Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

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Contents

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DEVELOPMENT OF A COMPOSITE TORQUE LINK FOR HELICOPTER LANDING GEAR APPLICATIONS

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SUMMARY: In the framework of a composite landing gear technology programme, a composite torque link for helicopter landing gear applications was developed. The torque link was designed by finite element analysis and optimised for minimal weight. The torque link was fabricated by Resin Transfer Moulding (RTM) for which a tooling concept was developed. Static tests demonstrated the load carrying capabilities in undamaged and damaged condition of the torque link since all specimens failed beyond their Design Ultimate Load level.

KEYWORDS: Integrated Design and Manufacturing, Resin Transfer Moulding, Composite Torque Links.

INTRODUCTION

Composites are being used increasingly for new structural concepts for the aerospace industry. One of the reasons for using composites instead of traditional metals in these structures, besides a reduction in weight, is the potential to reduce the total life cycle costs of the structure. In order to achieve this cost reduction, new and cost effective fabrication techniques are being developed. One of these new fabrication techniques is Resin Transfer Moulding (RTM). The RTM fabrication technique is based on the injection of resin into a mould cavity that contains an assembly of dry fibres (perform). RTM has been in use within the automotive and sports industry for many years. However, now that high quality RTM resins have become available, the use of RTM as fabrication technique for structural components for the aerospace industry is increasing gradually. The main improvement of these resins, besides their improved mechanical properties, is that they have a low viscosity for a reasonable time. This means that large products with high fibre volume fractions can be made without excessive high injection pressures. Although RTM moulds often are complex and expensive, RTM has several advantages compared to the autoclave prepreg fabrication method, which, at this moment, is the standard method used in the aerospace industry. The main advantages are:

- Two sided tooling concepts can be used in which net shaped products can be made: this reduces the amount of trimming of the cured product and reduces the amount of shimming during assembly.

- No high capital investments (like an autoclave) are required.
- Complex shaped components can be made.

Especially the last point (complex shaped components) is interesting for designers, since they now can design components in composites, which used to be too difficult to fabricate by the standard prepreg fabrication methods. Examples of complex shaped components are brackets with concentrated load introductions.
To demonstrate the feasibility of RTM for the fabrication of composites in landing gears a technology programme was carried out in which a composite torque link for a helicopter landing gear was developed as a replacement for a metal torque link. The technology programme was carried out in a collaboration of the following partners: SP aerospace and vehicle systems, MARC Analysis BV, Eurocarbon and NLR. For the present component, SP aerospace and vehicle systems delivered the design specifications and assisted during the preliminary design phase. MARC Analysis carried out finite element calculations and NLR made the preliminary design, developed the performing and RTM tooling concept, fabricated several torque links and carried out the static tests.

Figure 1 presents the location of the torque links in the helicopter main landing gear. The finite element method was used to design the composite torque link. During the design phase, the torque link was optimised for minimum weight while fabrication constraints were incorporated in the optimisation route to minimise fabrication costs. An RTM mould concept was developed to fabricate the torque links. Several torque links were produced. A test set-up was designed and fabricated in which the torque links were tested. Impact damages were applied to all torque links during the test programme.

THE METAL REFERENCE TORQUE LINK

In landing gear applications, a torque link is used to avoid shimmying of the landing gear wheel during landing operations. Figure 2 presents the aluminium reference torque link. The torque link is composed of two elements: an upper and a lower torque link. The weight of the metal torque link is: 182 gram for the lower torque link and 175 gram for the upper torque link. Design Ultimate Load for the metal torque link is 4.548 kN (see fig. 2).

MATERIALS USED FOR THE COMPOSITE TORQUE LINK

The composite torque links are composed of the following materials:

- Unidirectional HTA carbon fabric (90% of the fibres are in warp direction and 10% of the fibres are in weft direction) Lyvertex G808 (220 gram/m^2)
- RTM-6 epoxy resin.

