ALCAS CENTRE WING BOX – LOWER COVER LOW COST RESIN INFUSION STRINGER MANUFACTURING

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OVERVIEW

ALCAS (**A**dvanced **L**ow **C**ost **A**ircraft **S**tructure) is a research and technology project, which is conducted under the 6th framework program of the European Union. Among other topics AIRBUS investigates into new wingbox structural design principles in order to achieve a substantial cost reduction at reduced structural weight compared to current wingbox concepts. To validate the feasibility of the chosen concept and to verify the achievability of both the cost and weight reduction objectives, a wing box demonstrator consisting of a partial centre wing box, a partial lateral wing box and the root joint is built and subjected to representative test load cases. Within this framework, AIRBUS and their partners are responsible for the development and delivery of the centre wing box lower cover. To achieve the cost saving objectives at the component level, modern low cost CFRP infusion techniques with new NCF materials were selected. A concurrent engineering approach led to design principles that allow for the use of low cost manufacturing and industrialization techniques with excellent structural weight performance. The differential design of the lower cover promoted the application of a low cost stringer manufacturing process, which is described in-depth in this paper. These stringers will be assembled to the ALCAS centre wing box lower cover in 2007. The final ALCAS wing structural test is planed for 2009.

1. INTRODUCTION TO ALCAS

The objective of the ALCAS project is to concentrate on the cost reduction of major structural aircraft components. Among those, is the highly loaded wingbox structure at the root joint, i.e. the joint between centre wing box, fuselage and lateral wing box, which is of major interest. Therefore, a principal objective of the CEC FP6/AIRBUS project ALCAS concentrates on investigations in:

- Innovative root joint design concepts to facilitate more cost effective wing assembly processes
- Innovative main landing gear attachment concept respecting the needs of a full CFRP wingbox
- Application of low cost component manufacturing processes

A structural test of the complete wing box and fuselage attachment shall demonstrate the feasibility of the chosen design and assembly principles and the achievability of the cost reduction objectives for future aircraft wing structures.

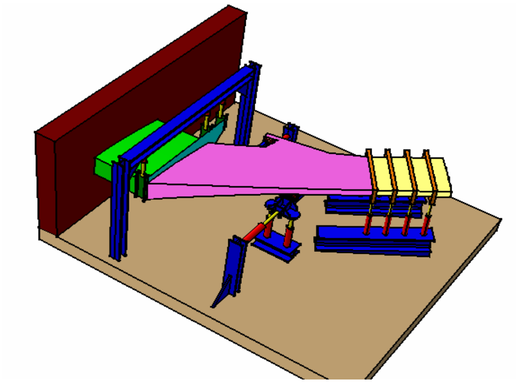
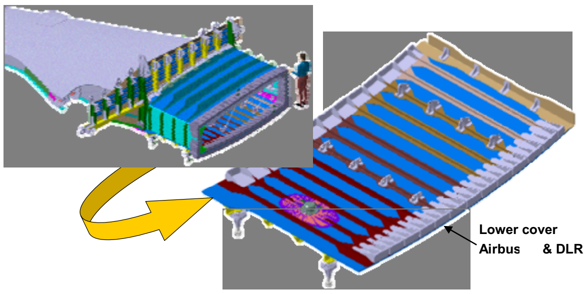


Fig. 1: ALCAS wing box structural test principle

AIRBUS and its project partners are responsible for the design and delivery of the centre wingbox lower cover.

Fig. 2: ALCAS centre wing box lower cover



To accomplish the overall ALCAS objectives at both global and component level, dedicated lower cover development objectives have been fixed during early concept trade-off studies:

- Application of resin infusion processes using dry fibre multi-axial NCF textiles for a large and thick primary structure such as the lower cover (3,7 m x 2,5 m with up to 22 mm thickness in the high-loaded areas)
- Improvement of the NCF laminate toughness to prepreg level in order to allow for weight optimized structures
- Choice of design principles to support low cost/low risk manufacturing and assembly of the lower cover.

The consequent application of concurrent engineering involving the different disciplines: materials and processes, design and stress, manufacturing and inspection, was identified to be the key feature to realise the above mentioned lower cover objectives and to allow the application of low cost manufacturing processes. As an example for the cost effective manufacturing process capabilities, the manufacturing of the stringers at the ALCAS partner DLR Braunschweig is chosen.

