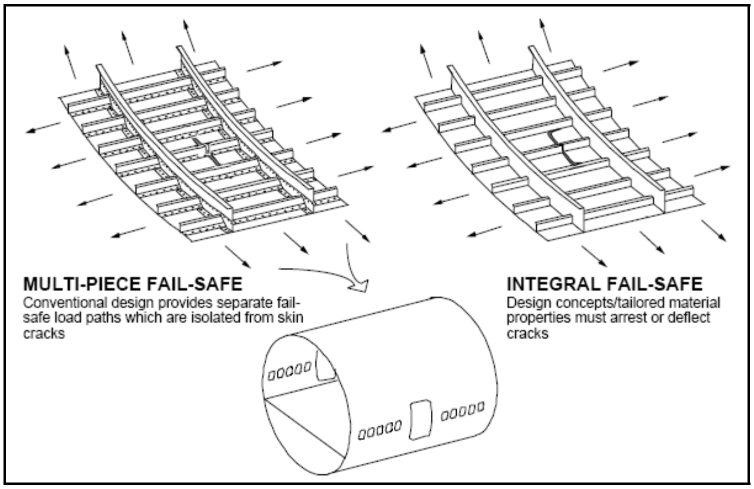

Figure 7: Fail safe in built up and integral structures [1]

Hence there is still the need to have a RS as high as possible. In a riveted structure high RS is determined by the R-curve properties of the skin material **and** (more or less additively) of the (tensile) strength of the stiffener. In an integral (welded) structure the RS is also defined by the R-curve of the skin material **in conjunction with** the notch tensile (crack) strength of the weld zone area, which is a complex material behavior of 1) heat affected zone skin + 2) weld material + 3) heat affected zone of stiffener + stiffener.

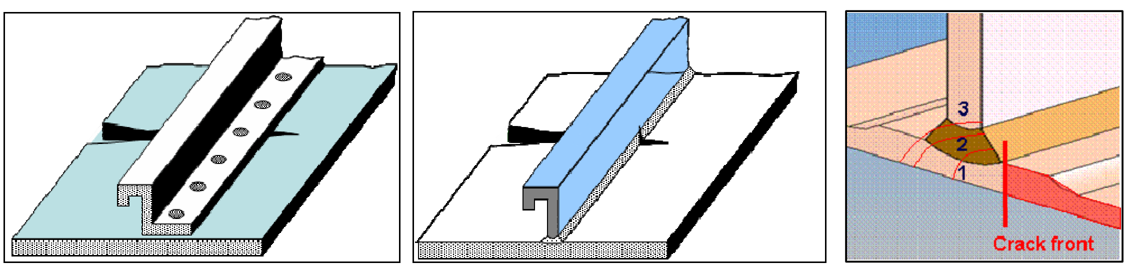

Figure 8 a-c: Differences in crack bridging in riveted and welded T-joint configurations [8] [10}

Unfortunately it is a widespread observation (and material propensity (fracture mechanical reality)) that a higher the strength of stiffener alloy a more worse the "crack strength" of the similar material. Therefore the major question remains:

- **How can this (mainly) material related issue be bypassed without sacrificing the inherent prospects of laser beam welding for airframe structures?**

3 INVESTIGATION AND TEST PROGRAM

To cope with these challenges we started (in collaboration with Airbus) at EADS Innovation

Works a longer lasting research activity addressing the 2 main drivers derived from the above described observations:

- Try to understand the main parameter managing the weldability of high strength aerospace aluminum alloys in order to be able to tailor materially welded structure (tough skin – high strength stringer – ductile weld zone)
- Develop a simple (cheap) and reliable method to manufacture reinforced stringer materials => Co-extrusion of high strength metal wire reinforced profiles

In year 2001 we started with laser welding of so called 3-stringer panels, followed by 4-stringer panels and the work culminated in 7-stringer panels which represent sample geometries widespread in use at Airbus Germany for investigations dedicated to the damage tolerance behavior issue (upper fuselage shell, circumferential crack growth scenario)(s. fig. 9a – c).