The material properties of the materials used for the design, were determined by testing specimens in tension (250 mm x 25 mm x 3.5 mm) and compression (45 mm x 40 mm x 3.5 mm). These specimens were fabricated by RTM and had a fibre volume fraction of 55%. Of each configuration three specimens were tested. The tests resulted in the following material properties:

$E_{1tension}$	107 GPa	$\sigma_{1tension}$	1090 MPa
$E_{1compression}$	95 GPa	$\sigma_{2tension}$	112 MPa
$E_{2tension}$	17 GPa	$\sigma_{1compression}$	775 MPa
$E_{2compression}$	16 GPa	$\sigma_{2compression}$	266 MPa
$\varepsilon_{1tension}$	1.0 %	$\varepsilon_{1compression}$	0.77 %
$\varepsilon_{2tension}$	0.65 %	$\varepsilon_{2compression}$	2.00 %
G_{12}	4.3 GPa		

These material properties were used as input for finite element calculations.

DESIGN OF THE COMPOSITE TORQUE LINK

The composite torque link was designed in such a way that both upper and lower torque links could be fabricated in the same RTM mould, in order to limit tooling costs. The finite element code B2000 was used during the preliminary design phase [1]. The optimisation module within B2000 [2] was used to optimise the torque links for minimum weight. In order to carry out the optimisation, the following sections in the torque link were defined (see fig. 3):

- Sections 1 and 4 with lay –up: [+45,0_2,-45,0_2,90,0_2,-45,0_2,+45]
- Section 3 with lay-up: [+45,0,-45,0,90,0,-45,0,+45].

Design variables were the thicknesses of these different sections. After the optimisation the laminates of the preliminary design were rounded up to integer ply thicknesses. Also, the dimensions of the composite torque links were modified so that the assembled torque links could meet the landing gear requirements (e.g. a curvature was introduced in the torque link in order to avoid mutual interference during retraction of the landing gear).
A detailed finite element analysis of the optimised and modified torque link was made by MARC Analysis [3]. The FE models were full three dimensional models consisting of eight-noded brick elements (MARC element type 7). Figure 4 presents the finite element model of the lower torque link. MARC's automatic contact algorithm was used to describe the contact between the pin loaded holes of the torque link and the connection pins. No friction was modeled between the bolts and the pin loaded holes. Figure 5 presents the stress distribution in the lower torque link at Design Ultimate Load.
The weight of the final configuration of the upper torque link is 121 gram. In comparison to the weight of the aluminium torque link (175 gram) a weight reduction of 31% was achieved. The weight of the final lower torque link is 129 gram. In comparison to the weight of the aluminium torque link (182 gram) a weight reduction of 29% was achieved.

FABRICATION OF THE COMPOSITE TORQUE LINK

The RTM mould for fabrication of the composite torque links was designed for fabrication of both upper and lower torque links at the same time. Figure 6 presents the RTM mould. The mould was composed of aluminium elements in combination with an elastomer (Techtron) core element. The elastomer was selected because of its large coefficient of thermal expansion, which eases demoulding of this mould element after curing the torque link.

Figure 7 presents the cross section of the RTM mould. Resin was injected through the central injection point. Nine vents were used to evacuate the air during resin injection. The resin was injected with an injection pressure of 5 bar without vacuum assistance. During resin injection the mould temperature was set to 120 °C. After resin injection, the mould was heated to 180 °C for three hours in order to cure the resin. During one RTM fabrication cycle six torque links were made in one piece simultaneously. After curing, the components was sliced into six torques and inspected by C-scan, which showed no delaminations or entrapped air. The fibre volume fraction of the torque links was 58%. Figure 8 presents a torque link after being machined.

Impact tests

According to the test specification report [4], both Barely Visible Impact Damages (BVID) and Visible Impact Damages (VID) must be applied to the torque links during the test programme. However, the maximum impact energy to be applied was limited to 30 Joule, based on a probability assessment of impacts that may occur during assembly, maintenance and in-service. A BVID was defined as a dent with a dent depth of 1.0 mm. Figure 9 shows the impact locations that were considered to be the most vulnerable locations on the torque links during assembly, maintenance and in-service. During impact tests on spare torque links it was demonstrated that an impact level of 30 Joule (with a steel spherical tub of 2.312 kg and a diameter of 12.7 mm) still did not result in a BVID. Therefore, it was decided to impact all torque links with the 30 Joule impact level.