2. ENGINEERING AND PROCESS DEVELOPMENT

2.1. Material Screening

A key criterion for the evaluation of composite structures is the laminate performance. Despite fibre dominated laminate properties, which seem to be less dependent on the manufacturing method, matrix dominated laminate properties, for example Compression After Impact (CAI) or Bearing strength, differed in many cases quite significantly depending on the applied manufacturing technology. Prepreg based laminates with highly toughened, high viscosity epoxy matrix systems, seemed to be advantageous over Liquid Resin Infusion (LRI) based laminates, because LRI requires low viscosity resin systems are required. To utilize the cost saving potential of LRI based composite components at a competitive performance level two different approaches have been investigated. A rather conservative approach was to use a last generation standard NCF (Non Crimp Fabric) fibre reinforcement in combination with a nano particle modified resin system (Laminate A). A more innovative approach was to use a prototype NCF material, which was equipped with special toughening additives in combination with a relatively conventional resin system (Laminate B).

2.1.1. Material Selection Procedure

Both manufacturing approaches successfully proved their potential to infiltrate typical high thickness wing skin structures of more than 30 mm thickness in an out of autoclave process but the resulting laminates showed specific differences. In case of Laminate A the maximum possible flow length was smaller, but the resulting fibre volume content was close to 60 %. In case of Laminate B it seemed that the fibre reinforcement architecture had an increased permeability because it showed a higher maximum flow length and lower final fibre volume content near 55 %

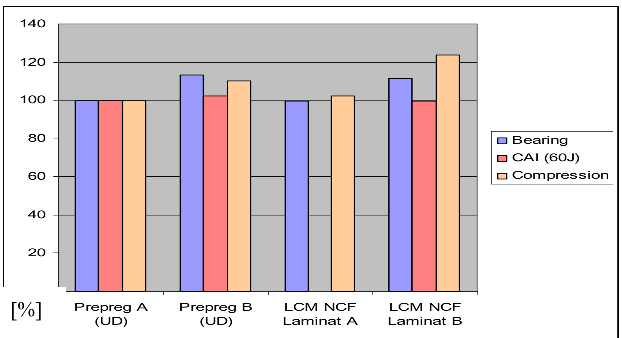


Fig. 3: Material Screening Results

From a performance point of view both laminates showed very promising results relative to prepreg level, with respect to compression and bearing strength but only laminate B showed excellent CAI performance on current prepreg level.

2.1.2. Material Decision

To demonstrate the outstanding potential of LRI based high performance, low cost manufacturing approaches, Laminate B was selected as the baseline material even though the NCF product had a prototype status, which meant larger production tolerances had to be accepted. Further investigations and manufacturing trials on a smaller scale were also carried out with Laminate A to have a back-up solution.

2.2. Design Approach

2.2.1. Objectives for the Selection of Design Principles

The ALCAS CWB Lower Cover development goals were envisaged to be met by the use of advanced materials and design features in order to realise the weight and cost saving potential of composite materials in a realistic wing box structure by:

- Extending the application of composites to more complex and highly loaded structure
- Improving the performance of composite structures (toughness)
- Increasing the “Design for Composites” approach respecting different tolerance performance than metallic structures by defining suitable interfaces
- Assessing System architecture requirements (root joint principles, tank requirements)
- Developing designs that meet architecture requirements while minimising the weight of installation and cost of manufacturing and assembly.

The shape of the lower cover is characterized by being curved in the chordwise direction, but being straight in spanwise direction, which provided the foundations for the design alternatives, which have been formulated in the beginning of the project. The cover assembly consists of the following components, which had to be taken into account for the formulation of the different design configurations:

- Skin 2500 (spanwise) x 3700 mm (chordwise)
- 13 stringer length =2500 mm
- 4 rib caps length =3700 mm
- 1 pump hole doubler
- 8 strut fittings

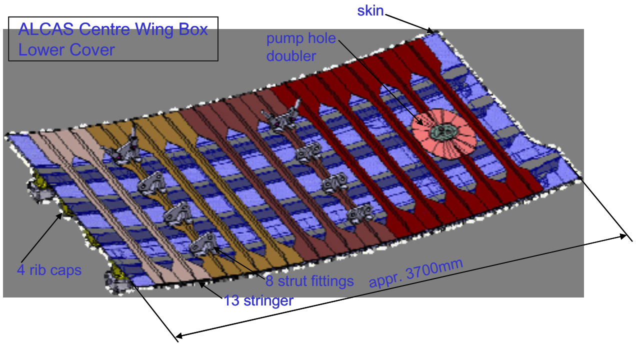


Fig. 4: ALCAS CWB Lower Cover Components

From the general geometric shape of the lower cover, its components, the envisaged manufacturing techniques, the possible assembly strategies and available assembly processes, several design configurations have been investigated and evaluated.

