

# COMPOSITE LANDING GEAR COMPONENTS FOR AEROSPACE APPLICATIONS

**H.G.S.J. Thuis**  
**National Aerospace Laboratory NLR**

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## Abstract

Composites are being used increasingly for structural components for aircraft and space applications because of their superior specific strength and stiffness properties in comparison aluminum and steel. The weight savings that were realized by applying composites used to be one of the main drivers to apply these materials. However, nowadays a reduction in fabrication cost is becoming important as well. The objective therefore is to combine new cost effective fabrication methods with lightweight structural concepts in order bring the exploitation of composite materials to a higher level.

Up to now, the autoclave process is the standard fabrication technique to produce composite components for the aerospace industry. Recent developments show the evolution of new cost efficient fabrication techniques and of composite materials for these new techniques. One of these (for the aerospace) new fabrication methods is Resin Transfer Moulding (RTM). The RTM fabrication concept is based on the injection of resin into a mould cavity containing dry fibers (preform). During the injection process, air in the mould is being replaced by resin and the fibers are impregnated. Although RTM tooling can be complex and expensive, RTM has several advantages compared to autoclave processing. One of these advantages is that thick 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 several technology programs the Structures Technology Department as part of the Aerospace Vehicles division of NLR developed several composite landing gear components for a large military helicopter and a fighter aircraft. These programs were carried out in close collaboration with the landing gear manufacturer SP aerospace and vehicle systems. The targets of the programs were to achieve not only weight reductions of 20% but also to reduce the manufacturing costs by 15% and to achieve a reduction in lead-time.

Several different landing gear components were fabricated successfully by RTM and tested. All tested landing gear components failed beyond their required failure load levels. All program targets were met.

The present paper will present an overview of the design concepts of these composite landing gear components. The RTM tooling concepts and the RTM manufacturing set-ups will be described and a brief overview of the test results will be given.

## 1 Introduction

Composites are being increasingly used for structural components for aircraft and space applications because of their superior specific strength and stiffness properties in comparison aluminum and steel. The weight savings that were realized by applying composites used to be one of the main drivers to apply these materials.

However, nowadays a reduction in fabrication cost is becoming important as well. The objective therefore is to combine new cost effective fabrication methods with lightweight structural concepts in order bring the exploitation of composite materials to a higher level.

Up to now, the autoclave process is the standard fabrication technique to produce composite components for the aerospace industry. Recent developments show the evolution of new cost efficient fabrication techniques and of composite materials for these new techniques. One of these (for the aerospace) new fabrication methods is Resin Transfer Moulding (RTM). The RTM fabrication concept is based on the injection of resin into a mould cavity containing dry fibers (preform). During the injection process, air in the mould is being replaced by resin and the fibers are impregnated. Although RTM tooling can be complex and expensive, RTM has several advantages compared to autoclave processing:

- Matched die tooling concepts can be used, assuring tight outer dimensional tolerances, hence reducing the amount of shimming during assembly
- Net-shaped or nearly net-shaped components can be made, hence reducing the amount of trimming after curing the composite component
- Complex shaped thick components can be made that would be very cumbersome or even impossible to produce by autoclave processing.

The RTM fabrication concept makes it possible for designers to replace metal forging by composite components. This opens the door for designers to develop composite landing gear components. In order to demonstrate the feasibility of composite materials in landing gear applications, NLR carried out several technology programs. These programs were carried out in close collaboration with the landing gear manufacturer SP aerospace and vehicle systems. The main targets of these

programs were to realize a cost reduction of 15% and a weight reduction of 20% by replacing metal landing gear components by composite components.

The present paper presents the development of two different landing gear elements: a drag brace for a fighter aircraft and a trailing arm for a helicopter. The design concepts will be described followed by a description of the manufacturing process. Most of the landing gear components were tested. The paper will present a brief overview of these test programs followed with a presentation of the test results.

## 2 F-16 Drag brace development

In order to demonstrate the feasibility of highly loaded composite landing gear components a technology demonstrator had to be selected. After a survey, the lower drag brace of the main landing gear of a fighter was selected. Figure 1 presents an overview of the F-16 main landing gear and the location of the lower drag brace.