Laser beam welding was always done with Nd-YAG lasers, the use of appropriate filler materials to overcome hot cracking issues was mandatory. The structural stiffness of the panels varies from 0.33 (3-stringer panel) down to 0.25 for the 7 stringer panel. Fatigue crack growth investigations **and** residual strength assessments were always done with anti-bending devices as preliminary tests revealed a RS increment of about 5% higher strength compared to "free moving" samples. Before starting the RS tests crack tip locations were close to the (welded) stringer root, at least in the skin heat affected zone of the welded joint.

Figure 9a - c: Panel configurations with pre cracked middle stringer (for 3 or 7 stringer panels) or center crack (4 stringer panels)

Overall panel geometries were nominally:

	Length	Width	Stringer pitch	Gross section
3-Stringer Panel	1000 mm	470 mm	100 mm	1595 mm²
4-Stringer Panel	1000 mm	685 mm	185 mm	1800 mm²
7-Stringer Panel	1300	1200 mm	185 mm	2710 mm²

Table 1 : Nominal geometries of tested panel hard ware

RS tests were done with 2 bay crack scenarios in 3 stringer and 7 stringer panels and 1 bay crack scenario in 4 stringer test panels. Summarizing the observations made during testing of all panels over the years (about 50 panels), it is meanwhile more or less a fact (and not surprising) that the RS in sheet-stringer elements can be improved significantly if:

- The skin material has a better R-curve
- The stringer material has a high strength coupled with a high notch toughness
- The connection (weld seam) between the skin and the stringer should be of good or better said sufficient strength but even more important of high toughness (owing distinct plasticity) => low plasticity capabilities in the weld zone region are detrimental to the RS
- To protect the stringer close to the crack mechanically it is helpful to increase the bulk material locally

Last but not least

- To reinforce the stringer close to the attacking crack by 2nd material which (should) has a higher specific strength (and young's modulus) than the stringer itself (in order to be weight efficient)

But it remains the question to which extent the RS can be improved by applying these measures. This shall be clarified with the help of the next diagrams by a step to step approach.

3.1 Step 1: Improvement of RS by more weld material ductility (plasticity)

A positive strength increment of about 10% is demonstrated in figure 10.