2.2.2. Selection of the Design Principles

Initially different shapes for the rib caps and stringers (I, Ω, T…) were investigated concerning structural efficiency, weight saving potential, manufacturing costs, manufacturability as integral part of the cover and assembly consequences for a secondary bonded (pre-cured to pre-cured) assembly to the cover. As a result of this investigation the weight efficiency of I-profile rib caps were demonstrated to be superior to the Ω-profile for this special configuration of the CWB lower cover structure. For the stringer profiles T- and Ω- profiles showed different advantages. While Ω-profile showed slightly better structural efficiency, the assembly and interface capabilities (e.g. interface to the strut fittings) led to better rating for the T-profile stringers.

From these considerations two principal configurations with four sub-variants have been derived:

- Configuration 1: stringers on IML, rib caps on OML
- Configuration 2: stringers on OML, rib caps on IML

The sub-variants to each configuration concerned the rib cap cross section and the pump hole doubler location:

- A: rib cap = Ω-profile, pump hole doubler on IML
- B: rib cap = I-profile, pump hole doubler on OML
- C: rib cap = Ω-profile, pump hole doubler on IML
- D: rib cap = I-profile, pump hole doubler on OML

These configuration have been appraised by the multifunctional project team, in order to select the best design principles for the special CWB lower cover architecture and to meet the project objectives. The topics used to rate the configurations were:

- Applicability for a family concept of stringers (to facilitate commonality in tooling and manufacturing sequence thus leading to cost reduction in component manufacturing)
- Solution for tolerance issues (to allow for cost effective assembly without weight penalties)
- Minimized manufacturing risk for components and the complete assembly (integral design versus fully differential design (secondary bonding assembly of all separate components)
- Component manufacturing and lower cover assembly efforts
- Structural weight

++ VERY GOOD (5P) / + GOOD (4P) / O NEUTRAL (3P) / - BAD (2P) / -- VERY BAD (1P)

	FAMILY CONCEPT		TOLERANCING PROBLEMS		MANUFACTURING EFFORT		ASSEMBLY EFFORT		WEIGHT		Σ
CRITERIA WEIGHT	2		14		2		14		8		
CONFIG. 1A (RIB CAP=OMEGA; PHD=IML)	+	8	+	56	O	6	+	56	O	24	150
CONFIG. 1B (RIB CAP=OMEGA; PHD=OML)	O	6	-	28	-	4	-	28	-	16	82
CONFIG. 1C (RIB CAP=I; PHD=IML)	+	8	+	56	+	8	+	56	+	32	160
CONFIG. 1D (RIB CAP=I; PHD=OML)	O	6	-	28	O	6	-	28	O	24	92
CONFIG. 2A (RIB CAP=OMEGA; PHD=IML)		0		0		0		0		0	0
INSIDE TANK! NOT DESIRABLE FOR DRAINAGE AND INSPECTION REASONS!											
CONFIG. 2B (RIB CAP=OMEGA; PHD=OML)		0		0		0		0		0	0
CONFIG. 2C (RIB CAP=I; PHD=IML)	--	2	+	56	--	2	O	42	-	16	118
CONFIG. 2D (RIB CAP=I; PHD=OML)	--	2	-	28	--	2	+	56	-	16	104

Fig. 5: Rating of Investigated Configurations

Configuration 1 with straight T-profile stringers and the pump hole doubler both on the IML performed best in the rating. This solution allowed for a family concept of all stringers promising cost reduction at component level. To keep the layup tool for the cover itself as simple as possible, and to minimize the manufacturing risks, a differential design approach for all components was chosen (shifting manufacturing risks to lower level of integration status). The decision for a male layup tool for the skin was made to fulfil the tolerance requirements for the bonding of stringers to the IML of the skin without weight penalties for bridging of large assembly gaps.
For minimizing structural weight, the design principle for the skin layup sequence was to place the butt joints of the dry fibre textile stacks in line with the stringer centre lines. Thus, additional duplication layers for bridging the butt joints of the dry fibre stack material could be avoided, since the stringer foot served as an additional load path.

This concurrent engineering approach of rating different design principles across the involved engineering and manufacturing disciplines extended the scope for optimization in low cost manufacturing and industrialization. The verification of the efficiency of this approach can be demonstrated by the cost reductions achieved in the stringer production according to the enabled family concept.