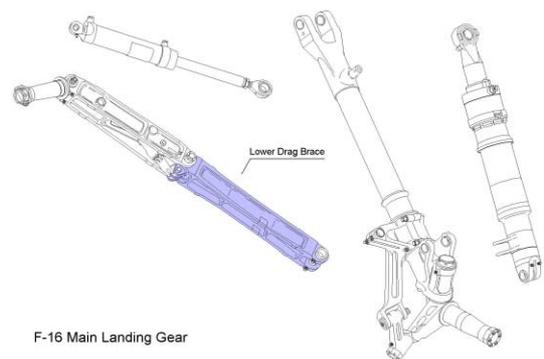


Figure 1: F-16 main landing gear and position of the lower drag brace.

This component was selected since the lower drag brace is one of the main load carrying elements of the landing gear and is loaded both in tension and compression during take-off and landing operations. Therefore the technological value of this component was 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 the 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<sup>0</sup>C and 85% relative humidity
- The chemical resistance of the composite material used should be high.

The present metal (high strength steel) 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 that 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. Since at the moment the conceptual design was made no design allowable of the materials used were at hand, the conceptual design was based on assumed design allowable.

### Materials used and material properties

For fiber reinforcements Non Crimped Fabrics (NCF) were selected with IM7 carbon fibers.

Before being processed to a pre-form the NCF's were bindered 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  $T_{g\text{ wet}}$  of 169<sup>0</sup>C.

In order to determine design allowable 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<sup>0</sup>C and 85% relative humidity) conditions. In order to determine the chemical resistance, Interlaminar Shear tests were carried out on specimens that had been 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<sup>0</sup>C) and hot/wet conditions (70<sup>0</sup>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 ensure the load carrying capability of the drag brace after being damaged by an impact.

### Detailed design

After the design allowable were determined the detailed design was made by carrying out finite element calculations for which B2000 was used. The finite element model was composed of four nodes Stanley-type shell elements. The optimization module B2OPT within B2000 was used to optimize the composite drag brace for minimal weight with maximum values for the strains and displacements as constraints. In order to facilitate the optimization, laminate design variables were defined. The means that the number of 0<sup>0</sup>/90<sup>0</sup> NCF and +45<sup>0</sup>/-45<sup>0</sup> NCF layers varied during the optimization leading to

an optimal laminate. The Tsai-Hill failure criterion was used as a failure criterion. The optimum was found after 12 optimization cycles. After completion of the optimization a buckling analyses was carried out. The first buckling mode had an eigenvalue of 4.05. The lugs were not modeled in detail. The load carrying capability of the lugs was determined experimentally by testing scaled lug specimens

The weight of the optimized composite drag brace was 4.7 kg which is a reduction of 39% in comparison to the steel lower drag brace.

### Sub-component testing

As mentioned before, the lugs were not modeled in detail since it would be very difficult to predict the failure load of the composite lugs accurately due to the lack of an accurate failure criterion. Therefore it was decided to fabricate scaled lug specimens with scale 1:2. The lug specimens had the same lay-up as the optimized 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 generic lug specimens were made with the same thickness and lay-up as the lugs of the full-scale 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 2 presents one of the cross sections that were made. It was therefore decided to configure the composite drag brace also with titanium protection plates.

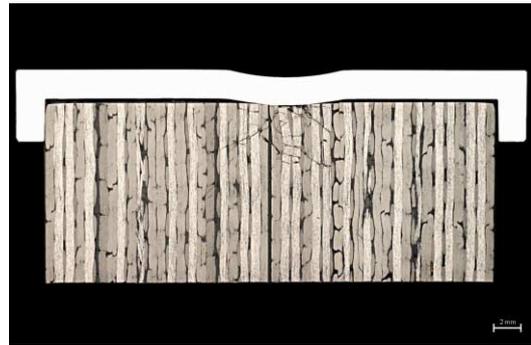


Figure 2: Cross section of the generic lug specimen with a 2.0 mm thick titanium protection plate after an 86 Joule impact.

### Description of the tooling concept

The RTM tooling should enable the fabrication of three drag braces per day during a period of 10 to 15 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 a heated press could replace this outer mould.

In a full rate production environment, the inner mould would be duplicated several times resulting in parallel pre-form stations. By doing this an RTM carousel can be introduced in which three composite drag braces per day can be made without needing three expensive heated tools.