TEST RESULTS

Before being tested, all torque links were instrumented with a number of strain gauges. Six torque links (three upper and three lower torque links) were subjected to the following static test programme:

- Test to Design Limit Load
- Test to Design Ultimate Load (1.5 x Design Limit Load)
- Applying two 30 Joule impact damages
- Test to Design Ultimate Load
- Test to failure.

Figure 10 presents the test set-up for these static tests All torque links failed beyond their Design Ultimate Load levels with margins of safety between 1.4 and 1.45 (margin of safety = Failure Load / Design Ultimate Load). Unfortunately at the time this paper was prepared, no comparison between measured and calculated strain levels had been made yet.

CONCLUSIONS

In the framework of a composite landing gear technology programme a composite torque link was designed, fabricated and tested. Weight savings of approximately 30% were realised. All torque links failed beyond their Design Ultimate Load Level (even after being damaged by 30 Joule impact damages). Therefore, the load carrying capability of the torque link was demonstrated successfully.

ACKNOWLEDGEMENTS

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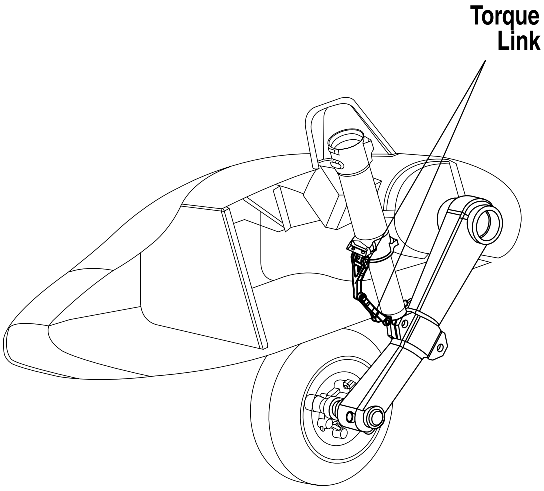