2.2.3. Design Principles for Stringer family

The family design concept of the stringers comprised

- Stringers with integrated “duck foot” load introduction areas, with accurate stringer foot thickness in the range of metallic stringers (4,15±0,2 mm) to provide a smooth interface to the cover as well as to the attachment fittings mounted later on top of the stringer feet
- There are 4 families of stringers, based on constant web thicknesses (5,5/6,9/8,25/9,65 mm), determined due to the varying chordwise loading conditions, every stringer family has the same constant foot thickness, with the web thickness being varied through the use of a web packer. Oversized raw stringers which are routed to final profile to allow for weight optimization and late design changes without special tooling or expensive tooling modifications, and avoids local doublers in the stringer web.

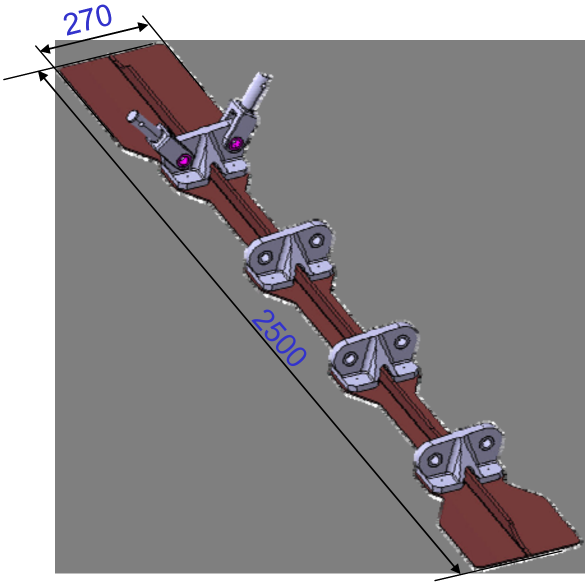


Fig. 6: ALCAS stringer with Strut Fittings

2.3. Process Development Phase

The development phase for the production started with T-profile stringers with a full scale cross section but limited length to allow for manufacturing in a conventional fan oven.

2.3.1. Mould Design for Manufacturing Trials

To realise smooth surfaces on every stringer face it was necessary to use metallic mould elements for the stringer web and the stringer foot. To reduce lead-time and costs, a large aluminium base plate, a floating aluminium caul plate and two substantial, floating aluminium mould blocks were used. To seal the manufacturing set-up two vacuum bags were used for process reliability reasons. Both vacuum bags were sealed to the base plate before the manufacturing set-up is evacuated. The decision to use an open mould concept with floating mould blocks offered the opportunity to manufacture different web and foot thicknesses without modifying the global mould concept.

2.3.2. Infusion Strategy

Since the mould elements needed to be in direct contact with the fibre preform, to ensure the required surface quality, the application of a flow aid to support the out of autoclave infusion process was not possible. For this reason the first investigations focussed on suitable infusion strategies to ensure that the fibre preform could be infiltrated completely and without voids. To evade the meeting of flow fronts and subsequent void entrapment two different infusion strategies have been analysed.

For the evaluation of the first strategy the infusion line was located at the stringer foot opposite to the stringer web The advantage here is that the flow length is relatively small but the disadvantage is that the resin has to penetrate the fibre preform through the less permeable thickness.

For the evaluation of the second strategy the infusion line was located on top of the web. Here the resin could flow directly between the different layers of the preform but the flow length is significantly longer since resin has to flow through the web and then has to split-up to infiltrate the two foot sections.

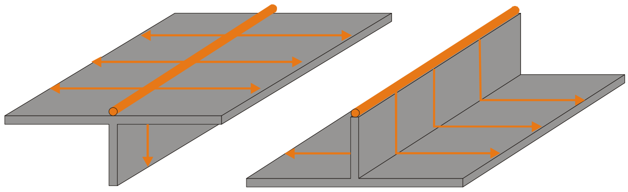


Fig. 7: Different Infusion Strategies

For both strategies it was important to avoid race tracking because otherwise the results of the trial would be invalid.

2.3.3. Infusion Technology

Typical resin infusion technologies like VARI (Vacuum assisted Resin Infusion) use vacuum ports to permanently evacuate the manufacturing set-up during the infusion phase. To protect the vacuum pump from resin ingress and sometimes to adjust the fibre volume content, resin traps are used. In order to simplify the manufacturing set-up a different infusion strategy was chosen for the manufacturing of the stringers. The so-called “Single Line” principle was derived from the autoclave based SLI (Single Line Injection) process and uses only one line to evacuate the set-up before infusion and to infuse the resin afterwards.