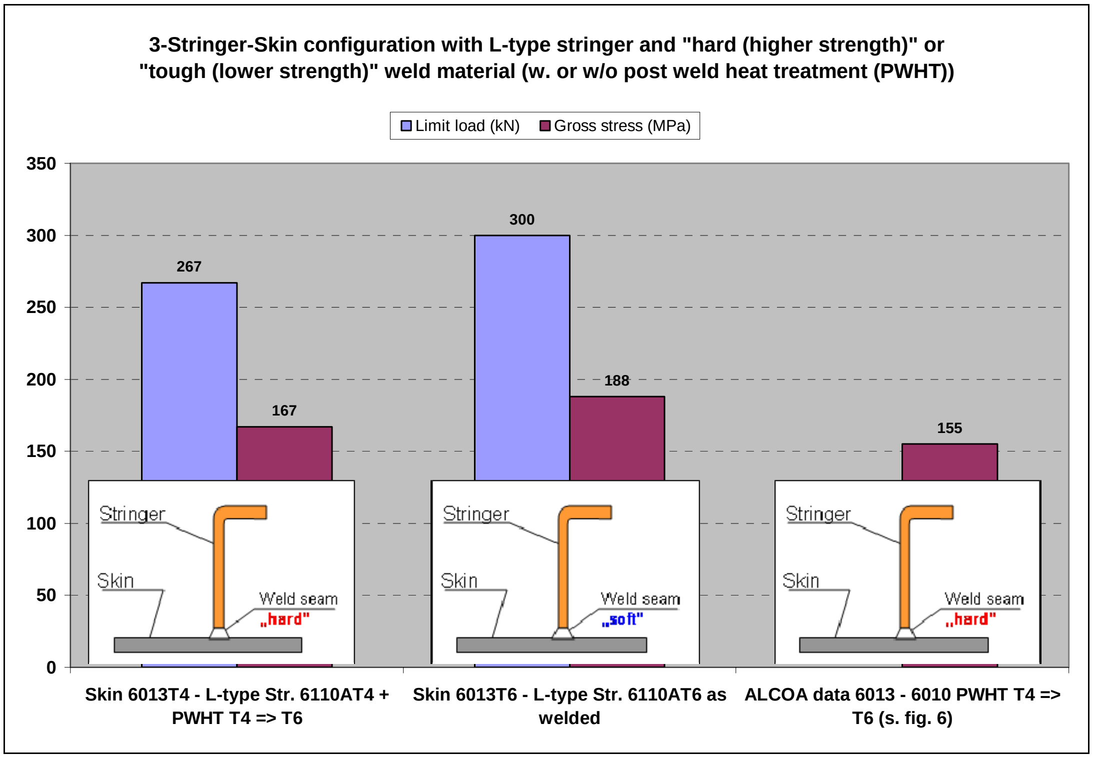

Figure 11: 3-Stringer test panels with laser beam welded stringer

If the weld seam plasticity remains high (because no post weld heat treatment was performed)

premature rupture of the cracked panel can be delayed considerably.
A comparison of the in house data with results generated and published by ALCOA (s. fig. 6, caution: cross section and of EADS IW and ALCOA panel stiffness are slightly different) confirms the observed dependencies. An improvement of gross stress from 167 → 188 MPa is achievable.

3.2 Step 2: Improvement of RS by stringer foot thickening

Further improvements concerning RS may be accomplished via supporting the critical weld zone by a local stringer foot thickening. Numerical calculations ensured a significant reduction of stress intensity. Figure 12 and 13 are outlining the achievable amount of property improvement of this concept during real testing. Although in both cases (compare fig. 11 with fig. 12) the overall geometry (cross sections) stayed constant, the stringer foot reinforcement in alloy 6013 can generate a RS (gross stress) increase of additional 6% (11 MPa).

