Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

NLR-TP-2002-020

The development of a composite landing gear component for a fighter aircraft

H.G.S.J. Thuis

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR-TP-2002-020

The development of a composite landing gear component for a fighter aircraft

H.G.S.J. Thuis

This report is based on a presentation held at the SAMPE Europe International Conference 2002, Paris, France, 9-11 April 2002.

Division:	Structures and Materials
Distribution:	Unlimited
Classification title:	Unclassified
	January 2002

Summary

The use of Resin Transfer Moulding (RTM) as fabrication technique for structural components for the aerospace industry is increasing gradually. Although RTM moulds often are complex and expensive, RTM has several advantages compared to the autoclave fabrication method, which at this moment is the standard method used in the aerospace industry. One of these advantages is that complex shaped components can be made that would be very cumbersome or even impossible to make by autoclave processing. This means that designers now can design composite components as replacement of components made with metal forging.

In the framework of a technology programme, a composite landing gear component for a fighter aircraft was developed as replacement of a steel component. The targets of the programme were to achieve a weight reduction of 20 % and a cost reduction of 15 %, which both were met. Several components were fabricated by RTM and tested successfully.

In the paper a brief presentation is given of the design of the composite component, the RTM tooling concept and RTM set-up, and a brief overview of the test results.

Contents

(12 pages in total)

1 Introduction

Composites are increasingly used in aerospace components like wing panels, stabilizers and control surfaces. With new fabrication techniques like RTM, designers get the opportunity to replace metal forging by composite components. This opens the door for designers to develop composite landing gear components.

In the framework of a national technology programme, a composite landing gear component was developed. The main targets to be met were to realize a cost reduction of 15 % and a weight reduction of 20 % by replacing a steel landing gear component by a composite component. The technology programme was carried out in close collaboration with SP aerospace and vehicle systems. The National Aerospace Laboratory NLR carried out the design of the component, developed the RTM tooling concept, carried out a limited material qualification of the composite materials used and fabricated the landing gear components. SP aerospace and vehicle systems was responsible for the requirement specifications and the test programme on the full scale components.

The paper presents a description of the landing gear component. The RTM tooling and fabrication concept developed are presented in detail, followed by a brief description of the test programme and a brief presentation of the test results.

2 Description of the component

In order to demonstrate the feasibility of composite landing gear components, a demonstrator had to be selected. After a brief survey, the lower drag brace of a main landing gear of a fighter was selected. Figure 1 presents an overview of the main landing gear and the location of the lower drag brace.

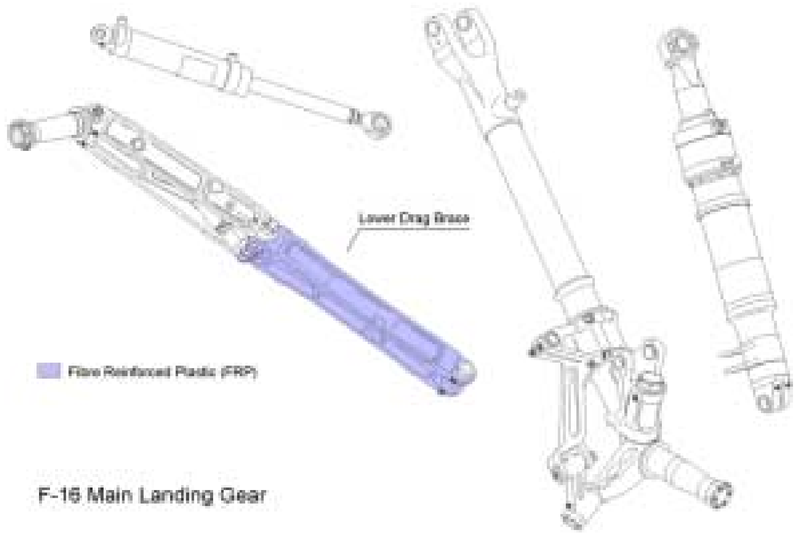

Fig. 1 Overview of the main landing gear and the position of the lower drag brace

This component was selected since the lower drag brace is one of the main load carrying elements of the landing gear and will be loaded in tension and compression during take-of and landing. Therefore the technological value of this component is high. Another reason for selecting this component was the fact that SP aerospace and vehicle systems fabricates the metal (high strength steel) drag brace in series production. This means that within this program a good comparison in performance, weight and costs between the composite and metal drag brace could be made.

