



## **CFRP APU INTAKE DUCT FOR MEGALINER**

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### **SUMMARY**

Since weight and cost effectiveness are essential for a successful megaliner design it was of high interest to analyse the feasibility of a composite based APU Intake Duct structure that is able to meet the fire safety demands and provides a significant cost and weight reduction. Within the development phase a resin system with acceptable fire characteristics has been identified and a cost effective manufacturing concept has been set up. In a second step a smaller test structure has been developed and manufactured in order to investigate flammability properties under realistic conditions. The results of the tests were used to optimise the design of the Megaliner APU Intake Duct. To minimise mould costs a low cost approach based on cost efficient machined foam blocks has been chosen. Even though numerous problems had to be solved during the development phase, the final design and manufacturing concept proved to be viable.

### **1. INTRODUCTION**

Within the past ten years there has been a boom in the development of promising new production technologies, matrix materials and fibre products, all of them heading towards a reduction in manufacturing costs. Some of these proved to be suitable for aerospace applications while others failed, but from today's point of view, none of these approaches seems to have the ultimate potential to be the only future technology in every respect. The technology boom itself was initiated by the Resin Transfer Moulding (RTM) philosophy which basically offered a new potential for specialised fibre products and textile manipulation methods such as draping or stitching. In order to compete with highly accepted, but also expensive and time consuming Prepreg concepts newly developed RTM and LRI (Liquid Resin Infusion) composite components have to provide both, a competitive structural performance and a significant cost saving potential. Another important factor to be considered when manufacturing aspects are addressed is the detailed design of structural components. A high degree of structural integration reduces the over all part number and therefore assembling and logistic efforts and costs. Since interface aspects are generally crucial for the effectiveness of CFRP components, a reduced

number of interfaces can simplify the design process tremendously and also provides a high potential for effective lightweight design concepts. On the other hand the manufacturing of highly complex parts can cause enormous tooling expenditures and increases the manufacturing risk. Furthermore repairability of highly complex parts is difficult to ensure with conventional methods.

## 2. MATERIAL AND PROCESS SELECTION

In addition to typical performance related criteria the APU Intake Duct has to meet quite critical Fire Smoke Toxicity demands as well. That is because the structural integrity and especially “Burn Through” safeness of the Intake Duct has to be ensured in case of a kerosene fire within the APU compartment.

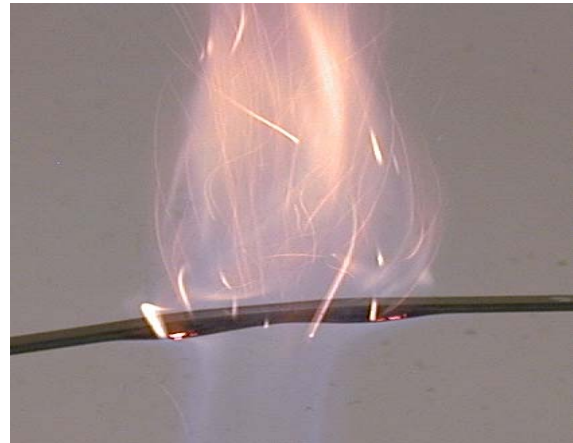
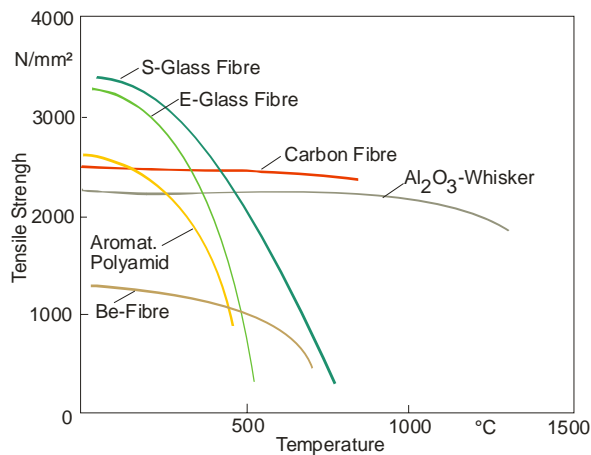


Figure 1: Temp. Resistance of Fibres (left) Test of residual laminate strength (right)