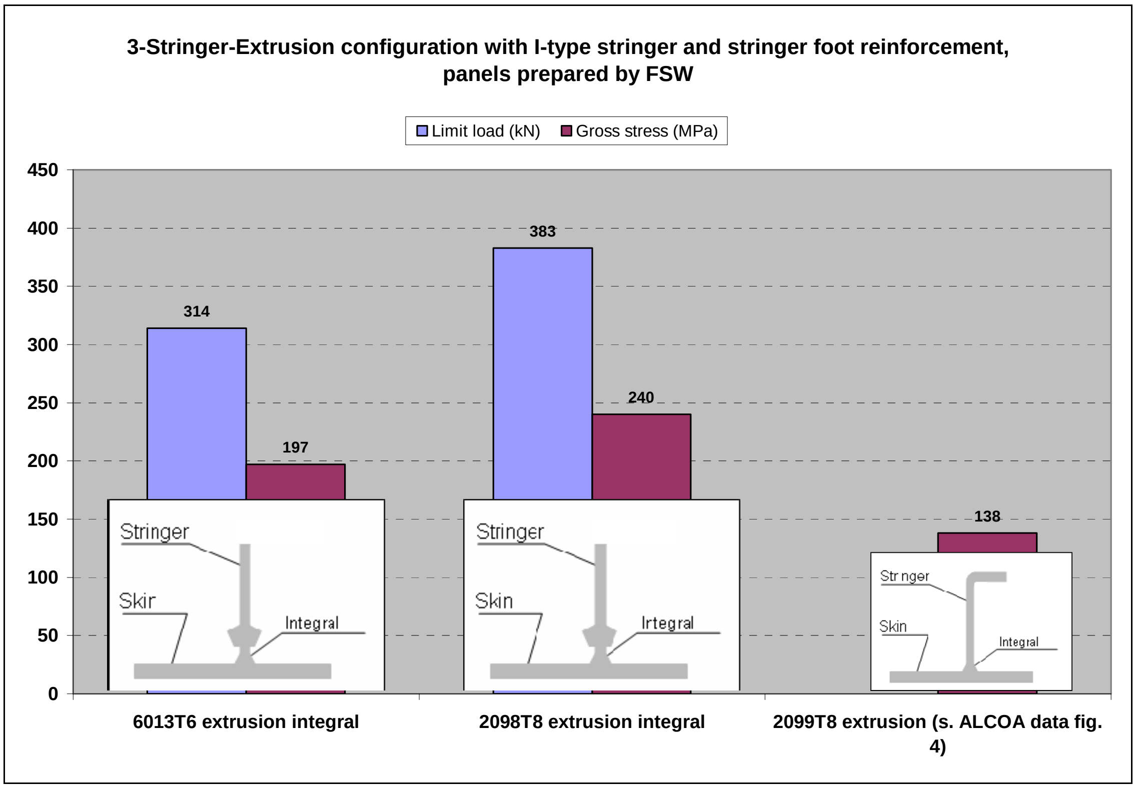

Figure 12: 3-Stringer test panels made from extrusions by Friction Stir Welding

Substituting the incumbent alloy 6013 T6 (AlMgSiCu) by the innovative AlCuLi alloy 2098 T8, known for its very good R-curve properties, this gives another push towards higher strength. Now we reach a residual gross stress value of 240 MPa which means a further RS amplification of more than 20%. In contrast to this, the partly comparable, also Friction Stir welded panel alloy AlCuLi 2099 suffers during residual strength testing a pretty early failure, considerably lower than alloy 2098 or even than alloy 6013. This premature failure of the non reinforced 2099 profile geometry promotes vice versa the previously elaborated reinforcement concept.

3.3 Step 3: Improvement of RS by stringer foot thickening + High strength material reinforcement (“2nd material body”)

In order to maximize the “stringer strength efficiency” in a limit load testing scenario, it was investigated whether “second body” reinforcements might further protect the stringer against undesired premature rupture. After 1st successful trials with co-bonded high strength Inconel 718 wires we switched over to so called co-extruded stringer profiles where the reinforcement wire or ribbon is placed during the extrusion intimately in the profile core. Between both components a reliable metallurgical bond (diffusion bond) is accomplished insuring best load transfer capabilities but only minor additional costs compared to a “standard” extruded stringer.