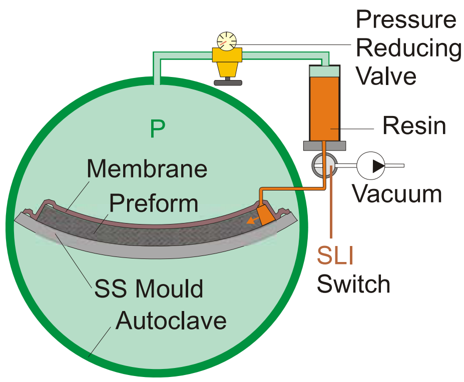


Fig. 8: SLI Technology

Trials showed that the flow front speed was only slightly slower compared to a permanently applied vacuum and the maximum flow length was comparable under the same boundary conditions. Since no hoses had to be closed, no resin traps had to be cleaned and no vacuum lines had to be connected, therefore the costly manual assistance during the infusion process was significantly reduced.

2.3.4. Results of Infusion Trials

Infusion strategy 1 (infusion line located on the foot laminate) failed because the infusion was incomplete. Resin flow stopped after half of the foot laminate was infused. Since the infusion process took more than two hours, large parts of the preform were infiltrated by resin flowing along the edges of the preform (race-tracking).

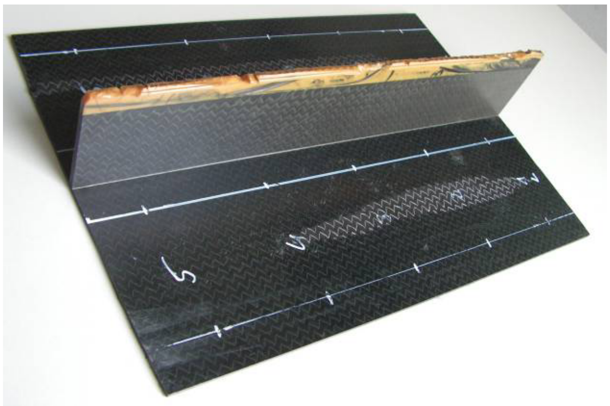


Fig. 9: Result of First Infusion Strategy

The second infusion strategy (infusion line on top of the stringer web) showed much better results. The preform was completely infiltrated and no voids in the foot section were identified, indicating that no significant race tracking occurred during the infusion.

Fig. 10: Result of Second Infusion Strategy

For the manufacturing of the full-scale stringers the second infusion strategy clearly showed a better maturity. Since the final stringer length was more than 2,5 m, race tracking effects at the stringer faces were expected to be less critical.

3. FULL SCALE PROTOTYPE PHASE

After manufacturing trials proved the viability of the manufacturing approach the results had to be transferred to the full size component.

3.1. Mould Design for Full Scale Stringer Prototypes

Cost aspects were a major design driver for the mould design. For this reason conventional aluminium plates for the base and caul plates and pultruded aluminium profiles for the floating block elements were used. The hollow block elements were closed by welding a face plate to the ends of the aluminium profiles. To ensure small tolerances for the 2,8 m long base plate a truss web support structure made from welded square steel profiles was realised. To avoid thermal distortion the base plate was only fixed to the steel support structure at two particular points close to each other. Several adjustment screws in the truss web structure were used to level the base plate.

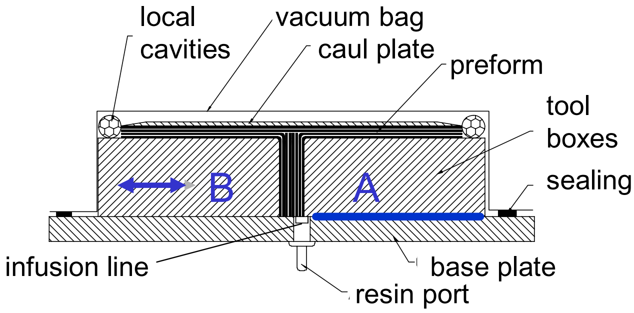


Fig. 11: Mould Design for Full Scale Prototypes

To ensure the correct positioning of the mould integrated infusion line, toolbox A was fixed to the base plate. To allow the manufacturing of different web thicknesses, toolbox B was able to move on the base plate. The caul plate on top of the manufacturing set-up was also floating allowing the manufacturing of different foot thickness. Since vacuum tightness of the hollow tool box elements was essential for the process maturity special leakage test were carried out under curing conditions (180° C)

3.2. Infusion Strategy

As a result from the manufacturing trial, the infusion line was located at the tip of the web. To increase the overall resin flow, a larger Infusion line cross section had to be realised. To avoid the problem of NCF layers slipping into the infusion line and possibly blocking the resin flow only a small gap of the infusion line was open to the preform. The rest of the infusion line was covered by toolbox A.