The composite drag brace had to meet a large number of requirements. The most important were:

- The lower drag brace had to fit in the main landing gear of an F-16 fighter.
- The maximum weight was limited to 6.2 kg (80 % of the weight of the steel drag brace).
- Impact damages up to 86 Joule should not lead to a reduction in strength.
- The drag brace should be able to operate at 70 °C and 85 % relative humidity.
- The chemical resistance of the composite material used should be high.

The metal lower drag brace is configured as an I-shaped beam. For the conceptual design of the composite drag brace, the box girder concept was selected. This concept was selected since a box girder has a limited number of free edges (as these are sensitive to impact damages), hence increasing the damage tolerance of the drag brace. The composite drag brace was configured with three lugs: two to enable the rotation of the component during take-off and landing of the aircraft and one for connecting a locking device. The middle of the drag brace was tapered, in order to meet the interface requirements of the main landing gear. The RTM fabrication method was selected to produce the composite drag brace. This fabrication concept was selected, because with RTM complex shaped components can be made within very tight outer dimensional tolerances. Since at the time the conceptual design was made no design allowable of the materials used were at hand, the conceptual design was based on assumed design allowables.

3 Materials used and material properties

For fibre reinforcements the following Non Crimped Fabrics (NCF) were selected:
- [+45°, -45°], 705 gram/m^2 and IM-7 (12 k) fibres.
- [0°, 90°], 817 gram/m^2 and IM-7 (12 k) fibres.

Before being processed to a pre-form, the NCF's were applied with binder powder Cycom 790. The resin Cycom 890 was selected for its compatibility with the binder powder and its excellent mechanical properties and glass transition temperature $T_{g\ wet}$ of 169 °C.

In order to determine design allowables a limited material qualification program was carried out by testing coupons of one batch of NCF's and one batch of resin. The results of the material qualification program were transferred to B-basis values. Coupon tests were carried out at ambient and hot/wet (70 °C and 85 % relative humidity) conditions. In order to determine the chemical resistance, interlaminar shear tests were carried out at specimens that were exposed to white spirit, turbo clean, kilfrost, JP-8 and several hydraulic oils for a period of 1000 hours.

The allowable average design strain level was determined by testing Open Hole Compression (OHC) specimens at ambient as well as cold dry (-55 °C) and hot/wet conditions (70 °C and 85 % relative humidity). The OHC specimens had the same lay-up as the lay-up that was defined during the conceptual design of the drag brace. This allowable design strain level should enable the load carrying capability of the drag brace after being damaged by an impact.

4 Detailed design

Once the design allowables were determined the detailed design could be made. The detailed design was made by carrying out finite element calculations for which B2000 was used. B2000 is NLR's test bed for computational structural mechanics. The finite element model was composed of four-noded Stanley-type shell elements. The optimisation module B2OPT within B2000 was used to optimise the composite drag brace for minimal weight with maximum values for the strains, and displacements as constraints. In order to facilitate the optimisation, laminate design variables were defined. The means that the number of 0°/90° NCF and +45°/-45° NCF layers varied during the optimisation, leading to an optimal laminate. The Tsai-Hill failure criterion was used as a failure criterion. The optimum was found after 12 optimisation cycles. After completion of the optimisation a buckling analyses was carried out. The first buckling mode had an eigenvalue of 4.05 (margin of safety of 4.05). The weight of the optimised composite drag brace was 4.7 kg, which is a reduction of 39 % in comparison to the steel lower drag brace.