Fig 1 Helicopter main landing gear with torque link

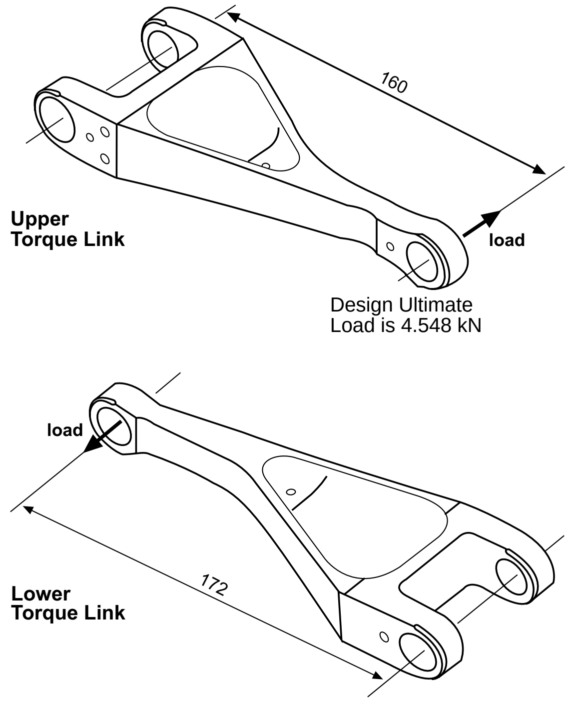

Fig. 2 Aluminium reference torque links

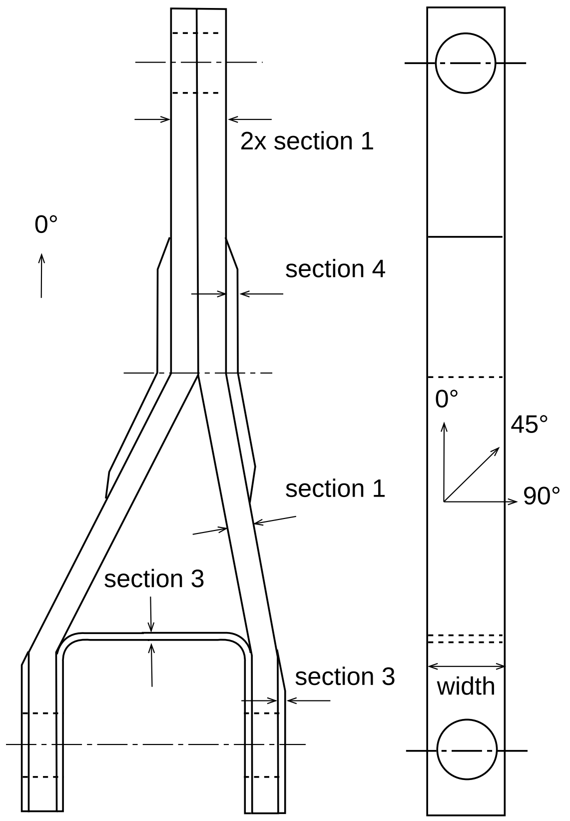

Fig. 3 Torque link during the preliminary design phase

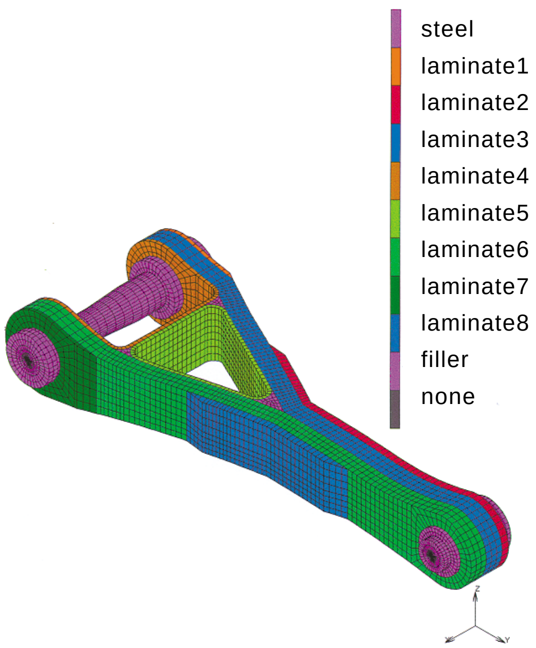

Fig. 4 Materials used for the different parts of the torque link assembly

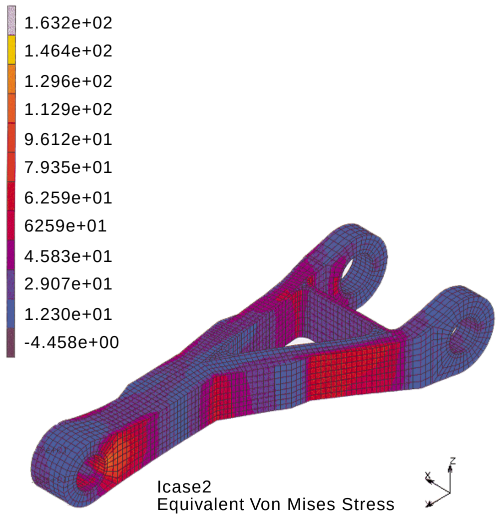

Fig. 5 Equivalent Von Mises stress in Upper Torque Link under tension at Ultimate Load