3.3. Infusion Technology

Instead of a permanently applied vacuum, local cavities were used at foot run outs, as was done for the manufacturing trials. To further simplify the process boundary conditions, the resin was not injected with a typical resin infusion machine located outside the oven but with a resin reservoir, which was placed inside the oven next to the manufacturing set-up.

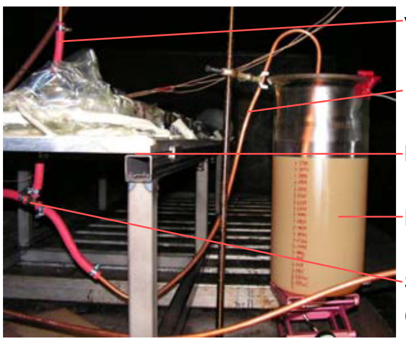


Fig. 12: Infusion Set-Up

By doing this, technical equipment like heated lines and heated resin storage containers were eliminated, and by watching the resin directly in the glass container the resin flow was monitored. The challenge here was to find the correct temperature for the resin at the start of the infusion to avoid uncontrolled exothermal reaction. Increasing the resin temperature and with reduced resin volume in the resin container during the infusion process, have to be adjusted in a way that a critical temperature is not reached until the remaining resin volume in the container is uncritical with regard to exothermal reactions. The last step towards a simplified infusion process was to use a heated tent instead of a conventional fan oven.

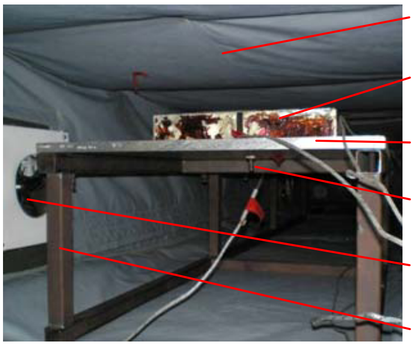


Fig. 13: Mould in Heated Tent

Apart from the cost efficiency the heated tent proved to be very flexible in terms of oven volume and installation space, which was a significant logistical advantage. In the last process configuration the stringer mould was fixed to the ground and the heated tent was built up on the prepared manufacturing set up. The heated tent was equipped with four mobile fan modules to heat up the air in the tent and to homogenise the tent temperature. Tests proved that the temperature distribution in the heated tent was acceptable at infusion temperature (120° C) and curing temperature (180° C).

3.4. Results of Full Scale Stringer Infusion

As a result of the material screening program and the manufacturing trials, the stringer production was carried out with the toughened prototype NCF fibre reinforcement and the more promising Infusion strategy. After the first infusion failed due to insufficient resin flow a second resin port was installed at the other end of the infusion line. From that point on the stringer production was both mature and reproducible. More than 29 stringers of different web and foot thicknesses have been successfully produced with only one rejection caused by a defect infusion port. The raw stringers had an excellent surface quality and no visible surface porosity. The fibre volume content was a little bit lower than expected so that the nominal target thickness had to be adapted.

Since four different web thicknesses have been produced also the spring-in angles varied from rather small spring-in angles for the smallest web thickness up to quite significant spring-in angles of more than 1° for the thick webs. To avoid bonding problems in the subsequent assembly phase, the spring-in angle was partially compensated by modifying the infusion mould. Laminate thickness variation in the foot section was within +/- 0,25 mm, which was quite acceptable for an open mould concept and the low cost aluminium mould being used.

Fig. 14: Successfully Infused Raw Stringer (Laminate B)

Even better thickness tolerances should be possible if a more accurate open mould concept with close tolerance mould elements or a closed mould approach were used.

3.5. Full Size Trials with Standard NCF and Nano particle modified Resin (Laminate A)

To analyse the producibility of stringers with last generation, standard NCF fibre products, and toughness optimised resins (Laminate A), further trials with full-size stringers were carried out. Since for most of the stringer derivatives only the "Duck Foot" area was critical for the infusion, a modified stringer preform with adapted foot width has been prepared. To ensure the infusion of the large "Duck Foot" area, limited race tracking at the preform edges was initiated to reduce the maximum flow length.