The lugs were not modelled in detail since this would increase the complexity of the model. The load carrying capability of the lugs was determined experimentally by testing scaled lug specimens. Figure 2 presents the finite element model of the composite drag brace after optimisation. The figure shows the two main lugs and the smaller lug to connect the locking device. The square hole in the drag brace was necessary to avoid interface problems in the main landing gear assembly.

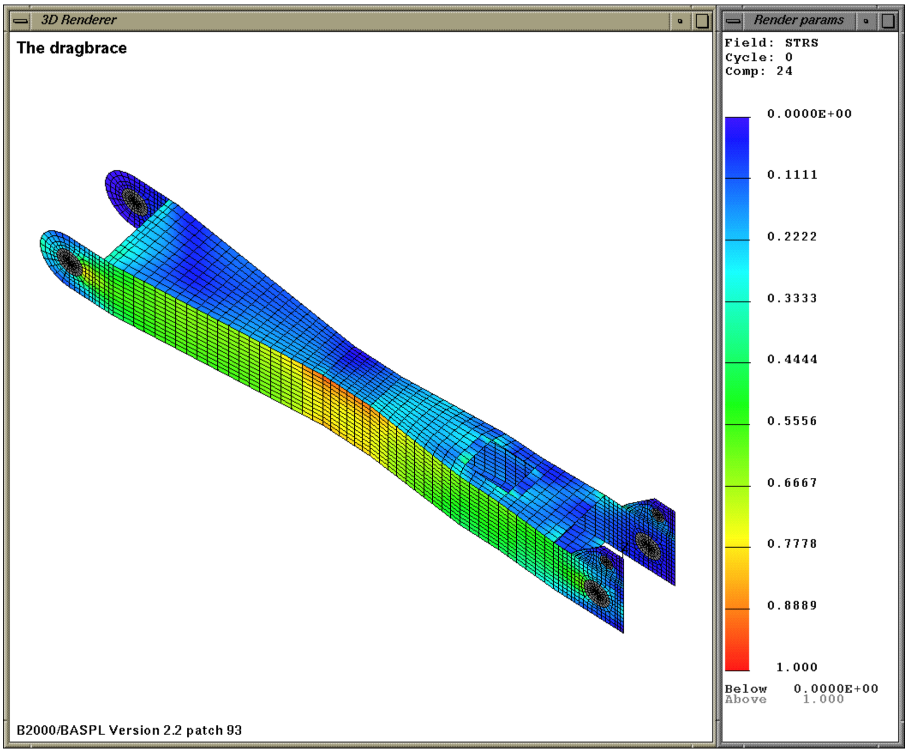

Fig. 2 Tsai-Hill values for the optimised composite drag brace

5 Sub-component testing

As the lugs were not modelled in detail it was decided to fabricate scaled lug specimens with scale 1:2 with the same lay-up as the optimised drag brace. The specimens were made by RTM and tested in tension to failure. The tests demonstrated that the load carrying capability of the lugs was sufficient, since all specimens failed beyond Design Ultimate Load.

Impact tests with impact energies up to 86 Joule showed that the lugs were sensitive to impact. To solve this problem full scale generic lug specimens were made with the same thickness and lay-up as the lugs of the composite drag brace. In order to increase the damage tolerance, titanium plates with a thickness of 2.0 mm were bonded to these generic lug specimens. These specimens were impacted with 86 Joule with a spherical tub with a diameter of 0.5”. After being impacted the specimens were cut and the cross sections were examined. The test demonstrated that the titanium plates protected the generic lug specimens sufficiently. Figure 3 presents one of the cross sections that were made. It was therefore decided to configure the composite drag brace also with titanium protection plates.

