Design and Technology Development for a Composite Standard Body Fuselage

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Abstract

The goal of the DLR's "Black Fuselage" project is to reduce the weight of the standard fuselage of a passenger aircraft by 30% and to cut its costs by 40% by using CFRP. In particular, higher safety standards in case of impact and crash are to be attained with the new structure. A CFRP design concept for a fuselage that takes into consideration the above-mentioned goals is discussed and a corresponding manufacturing method is presented here.

Some of these construction ideas were displayed by a full-scale demonstrator that was presented at the International Aerospace Exhibition in Berlin in 2002 (ILA 2002).

1. Introduction

The weight of the fuselage accounts for approx. 12-15% of the maximum take-off weight and approx. 40% aircraft's structural weight [1]. The use of CFRP greatly increases the potential of reducing the aircraft's construction weight as does the development of special design concepts that are adapted to the particular features of this material [2, 3].

Fuselages made of CFRP are already known for their application in small passenger aircraft (e.g. "Premier I"). However, they have not yet been realized for large passenger aircraft with container cargo compartments and that have a capacity for over 100 passengers.

As the starting point for the generation of design concepts for large CFRP fuselages the following was taken into consideration: the specifications for a future fuselage and for today's standard fuselage ("standard body") made of aluminum alloys as a reference structure. Furthermore the particular features of CFRP as a construction material were included. The design concept for a CFRP fuselage, the so-called Gondola Concept, [4], is presented and discussed here.

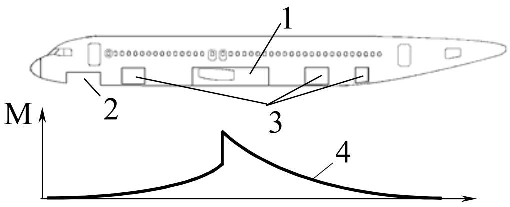
2. Basic Requirements for a CFRP Fuselage

Today's objectives for future fuselages of passenger aircraft to be developed in Europe contain the following basic requirements: a weight reduction of 30% and a cut in 40% of costs; an increase in passenger safety in case of impact and crash; a reduction in inspection efforts; technical solutions that can be realized in the near future; etc [5].

3. Special Features of the Reference Structure as the Metallic Fuselage of a Passenger Aircraft ("Standard Body")

A "Standard Body" passenger aircraft fuselage with a pressurized cargo compartment is considered as the reference structure of a CFRP fuselage (Fig. 1).

The supporting, pressure-ventilated lower panel has large cut-outs for the nose gear bay, the cargo doors, and for the interfaces and the main landing gear compartment. The latter is located in the area of the greatest bending moments.



1 - interface and main landing gear compartment;
2 - nose gear bay;
3 - cargo doors;
4 - bending moments alongside the fuselage

Fig. 1 "Standard body" as the reference structure of a CFRP fuselage

Each of the cut-outs weakens the construction and is also a source for the concentration of stress. In addition, the reference structure has pressure-loaded flat frames and panels, a pressure-ventilated floor (in the interfaces and landing gear compartment) that are subjected to bending loads. From a structural mechanics point of view, the supporting lower panel of the standard fuselage is not an optimized lightweight fuselage construction. In addition, the design of the above-mentioned cut-outs are elaborate and lead to high manufacturing costs.

4. Particular Features of CFRP as a Construction Material

CFRP shows high, specific tensile and compression strength and a rather low, specific shear bearing strength. When the UD share is increased, CFRP becomes "sensitive to notches" and loses its strength advantages in the areas of the cut-outs and bolted joints.