Fig. 15: Successfully Infused Raw Stringer (Laminate A)

The infused raw stringer had no visible porosity and the fibre volume fraction was 60 %. Depending on the higher fibre content, the spring-in angle was significantly smaller compared to the Laminate B stringers. Even though the process window for Laminate A stringers was even smaller than for Laminate B stringers, the results showed that a series production would be possible.

3.6. Manufacturing Costs

To evaluate the economic efficiency of the described manufacturing approach a detailed cost analyses was conducted. Both non-recurring costs (NRC) for moulds and production facilities, and recurring cost (RC) like labour and material costs were analysed.

3.6.1. Non Recurring Costs

As the major focus of the ALCAS research project was cost efficiency it was important to reduce manufacturing expenditure as much as possible. On the other hand 29 stringers had to be manufactured (2 lower covers with 13 stringers had to be equipped and 3 test stringers were needed) which means that a highly mature production concept was required in order to avoid rejections. Under these circumstances it seemed sensible to have a detailed development phase to identify possible production problems that would increase recurring costs later on. Since the budget for stringer manufacturing was extremely low, only highly improvised aluminium moulds made from standard elements were affordable. The low cost moulds were well suited to manufacture excellent laminate quality but component tolerances were affected in a negative way. Extremely important for the simple mould design was the fact that all critical geometrical details were successfully eliminated in the design phase and that commonality of the raw stringers had a high priority. Through avoiding the use of infusion machines and additional heated infusion lines, vacuum lines (only for safety vacuum bag) and resin traps, this also affected non recurring costs in a positive way. The heated tent was also an absolute low cost product but temperature control and temperature tolerances needed to be watched carefully.

3.6.2. Recurring Costs

Recurring costs for the full-scale stinger production were reduced to an extent, however quality assurance measures (ultrasonic inspection, DSC etc.) turned out to be more expensive than the production itself. Due to the simple design of the raw stringers it was possible to avoid a separate preforming phase that significantly contributed to the reduction of the manufacturing time. Furthermore, since the heated tent was built up directly above the stationary mould, no transportation of the heavy mould was necessary. As intended, the detailed development phase lead to a highly mature production process. This in turn not only helped to reduce labour costs but also the limited supply of the prototype NCF material was used very effectively. The square shape of the stringer plies lead to a very small scrap rate for the ply cutter, but it had to be taken into account that for some stringers up to 30 % of the stringer laminate was machined away in the end. Since costs for prototype resin and fibre materials of Laminate B could hardly be compared with serial products a price for a possible later serial product was estimated taking into account the excellent laminate performance. Last but not least, energy consumption was exactly measured and turned out to be insignificant for the chosen out of autoclave process.

3.6.3. Cost Analyses

The distribution of the different cost drivers shows a relatively small share of the pure labour costs (25 %), which is quite small compared with similar composite productions. Since the labour costs (time and number of people working) were extracted from real time video surveillance data their accuracy is fairly high. The share of material costs (60 %) is quite high but the possibilities to reduce these costs within the process are limited. A more net shape driven manufacturing approach would reduce material costs but would also significantly increase tooling cost. If the production rate would be high enough to justify a separate mould concept for each stringer a more net shape approach would be sensible. The tooling cost share for the production of one stringer was 14 %. This is not negligible even though tool costs were minimized as much as possible. Energy consumption (1 %) is not an important cost driver but the energy efficiency of the process is remarkable. On the other hand using an autoclave for the stringer production would increase the energy consumption but would also provide the opportunity to increase the weight efficiency of the stringers because under elevated pressure 60 % fibre volume fraction should be possible even with the high permeability prototype NCF (Laminate B).

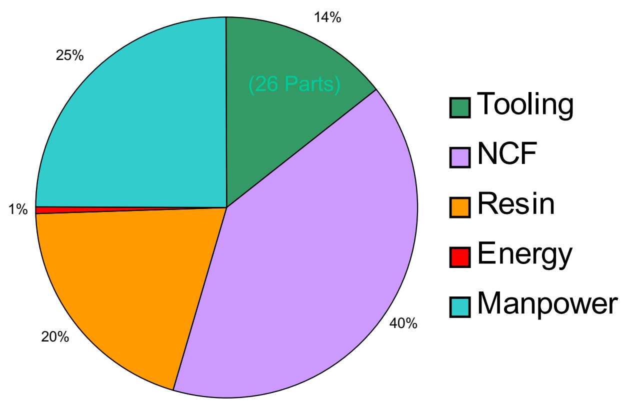


Fig. 16: Cost Distribution (Laminate A)

Development costs, quality assurance costs and machining costs were not included in the cost share distribution because they are hardly comparable.