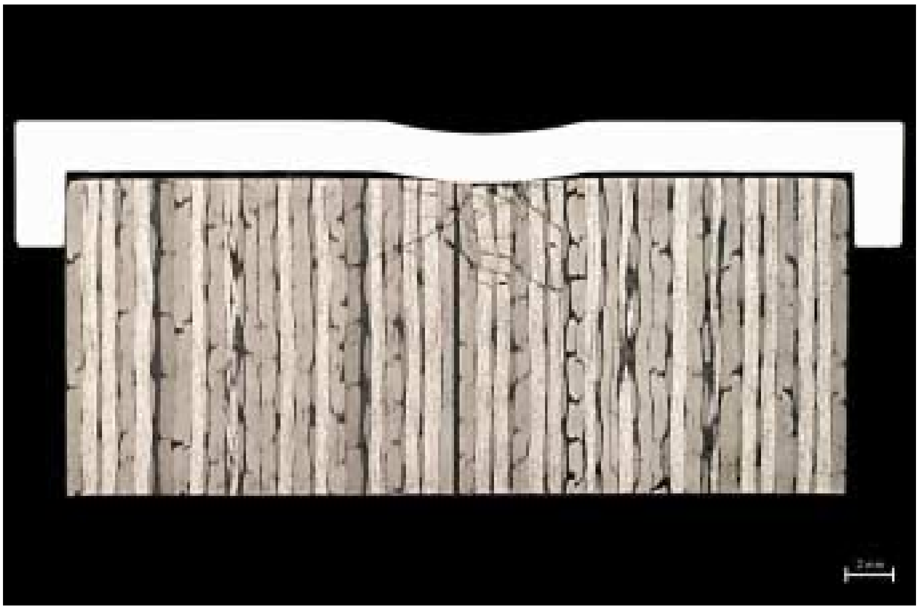

Fig. 3 Cross section of the generic lug specimen with a 2.0 mm thick titanium protection plate after an 86 Joule impact

6 Description of the tooling concept

As mentioned earlier, the composite drag brace was manufactured by RTM. The RTM tooling concept to be developed should be able to fabricate three drag braces per day during a period of years. Therefore it was decided to develop an RTM tool with a stiff heated outer mould, a relatively simple inner mould without heating elements and a core mandrel. All mould elements were made of steel. The core mandrel was used to make the pre-form. The inner mould was used to shape the pre-form to the required dimensions. The outer mould was used to heat the inner mould, the pre-form and the core mandrel. In a production environment this outer mould could be replaced by a heated press.
In advance of an RTM cycle, the core mandrel, the pre-form and the inner mould were positioned in the outer mould. By duplicating the inner mould several times, parallel pre-form stations can be made. By doing this, an RTM carrousel can be introduced in which three composite drag braces per day can be made without needing three expensive heated tools.

7 Manufacturing of the RTM drag braces

The RTM drag braces were made as follows. First, the core mandrel was used to make the pre-form. Due to the binder powder, the individual layers of the pre-form could be heated in order to make the layers tacky. Due to the tackiness the preparation of the pre-form can be compared with laminating pre-preg layers for autoclave processing. Figure 4 shows one of the pre-form layers that is pressed to the pre-form with a heated plate. The pre-form was stabilised by heating the pre-form under vacuum in an oven at 120 °C for 30 minutes.

Fig. 4 Making the pre-form on the core mandrel

After completion of the pre-form, the pre-form including the core mandrel were positioned into the inner mould (see Fig. 5)

Fig. 5 Positioning the pre-form and core mandrel into the inner mould

Then the inner mould was placed in the outer mould (see Fig. 6).

Fig. 6   Positioning the inner mould (including pre-form and core mandrel) into the outer mould.

Finally the RTM machine and the heating elements were connected to the outer mould and the resin was injected. During each RTM cycle, the most important RTM process parameters like temperature distribution of the RTM mould, temperature of the resin, injection pressure and resin flow were recorded. Resin was injected via one injection point at the end of the drag brace.

Entrapped air and excessive resin could escape through two ventilating points at the other end of the mould. Resin was injected at a temperature of 120 °C. Injection started with an injection pressure of 0.1 N/mm^2 and was increased gradually to 0.9 N/mm^2 at the end of the injection cycle.