### 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 were 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 3 shows one of the

pre-form layers that is pressed to the pre-form with a heated plate. The pre-form was stabilized by heating the pre-form under vacuum in an oven at 120 °C for 30 minutes.



Figure 3: 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. 4)



Figure 4: Positioning the pre-form and core mandrel into the inner mould.

Then the inner mould was placed in the outer mould (see fig. 5).



Figure 5: Positioning the inner mould (including pre-form and core mandrel) into the outer mould.

Then, 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 signals 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<sup>2</sup> and was increased gradually to 0.9 N/mm<sup>2</sup> 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. After the post-cure, the drag brace was inspected by C-scan. Six drag braces were made successfully. A fiber volume fraction of 58% was realized. After being inspected the drag brace was machined (see fig. 6). The square hole in the drag brace was necessary to avoid interface problems in the main landing gear assembly.



Figure 6: Cured composite drag brace after machining the lugs.

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. 7).

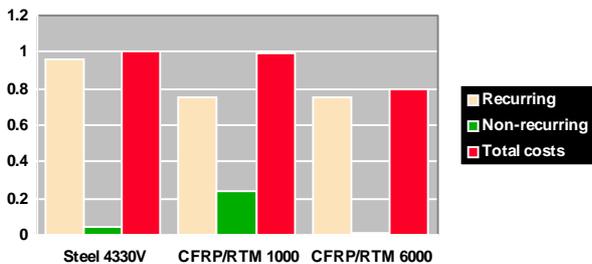


Figure 7: Cost comparison between a steel drag brace and a composite drag brace.

### Test program

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. These tests were carried out by SP aerospace and vehicle systems. All tests were carried out successfully which means that the drag braces failed beyond the required load levels or fatigue live. After completion of the test program 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 (see fig. 8).

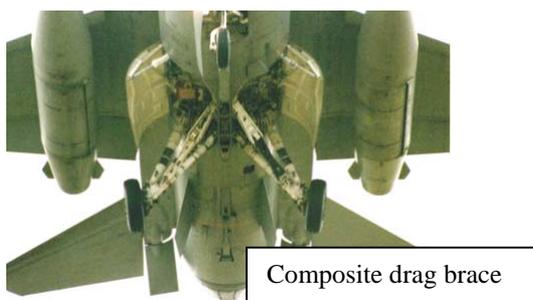


Figure 8: Composite drag brace during flight testing.

### 3 NH-90 Trailing arm development

After the successful demonstration of the feasibility of composites as replacement of steel landing gear components, the next step in the landing gear technology program was to develop a more complex shaped highly loaded element with a high level of part integration. For this purpose the trailing arm of the NH-90 was selected. This component was developed in close collaboration with SP aerospace and vehicle systems, Eurocarbon and MSC Nastran.

The trailing arm is one of the major elements of the main landing gear of this helicopter (see fig. 9).



Figure 9: Location of the trailing arm in the main landing gear.

#### The metal reference Trailing arm

The metal reference trailing arm is made by machining a high strength steel forging. This machining operation is very time consuming, which makes this component a very good candidate for realizing a reduction in manufacturing costs and a reduction in lead time by using composites. The main objective was to realize a cost and weight saving and to reduce the lead time by 20% in comparison to this metal reference.

#### The composite trailing arm concept

The composite trailing arm assembly consists of a tubular braided element, two composite tubes

with bronze bushings, a central lug made of fabric and a steel wheel axle (see fig. 10).

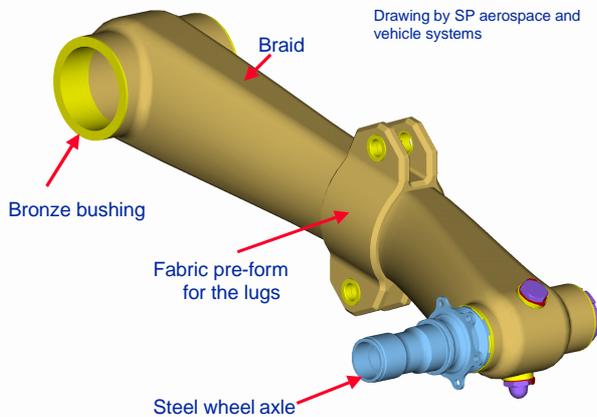


Figure 10: CAD drawing of the trailing arm after assembly.