4. CONCLUSION

The most important conclusion of this project is that today it is possible to manufacture cost efficient LRI (Liquid Resin Infusion) laminates at current UD-prepreg performance level. Unfortunately the resin and NCF materials (Laminate B) that have been used within the project are not available for a serial production although both materials had a very high development status.

The last generation standard NCF material (Laminate A) also demonstrated a very high performance level but CAI strength still has potential for further improvement.

Design principle investigations with very early involvement of manufacturing specialists led to a weight efficient lower cover structure and extended the scope for application of low cost manufacturing techniques and industrialization. Respecting manufacturing needs like restrictions in dry fibre textile material width in the choice of design principles led to the achievement of the stringent component mass targets.

The development phase for the stringer production took longer than expected because it turned out that the required flow length to infiltrate the large stringer foot and the web was quite extreme for an out of autoclave process. Flow aids could have solved that problem but the resulting uneven and wavy surfaces were unacceptable.

The production of the full-scale stringer prototypes was very mature, simple and according to the cost analyses also very cost efficient. The produced stringers showed an excellent laminate quality and high reproducibility. Taken into account that an improvised low cost mould concept was used, the resulting tolerances were acceptable. All attempts to increase the fibre content of the Laminate B stringers failed because they reduced the permeability of the NCF material to an extent that a complete infusion was no longer possible. According to CAI and other coupon test results the laminate performance was not affected by the low fibre content. By using autoclave based resin injection methods (e.g. SLI) laminates with 60% fibre volume fraction were possible but out of autoclave methods have been preferred. The application of the highly innovative heated tent was also successful since this approach offered new perspectives for a highly flexible and cost efficient production especially of very large parts.

Inline with the broad aspirations of the ALCAS project, a low cost manufacturing process has been created which shows great potential for future application. This manufacturing process does not require high-cost capital equipment such as an autoclave, which effectively lowers the barriers to enter the supply market for aerospace composite components. With a larger supply base this should, from an economics perspective, further reduce the cost of the part manufacture due to greater competition.

In order to increase the benefits of this manufacturing process, further work should be conducted to investigate the ability to co-infuse both the stringers with the skin together. If such a process would be feasible, a further saving in the manufacturing cost of the cover could be envisaged.

5. REFERENCES

[1] Kleineberg M., "LOW COST PRIMARY COMPOSITE STRUCTURES"
20th SAMPE Europe, 1999, Paris

[2] Kleineberg M., "SLI-RTM FAIRINGS FOR THE FAIRCHILD DORNIER DO328 JET"
22nd SAMPE Europe 2001, Paris

[3] Kleineberg M., " FOAM CORES IN RTM STRUCTURES
MANUFACTURING AID OR HIGHPERFORMANCE SANDWICH? "
23rd SAMPE Europe, 2002, Paris

[4] Kleineberg M., ADVANCED EQUIPMENT FOR AUTOMATED INFUSION TECHNOLOGY,
ISCM 2006, Noordoospolder

[5] Schradick M., "TANGO LATERAL WING BOX – ENGINEERING AND MANUFACTURING OF COST EFFICIENT LARGE PRIMARY A/C STRUCTURE COMPENTS"
25th SAMPE Europe, 2004, Paris

[6] Schradick M., “TANGO FLÜGELUNTERSCHALE – AUSLEGUNG, KONSTRUKTION UND FERTIGUNG VON KOSTENGÜNSTIGEN FLUGZEUGGROSSBAUTEILEN DER PRIMÄRSTRUKTUR“
DLGR-Kongress, 2004, Dresden

[7] Schradick M., “TANGO Wing – DEVELOPMENT AND MANUFACTURING OF LARGE PRIMARY STRUCTURE COMPONENTS USING NCF AND RESIN INFUSION TECHNOLOGY AND SECONDARY BONDING”
DLR-NLR Symposium, 2004, Braunschweig

[8] Sperlich, E. Lauda, S., Dürr, W., Sisk, D., EFFECTIVE MANUFACTURING OF LAUNCHER STRUCTURAL COMPONENZS, PROCEEDINGS
Int. Symposium on Advanced Materials for Lightweight Structures, ESTEC, 1994, Noordwijk

[9] Sperlich, E. Vogel, M., Aluminium SCHWEISSVERFAHREN – ANWENDUNGEN BEI RAUMFAHRT – TRÄGERSYSTEMEN,
DLR Werkstoff-Kolloquium’97
“Aluminium - Leichtbaustrukturen“

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