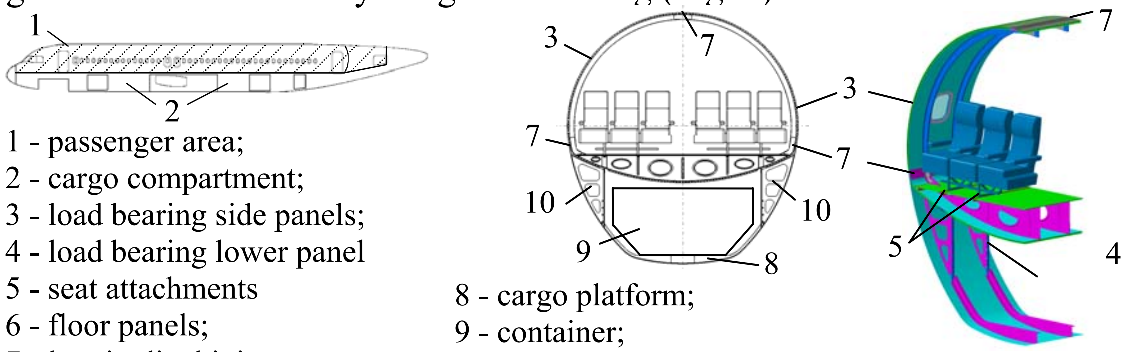
In addition, components made of CFRP are much more sensitive to impact, i.e. a degradation in the mechanical properties can be expected after impact. This condition can result in the need for short inspection intervals and high maintenance efforts.

Analysis of the reference structure and the particular features of the CFRP material has clearly shown that the requirements for the CFRP fuselages of large passenger aircraft can only be met with new design concepts. The search for solutions took place on both a global level by creating a comprehensive concept for a CFRP fuselage and on a local level by examining the design concept of panel components.

5. The Gondola Concept: CFRP Fuselage Construction with a Pronounced “Sacrificial” Structure

5.1 Overall Concept

The "Gondola Concept" CFRP fuselage design is based on a typical low-wing aircraft configuration. The characteristic of the basic variant of this concept is that the passenger area is a pressure-loaded primary structure and is stressed by the global loading. The cargo area, on the other hand, is a non-pressure-ventilated secondary structure (gondola) that is stressed locally by the cargo containers and not by the global loading (Fig. 2).



1 - passenger area;
2 - cargo compartment;
3 - load bearing side panels;
4 - load bearing lower panel
5 - seat attachments
6 - floor panels;
7 - longitudinal joint
8 - cargo platform;
9 - container;
10 - longitudinal beams;
11 - crash elements

Fig. 2. Gondola concept of a CFRP fuselage (basic variant)

The passenger area is made up of three circular load bearing panels: two side panels and a lower panel. The latter contains seat attachments and floor panels that are additional supporting structures which are stressed by the global loading. The lower panel is approx. twice the radius of the side panels. The length of the panels is the same as that of the passenger area. The frames, stringers, and local reinforcements are integrated into the panels. The supporting construction of the fuselage is therefore a highly integrated unit and contains only two longitudinal and three transversal joints, which leads to a reduction in weight and in cost during the assembly process. From a structural mechanics point of view, this is a supporting construction without large cut-outs and large differences in stiffness.

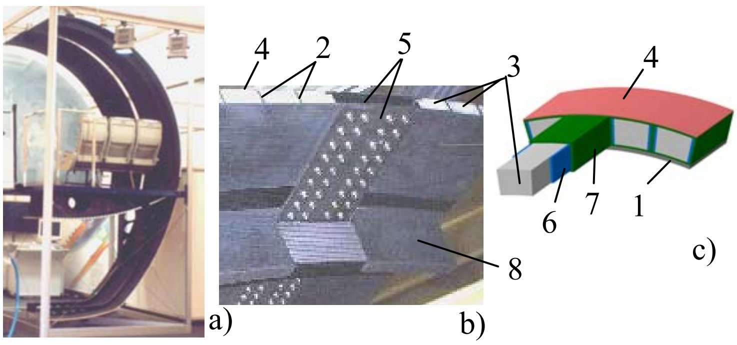
In the basic variant of the concept, the gondola cargo compartment contains cargo platforms that are attached to the lower panel of the passenger area. Since the construction height of the main structure (passenger area) is purposely reduced, the cargo compartment can contain reinforcing, uninterrupted longitudinal beams which take on the global loading and between which a main landing gear can be placed when being retracted. The cargo platforms are manufactured as modules and do not have a supportive function with regard to global loading.