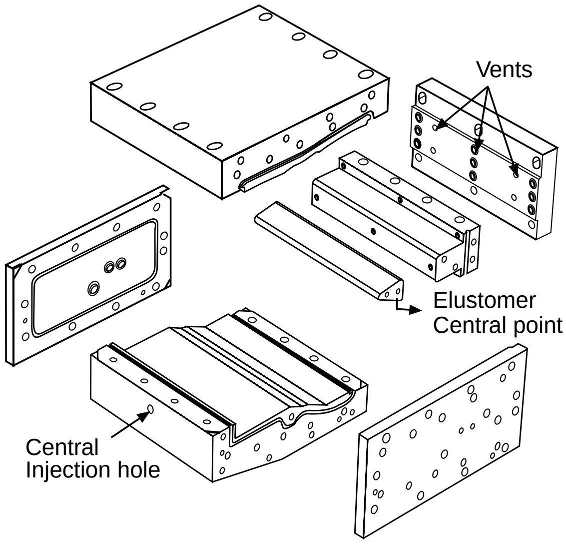

Fig. 6 Exploded view of RTM mould for the production of composite torque links

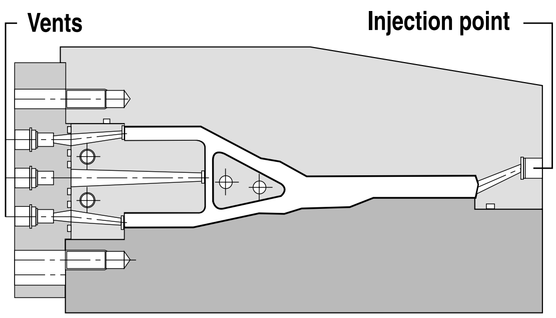

Fig 7 Cross section of RTM mould

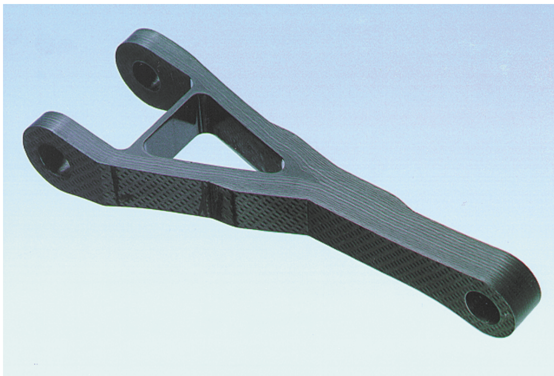

Fig. 8 Torque link fabricated by RTM

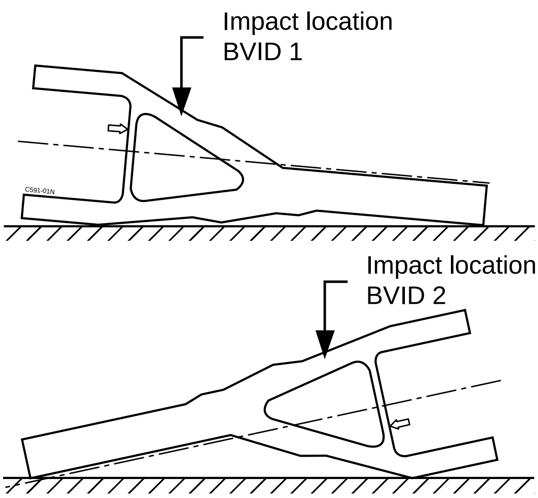

Fig. 9 Impact locations

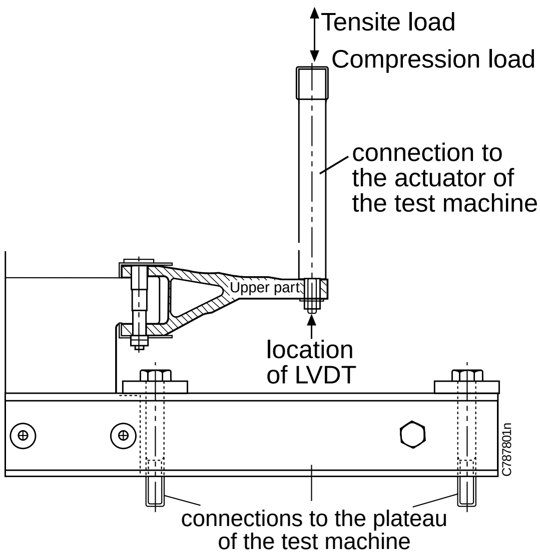

Fig. 10 Test Set-up to test Torque Links