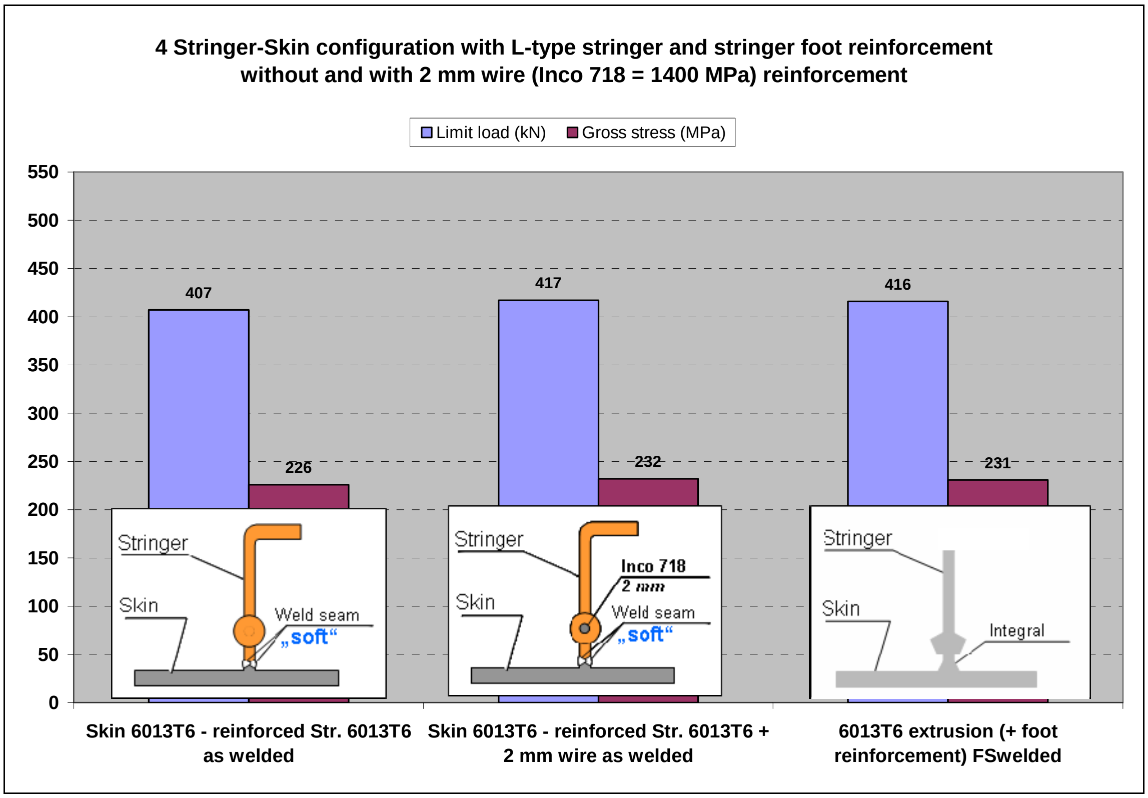

Figure 13: 4-Stringer test panels with laser beam welded stringer compared to a test panel made from extrusions

Depending on the strength of the used wire, as visible in figure 13, and the bulk material strength of the stringer alloy the residual strength is further improved. There is a good

agreement between the rupture strength of the Inconel 718 wire contributing about 4,4 kN each. As during limit load failure especially the wires in stringer 2 & 3 are charged, the strength increment of about 10 kN fits pretty good with the contributed wire strength. The overall ranking and leveling of the RS properties development derived from the 3 stringer–skin panel tests towards a 4 stringer–skin panel test can be finalized by the comparison of the 3 and 4 stringer integral profile element. Again a good agreement allows extrapolations what might be the "best" material selection on order to get best RS properties.
The 4 stringer-skin trials were followed by tests on laser beam welded 7 stringer-skin parts. Only for this test sample geometry comparable data on riveted or bonded specimen were available. The bench marks we have to respect here are:

- Riveted configuration (skin Alclad 2524T3 – stringer 7349 T76) ➔ 235 MPa
- Bonded configuration (skin Alclad 2524T3 – stringer 7349 T76) ➔ 245 MPa

Figure 14 is showing the behavior of a laser welded 7 stringer-skin panels made from medium tough skin 6013 T6 combined with a medium strength 6013 T6 stringer (~ 400 MPa) but "soft" weld zone.