To give the pilot a chance of an emergency landing in case of an APU fire the Intake Duct has to withstand 1100°C for at least 15 minutes. In contrast to the Carbon Fibres of the reinforcement which are not critical under short term fire conditions the matrix system is highly problematic. To pass the FST tests conventional Epoxy based matrix systems usually have to be modified with special flame-retarding additives which in turn may reduce the structural performance of the matrix. Other matrix systems based on BMI, Cyanat Ester or Phenolic Resins show much better fire properties but are either not qualified for civil aviation applications or do not meet the structural performance demands. To select a suitable resin system a large screening program has been carried out, where different laminates were tested under authentic fire conditions. Special aspects that have been investigated were FST and “Burn Through” properties as well as the residual strength of fire subjected laminates. Even though phenolic resins show the best fire resistance another resin system called “Blendur” (Polyisocyanurat, by Rheinchemie) seemed to be the best compromise when all requirements like structural performance, FST, processibility, availability and last not least costs are taken into account. A serious problem of the “Blendur” system is that the expected qualification expenditure is quite high in comparison to conventional Epoxy based resin systems.

Since the selected resin system “Blendur” requires elevated pressure conditions within the curing phase the SINGLE LINE INJECTION (SLI) manufacturing method proved to be best suited. The basic idea of the SLI method is to combine the

advantages of the semi-finished products of the liquid LRI technology with the laminate quality of the Prepreg autoclave technology. Compared to other LRI methods the advantage of SLI is that the resin is injected under pressure and that the laminate can be compacted by the autoclave pressure within the curing phase. Without elevated level of pressure resin systems like “Blendur” or e.g. Phenolic resins tend to gas out which in turn causes porous and therefore unacceptable laminate qualities.

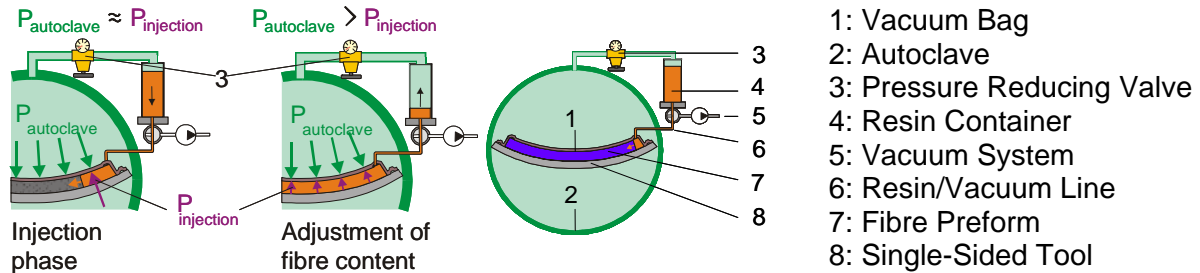


Figure 2: SLI method during injection and curing phase

An additional characteristic of the SLI method is the possibility to directly influence the fibre content by means of the process parameters. If the autoclave pressure is adjusted to be the same as the inner resin pressure, the fibre preform can relax in the thickness direction which in turn supports the impregnation due to a greater permeability. If the fibre preform is completely impregnated, the autoclave pressing on the fibre material can be selectively increased by reducing the injection pressure until the desired fibre volume content of typically 60% is reached. A great advantage of the SLI and other LRI methods is that unlike Prepreg the prepared production set up can be stored at ambient temperature without risk since it does not contain time-critical components such as active resin. In case of Autoclave based manufacturing concepts that means that the utilisation of the Autoclave plant can be optimised when resin infusion cycles are executed in times when Prepreg Cycles are inefficient.

### 3. STRUCTURAL APU DUCT CONCEPT: “SINGLE AISLE”

To reduce manufacturing costs a highly integral design consisting of two main structural parts was chosen. Both parts are joined together by “High Lock” Titanium bolts. MSC-Patran was used for dimensioning against aerodynamic related and static load cases. In case of the relatively small single aisle APU Intake Duct a single skin design was sufficient to withstand the loads resulting from differences in pressure between inside and outside of the APU Intake Duct. In some areas PMI foam core inserts were used to realise complex shaped structural details. Even though “Blendur” showed excellent fire properties there is a clear softening tendency at elevated temperature. For that reason a precured Phenolic reinforcing skeleton was added to support the “Blendur” laminate under fire conditions. For the manufacture of the Intake Duct massive aluminium moulds were used to infiltrate and cure the two U-shaped structural components. A critical aspect of the first manufacturing attempt was that the PMI foam cores were not sufficiently dried and therefore caused problems in combination with the Isocyanide components of the “Blendur” resin.