After being cured at 180 °C, the drag brace was removed from the mould and was post cured at 200 °C for 2 hours. After the post-cure, the drag brace was inspected by C-scan. Six drag braces were made successfully. After being inspected, the lugs were machined and the square hole was machined in the center of the component (see Fig. 7).

A rough cost model was generated in which non-recurring cost (e.g. heated press, RTM moulds, C-scan, RTM machine etc.) and recurring costs (composite materials and labor) were incorporated. Cost calculations were carried out for a series of 1000 and 6000 components. The model showed that for 6000 components the cost target of 15 % can be met (see Fig. 8).

Fig. 7 Cured composite drag brace after machining the lugs

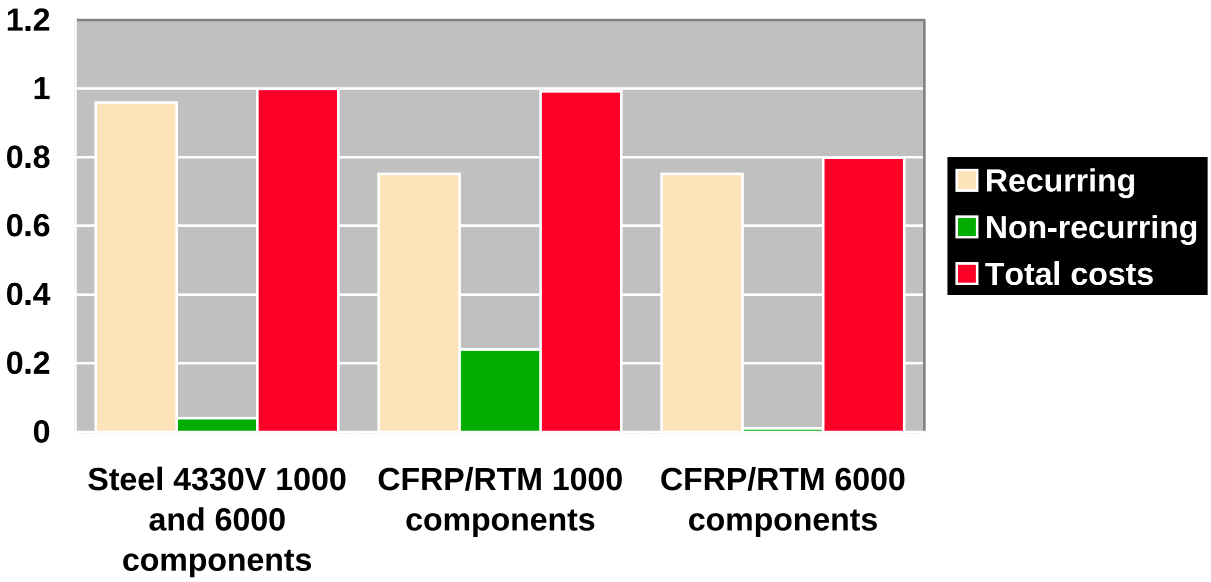

Fig. 8 Cost comparison between a steel drag brace and a composite drag brace

8 Test programme

In total, six composite drag braces were fabricated. These drag braces were subjected to static as well as a limited fatigue test program. The static tests also comprised damage tolerance tests in which a drag brace was tested statically to failure with impact damages. All these tests were carried out by SP aerospace and vehicle systems. All tests were carried out successfully, which means the drag braces failed beyond the required load levels or fatigue live. After completion of the test programme, one drag brace was assembled in the main landing gear of an F-16 fighter and several take-off and landings were carried out successfully.

9 Conclusions

A technology programme was carried out successfully. The programme demonstrated that RTM can be used as fabrication method for making complex shaped damage tolerant landing gear components. By using composites in stead of steel large weight saving can be obtained. For large series cost savings seem also feasible.