In order to realize the savings in cost and the reduction in lead time, automated preforming concepts with a high level of part integration were developed.

### Fabrication of the composite trailing arm

The fabrication process can be described as follows. In the first phase of the process, two cured composite pre-preg tubes were bonded to a closed cell foam core. This core was positioned into a braiding machine. The over-braiding technique was used to apply a number of tri-axial layers onto this core (see fig. 11).

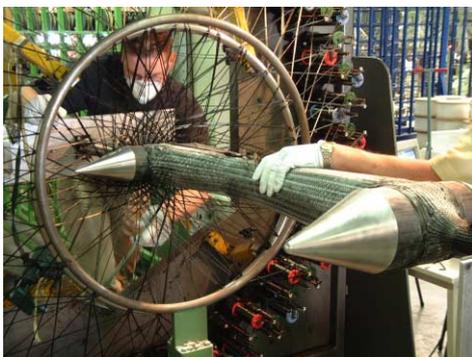


Figure 11: Applying fibers to the core by using the over-braiding technique at Eurocarbon.

During the development of the automated over-braiding concept it became clear that it was very difficult to predict the fiber orientations in the preform as a function of the braiding machine settings. However, these fiber orientations had to be known in detail in order to be able to predict the stiffness of the final component. It was therefore decided to start a research program together with the University of Twente. In this research program a braiding simulation tool is being developed. With this simulation tool, the fiber orientations as a function of braiding machine settings can be predicted. However, the simulation can also define the required machine settings on the basis of the desired fiber orientations. With this tool the development time and development costs of a braided preform are reduced dramatically. This will increase the competitiveness of braided preforms for tubular RTM components.

Parallel to this braiding process development a net shaped pre-forming process was developed for making the sub-preforms of the lugs. These preforms were made, using the binder powder compaction technique. As mentioned before, this technique enables the fabrication of nearly net-shaped preforms, which are very robust and are easy to handle (see fig. 12).



Figure 12: Net-shaped preforms for the lug area of the trailing arm using binder technique.

After finalizing the braided preform and the preform for the lugs, both preforms were positioned into a steel oil heated tool. Once the

RTM tool was heated to the required temperature, resin was injected. In order to determine the optimal injection strategy (short injection time and minimal risk for entrapped air) RTM flow simulations were carried out for which RTM Worx was used. On the basis of the flow simulations two resin inlet points at the ends of the trailing arm and four ventilation points near the lug areas were defined.

The thickness of the composite trailing arm was approximately 17 mm. Processing tests with the RTM resin used, demonstrated that during the cure phase an exothermal peak was likely to occur. In order to deal with this exothermal peak during curing, extensive temperature measurements were carried out during the curing phase, by measuring the temperature at several locations in the RTM mould and inside the low melting alloy core. These temperature readings were used to control the oil-heating unit. As a result, the oil unit successfully cooled the tool during the curing phase of the resin in order to keep the resin temperature within the allowable temperature range.

After curing the resin, the trailing arm was released from the mould. Then the trailing arm was post-cured in an oven. A fiber volume fraction of 58% was realized. Figure 13 shows a composite trailing arm after assembly of the steel wheel axle and the wheel. The weight reduction achieved was 20%. The reduction in lead time was more than 20%. Five additional composite trailing arms were manufactured successfully. These trailing arms will be tested in a landing gear test rig located at the test center of SP aerospace and vehicle systems.



Figure 13: Composite trailing arm after assembly of the steel wheel axle and the wheel.

## Conclusions

Several technology programs were carried out successfully by collaboration between industries, research establishments and universities.

The programs demonstrated that RTM can be used as fabrication method for making complex shaped damage tolerant landing gear components with a high level of part integration. By using composites instead of steel large weight saving can be obtained. For large series also cost savings are feasible.

Based on the results of the technology programs described in this paper, the conclusion can be drawn that composite landing gear components are feasible cost-effective alternatives for steel landing gear components. Composite landing gear components therefore are opportunities to be taken for application in the next generation civil and military aircraft.