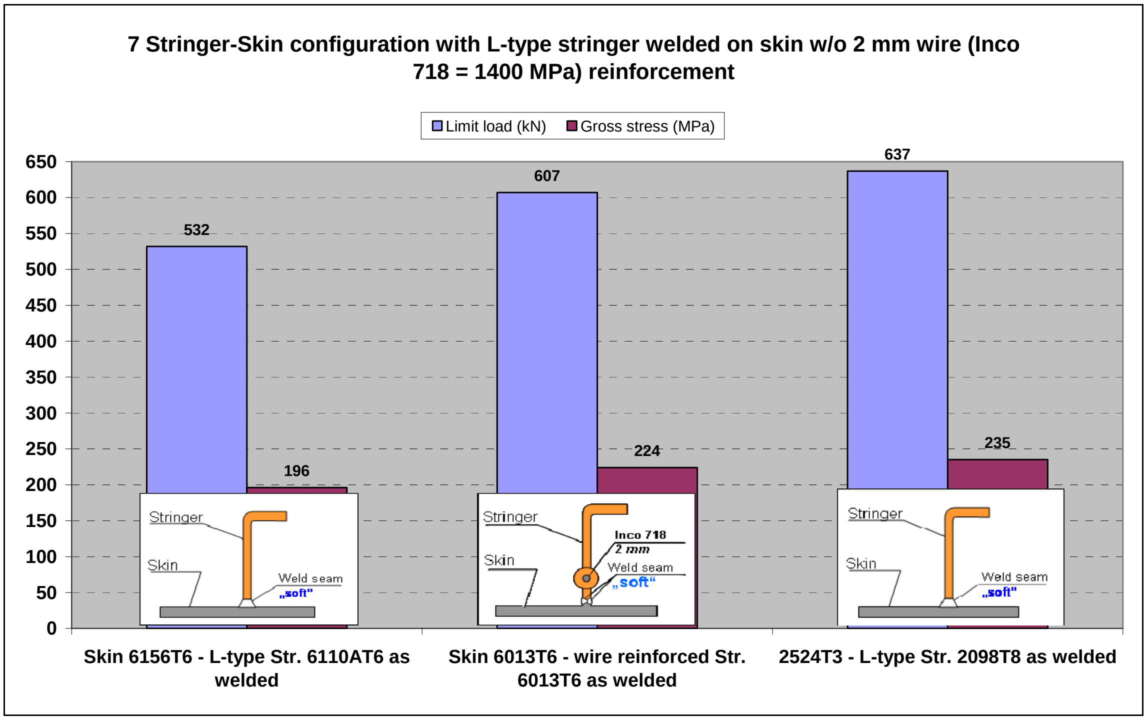

Figure 14: 7-Stringer test panels with laser beam welded stringer

The gross stress reaches nearly 200 MPa (still about 20% lower than the riveted/bonded counterpart!). Application of the stringer foot reinforcement concepts "thicker foot" and "high strength wire" enables a performance increase of about 30 MPa pushing the limit load stress beyond 220 MPa. Changing the skin from medium to high toughness (high R-curve) alcald 2524 T3 skin welded with higher strength AlCuLi 2098 T8 (UTS > 560 MPa) stringer reveals another performance gain which is now quite comparable to that of a riveted state of the art solution 2524 – 7349. Encouraged by the good results additional tests of the material combination 2524 with high strength stringer made from 2098 including local stringer foot reinforcement (more material + co-extruded wire) were performed. However the anticipated property improvements could not be fixed during residual strength tests on welded panels as an unexpected stringer peeling was discovered during limit load testing (although anti-bending devices were used during testing). A phenomenon cited as "equi-axed zone (EQZ) cracking caused this premature failure [11, 12]. A fine "grained" and thin layered solidification micro structure located at the fusion boundary adjacent to the AlCuLi alloy 2098 displays astonishingly low shear properties causing the stringer peeling which prevent required load transfer into stringer (as a prerequisite to achieve high RS numbers).

3.4 Step 4: Improvement of RS by tougher skin material and stringer foot thickening + more high strength material reinforcement ("2nd material body") and ductile weld seam

Having the negative results on laser beam welded AlCuLi type material in mind we analyzed in the next step other new high strength aerospace alloys like 2139 (AlCuMgAg) or 7081 (AlZnMgCu). Especially alloy 2139 T8 exhibits a very high R-curve.