All gondola elements have a protective function for the load bearing lower panel of the passenger area and therefore are so-called “sacrificial” structures. A small fracture as the result of debris impact (e.g. shrapnel from the runway) does not lead to leak in the passenger area and therefore to a risk of decompression. The gondola elements also serve as energy absorbers in the case of loading due to a crash landing and can be supplemented by additional crash elements. The gondola's outer panel skin serves as an impact detector which reduces the maintenance efforts of the load bearing inner panel skin.

The gondola concept has different derivation variants [4] , e.g. without cargo platforms and with light cargo compartment doors. The container can be directly attached to the supporting lower panel (the easiest way with regard to the weight) or with suspended supporting belts. The supporting belts can serve as additional impact protection in case the container is not installed. The non-pressure-ventilated cargo compartment structure allows for the cargo compartment to be adapted to different transportation purposes. This way it is possible to make use of different cargo compartment cross-sections, depending on the type of transportation, and therefore react more flexibly to cargo and passenger needs. The container and gondola can also be designed as pressure-ventilated cells which, however, would result in additional weight.

5.2 Panel and Full-Scale Demonstrator Design

Within context of the full-scale demonstrator of a CFRP fuselage (Fig. 3a), the SOFI principle (Stringer Outside, Frame Inside) was considered with the stringers in the position of a so-called 1½ sandwiches whose outer, thin, aerodynamic skin serves as a damage detector in the case of impact (e.g. hail), see (Fig. 3b).



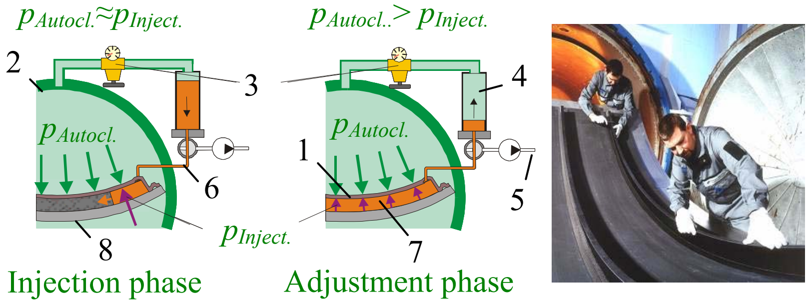
1- load bearing skin (primarily ±45 layers);
2 - stringers (high share of 0° layers);
3 - foam core;
4 - detector skin;
5 - CFRP/titan fittings;
6 - CFRP UD;
7 - CFRP tubes (±45°- и 0° layers);
8 - frame

Fig. 3. Demonstrator and supporting shells of the CFRP fuselage

The foam core protects the load bearing, inner skin from impact damages and serves as thermal insulation and a noise absorber. The load bearing skins of the panels are linked by bolted joints and CFRP/titan-hybrid fittings (primarily made of UD layers). The CFRP/titan-hybrid guarantees effective interconnection and reinforcement functions in the corresponding longitudinal and transversal directions of the fuselage. An arrangement of the sandwich components by means of stringer modules is shown in Fig. 3c.

6. Shell Manufacturing Methods and Weight Estimation of a Fuselage

The load bearing panels are manufactured by an injection method called SLI (Single Line Injection) [6], which is characterized by high quality comparable to the prepreg technology. A low pore level is attained and the fiber volume content can be adjusted during injection by controlling the autoclave and injection pressure (Fig. 4). This method does not require any massive moulds (as compared to RTM) and is flexible with regard to fiber and resin type, type of reinforcement, and manufacturing logistics.



1 - vacuum film;
2 - autoclave;
3 - pressure-reducing valve;
4 - resin container;
5 - vacuum system;
6 - resin/vacuum transfer line;
7 - fiber preform;
8 - single-sided tool

Fig. 4. Injection method for the manufacture of shells (SLI)

A weight estimation of the CFRP fuselage shows that a reduction of up to 28% in weight can be achieved if the same bending stiffness as that of the metallic standard body is taken into account. In this layout a maximum normal stress of only 260 MPa occurs (strength of bolted joint in CFRP/titan fitting amounts up to 700 MPa). The stiffness reserves allow for the weight to decrease even more in case the stiffness requirements can be reduced.

7. References

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