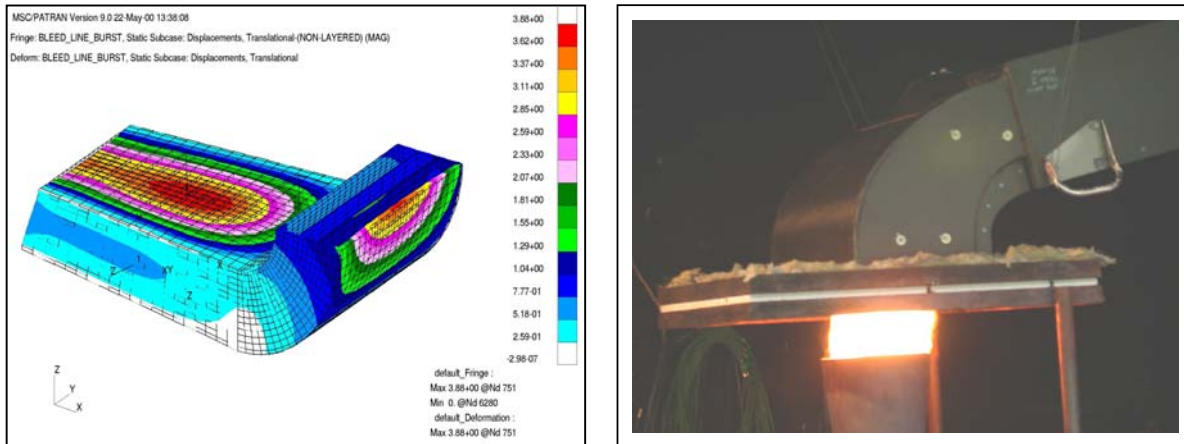


Figure 4: Stress plot (left) and Flammability test (right)

Another lesson learned was that the autoclave pressure had to be applied on the whole surface of the manufacturing set-up to avoid outgassing during the cure cycle. After these parameters have been considered within the manufacturing process, production of the CFRP components could be accomplished in the required quality. To verify the results a full scale test was carried out with one of the prototype structures under realistic kerosene fire conditions. Another prototype of the Single Aisle Intake Duct was used for a successful fit check in a real A320 Section 19. One of the results of the flammability test was that the “Blendur” laminate got soft after some minutes at 1100°C as expected and therefore needed an additional supporting concept to ensure structural integrity. Structural Integrity in turn is needed because the sealing of both ends of the Intake Duct is accomplished with spring-loaded flanges. Another important result was that bolted joints or continuous fibre reinforcements are best suited to carry loads under fire conditions. In addition bolted joints have to be designed in a way that they cannot be pulled out of the fibre reinforcement. Even though the “Burn Through” properties of the “Blendur” Laminate were acceptable it seemed that a single skin design might not be the ideal “Fail Safe” solution.

#### 4. STRUCTURAL APU DUCT CONCEPT: “MEGALINER”

Compared to the “Single Aisle” Intake Duct the Megaliner Duct was a far bigger challenge because of its size and highly complex shape. Since the material (Carbon/Blendur) and manufacturing concept (Single Line Injection) proved to be feasible they were selected for the Megaliner manufacturing approach as well. A first analytical assessment showed, that a single skin design without additional reinforcing components (like the one being applied to the “Single Aisle” Intake Duct) would result in enormous skin thickness which in turn causes an unacceptable weight penalty. To establish acceptable “Fail Safe” properties and also meet the increased structural demands a special truss web supported sandwich design was chosen for the Megaliner Intake Duct. In addition the flanges of the four main sandwich panels were designed in a way that they have a maximum distance to the hot core of a burning duct structure. Further more the flanges build up a framework between the two openings of the duct structure which is able to sustain structural

integrity. The sandwich itself also contributes to the “Fail Save” concept because even when the inner skin gets soft in case of an APU fire the outer sandwich skin is still within the temperature limits and therefore able to bear loads. The four main panels are manufactured separately and bolted together with titanium High Lock bolts. The noise absorber which consists out of aluminium honeycomb cells covered with a special felt sheet metal is integrated in the Duct housing to provide a safe interconnection between noise absorber and duct structure in case of an APU fire. The first major problem during manufacturing was that the project budget was insufficient to set up aluminium moulds for the four large and complex shaped sandwich panels.