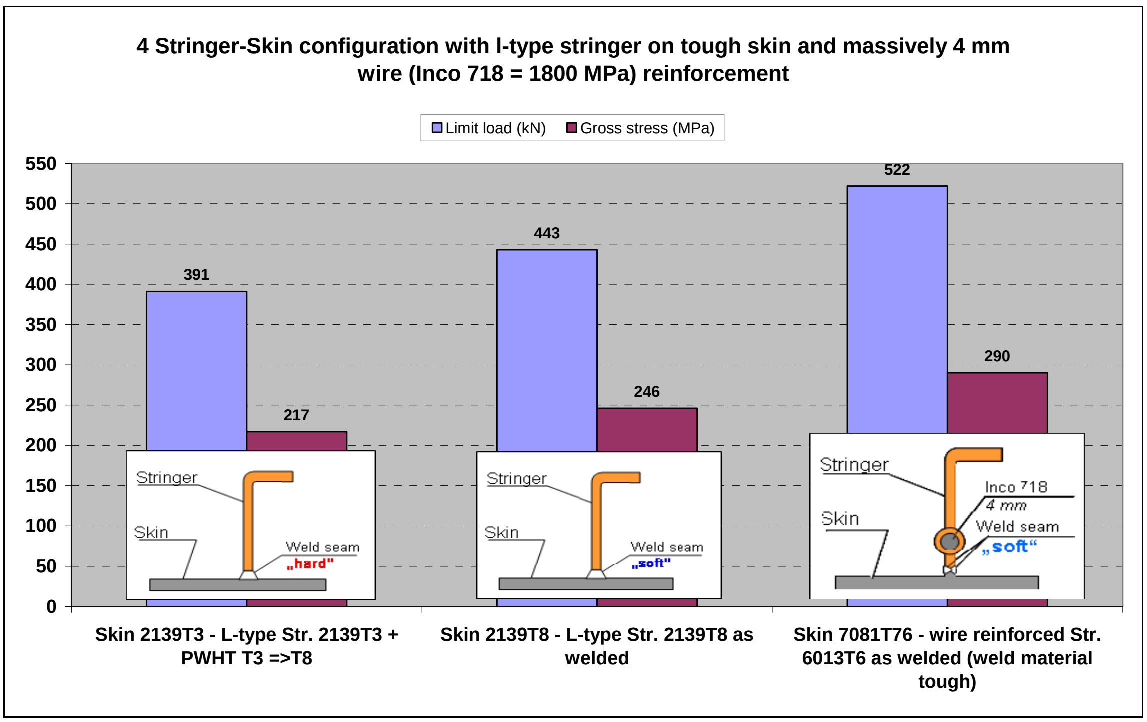

Figure 15: 4-Stringer test panels with laser beam welded stringer

Because manufacturing and testing of 7 stringer panels is pretty time and money consuming we stepped back to the 4 stringer panel geometry (s. figure 15). Again we applied the previously explained RS improvement concepts: “Soft” weld zone material (tested against 2139) and local stringer foot thickening coupled with high strength co-extruded wire. In order to see the maximum possible effect of the wire reinforcement we replaced the 1400 MPa Inconel 718 by a 1800 MPa (+ 30% in strength) wire of the same composition and a 4 fold cross section changing the limit load capabilities from 4,4 kN to 22,6 kN (each wire).
In both cases significant (positive) effects are detectable: A “soft” weld zone enables higher RS in 2139 welded structures. Compared to the results, generated with alloy 6013, we see gross stress increments of more than 40 MPa, originally to be derived obviously from the better R-curve of 2139 than 6013 and the higher strength and good notch toughness of the welded 2139 profile material than 6013 profile.
An even more pronounced improvement is shown by the wire reinforced test panels. Although the stringer base material 6013 strength is medium (~ 400 MPa) the soft weld zone area together with the tough skin and of course the massive wire reinforcement all together pushed the RS towards very high values. Taking the relation of 4 to 7 stringer panels into account (which can be calculated by comparison of the 6013 + foot/wire reinforcement data in diagram 13 and 14) the estimation demonstrates a residual strength (gross stress) of about 280 MPa, a values that surpasses the state of the art values (235/245 MPa) by nearly 20% !! Of course, the last discussed concept is not a viable flying hard ware concept but it proves where the “journey” might be headed for in order to create very good “differential” design properties in tailored (welded) integral thin sheet solutions.

3.5 Step 5: ➔ Extrapolation towards an optimum material selection for high damage tolerance (high residual strength) in tailored (welded) fuselages

So far all data generated up to now allows a more or less precise definition of particular material properties requested for competitive RS properties in welded structures:

- High toughness skin material with sufficient weldability
- Higher strength stringer profiles with even more important higher notch toughness coupled with reasonable weldability
- Weld zone material comprises of skin-, stringer- and if required filler-material that develops (mixed up) sufficient strength and high inherent plasticity
- 2nd body reinforcement wires or ribbons with very strength (to contribute specifically to the overall strength (density related)) unified with the stringer base material as reliable as possible (and cheap) => like co-extrusion)
- Locally thickened stringer foot area (if the notch toughness of the stringer alloy is limited to certain extent)

It is clear that beside the above mentioned properties other parameter like corrosion behavior, fatigue crack growth etc. are of great importance. Nevertheless many EADS Innovation Works in house results indicate that for instance a welded AlMgSc material skin solution using new high strength and notch tough Scalmalloy™ stringer combined with 3000 MPa Nivaflex Co-based wires would likely offer such anticipated progresses.

Fatigue crack growth investigations made in all this test panel variants complementarily, but not outlined in this paper in detail, showed also significant improvements concerning achievable lifetimes and da/dn ~ ∇K behavior.