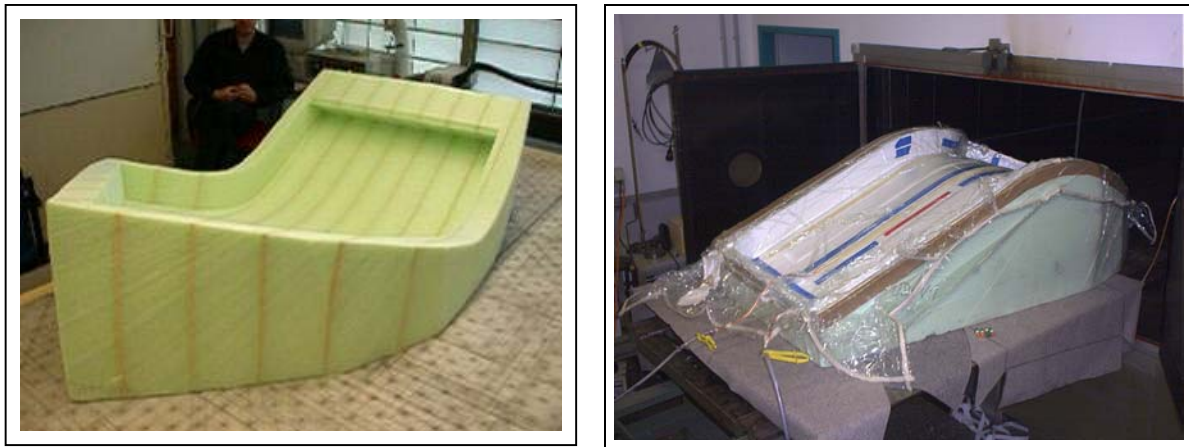


Figure 5: Low Cost Polystyrene Mould (left) and Infusion of the 100°C Mould (right)

To solve this problem a new low cost approach based on cost efficient foam moulds was chosen. The basic idea behind this approach was to start with integrally machined low cost but also low temperature (max. temp. 60°C) negative moulds that were used to manufacture a preliminary fibre reinforced positive mould with a maximum service temperature of 90°C after post cure. To reach 160°C service temperature (required to process “Blendur”) the positive 90°C mould in turn is used to form the final negative 160°C mould which is then used to manufacture the “Blendur” sandwich panels.

Mould	max. Temp.	Material	Material Supplier
Foam Mould	60°C	Polystyrene Foam	Time Out
Prelim. Mould	90°C	SICOMIN SR 8100, MAG	Time Out, Saertex
Final Mould	160°C	LY556/HY917/DY070, MAG	Vantico, Saertex

Table 1: Mould Stages

To realise the truss web sandwich, Rohacell PMI foam blocks (Röhm IG, 110 kg/m<sup>3</sup>) were cut to the required shape and wrapped with braided tubes and conventional fabrics. To form the upper and lower panel the wrapped foam blocks were arranged side by side and covered with additional skin plies. The smaller left and right panels were manufactured as conventional sandwich structures. At last the noise absorber was bonded to the upper and lower panel and the four panels were assembled.



Figure 5: Arrangement of wrapped foam cores (left), final APU Intake Duct (right)

## 5. CONCLUSION

The technical feasibility of a fire proof CFRP APU Intake Duct has been proved during the project. In addition a decisive cost reduction due to the simplicity of the manufacturing approach and a weight reduction of at least 25% over a steel design is within reach. Even though the fire resistance of the selected “Blendur” resin is superior to conventional Epoxy systems there is still the question if the results of this project justify a cost and time intensive qualification procedure.

## 6. ACKNOWLEDGEMENT

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