4 CONCLUSIONS

Integral upper fuselage structure parts which are mainly loaded by tensile stress stresses and which have to assure sufficient residual strength if already cracked can be composed by laser beam welding. All test results are emphasizing that a careful material selection (including filler material) is mandatory in order to establish a strong and tough joint zone between the skin and stiffening element. The application of a “secondary backing” intelligently created by a redesigned stiffener foot geometry and a stronger 2nd body (ultra high strength wire(s)) allows a rearrangement of acting stresses in the shell structure thus pushing the important residual strength values towards heights so far only known from differential designed aircraft structures. This can be achieved without sacrificing the cost advantages of integral design principals.

5 ACKNOWLEDGEMENTS

The author would like to thank all the contributors made all the investigations possible

- ALU-Menziken, Menziken, CH
- ALERIS (formerly CORUS) Koblenz, Germany
- ALCAN CRV Voreppe, France
- EADS Shared research organization (RTG)
- AIRBUS Bremen and Hamburg
- All my diploma & PhD-Students
- All my EADS Innovation Works colleagues in Ottobrunn, Germany
- European Community FP6 research projects “WAFS, WEL-AIR and DATON”

REFERENCES

[1] R. G. Pettit, J. J. Wang, and C. Toh, Validated Feasibility Study of Integrally Stiffened Metallic Fuselage Panels for Reducing Manufacturing Costs, NASA/CR-2000-209342, May 2000

[2] J. Munroe, K. Wilkins, and M. Gruber, Integral Airframe Structures (IAS)—Validated Feasibility Study of Integrally Stiffened Metallic Fuselage Panels for Reducing Manufacturing Costs, NASA/CR-2000-209337, May 2000

[3] M. Pacchione, J. Telgkamp, CHALLENGES OF THE METALLIC FUSELAGE, 25th INTERNATIONAL CONGRESS OF THE AERONAUTICAL SCIENCES (ICAS 2006), June 2006, Hamburg, Germany

[4] R. Martin and D. Evans, Reducing Costs in Aircraft: The Metals Affordability Initiative Consortium, Journal of Materials (JOM), 52 (3) (2000), pp. 24-28

[5] New Alcoa aerospace solutions presented at AeroMat 2005, Alcoa Worldwide Markets Aerospace News New Alcoa aerospace solutions presented at AeroMat 2005.htm,

www.alcoa.com

[6] J. C. Ehrström, S. van der Veen, S. Arsene, R. Muzzolini, Improving damage tolerance of integrally machined panels, International Committee of Aeronautical Fatigue (ICAF 2005), 8 – 10th June, 2005, Hamburg, Germany

[7] R. J. Bucci, Advanced Metallic & Hybrid Structural Concepts… tailorable solutions to meet the demanding performance/affordability requirements of tomorrow's aircraft, Improving damage tolerance of integrally machined panels, USAF Structural Integrity Program Conference (ASIP 2006), San Antonio, Texas, November 29, 2006

[8] Uwe Zerbst et al., Failure Assessment Concepts for Thin-Walled Structures, International Committee of Aeronautical Fatigue (ICAF 2005), 8 - 10th June, 2005, Hamburg, Germany

[9] R. J. Bucci et al., Large Panel Validation of Advanced Metallic and Hybrid Structural Concepts for Next Generation Transport Aircrafts, AeroMat 2007, Baltimore, MD, USA, 25 -28th June 2007

[10] F. Palm, Improvement of residual strength in integral (welded) fuselage structures - A step by step approach to tackle this challenging issue, International Committee of Aeronautical Fatigue (ICAF 2005), 8 - 10th June, 2005, Hamburg, Germany

[11] J. C. Lippold, A. Gutierrez, A proposed Mechanism for Equiaxed Grain Formation along Fusion Boundary in Aluminum-Copper-Lithium Alloys, Welding Journal, March 1998, pp.123-132, 1998

[12] J. C Lippold, A. Kostrivas, A Method for Studying Weld Fusion Boundary Microstructure Evolution in Aluminum Alloys, Welding Journal, January 2000, pp.1-8, 2000