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Design, fabrication and testing of composite structures

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This report is based on a presentation to be held on the symposium "Weight watching a new approach", organised by ISAAC Newton at the University of Twente, Enschede, The Netherlands, April 22nd, 1999.

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ABSTRACT

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DESIGN, FABRICATION AND TESTING OF COMPOSITE STRUCTURES[1]

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ABSTRACT

Three structural components are presented in this paper which have been designed from the start as a composite structure. A load carrying bracket for a launcher, a torque link for a landing gear and a mast for a sailing yacht. For each item the fabrication method is highlighted and the test results are presented.

1 INTRODUCTION

Composites are being used increasingly for structural components as these have a number of advantages compared to metals. The main advantage is that they reduce the weight of a structure as their specific strength and stiffness is higher than metal.
However, an advantage may always be impaired by a disadvantage. Fibre–reinforced materials are anisotropic and inhomogeneous, and the common fabrication process results in a material that is composed of a number of thin plies which are stacked together with rather weak interfaces between them. When an impact takes place on a composite structure during fabrication or service, for instance as the result of dropping a tool, delamination may occur inside the laminate. Such delaminations in layered material may not be visible, but can reduce the strength of the structure, and some could be fatal in heavy loading conditions.
Another advantage is that composites enable complex three dimensional structures to be manufactured in one piece. This reduces the number of parts and thus the assembly costs significantly, although part of the reduction in cost is needed to compensate for the more expensive tooling and materials.

Up to now, the autoclave process is the standard fabrication technique to produce composite components for aerospace applications. However, recent developments show the evolution of new composite materials and new fabrication techniques.

- One of these new fabrication techniques is Resin Transfer Moulding (RTM). The RTM fabrication concept is based on the injection of resin into a mould cavity containing dry fibres (preform). During the injection process, air in the mould is being replaced by resin and the fibres are impregnated. The RTM fabrication concept has several advantages compared to autoclave processing: a two sides tooling concept can be used, assuring tight outer dimensional tolerances, hence reducing the amount of shimming during assembly. Moreover complex shaped components can be made easily.
- A second already more mature technique is low temperature curing of pre-pregs in an oven instead of an autoclave. As new prepregs become available, parts with a good quality and properties can be obtained with this method

This paper gives several examples of composite components which have been designed at NLR, fabricated with the new techniques and tested for their strength.

Section 2 presents the development of a bracket for space application, section 3 presents the development of a landing gear component. Section 4 presents the development of a very large composite mast.

2 A COMPOSITE BRACKET FOR A LAUNCHER

The first case presents the development of a composite bracket for a launcher [Ref. 1]. Figure 1 presents the alumi-

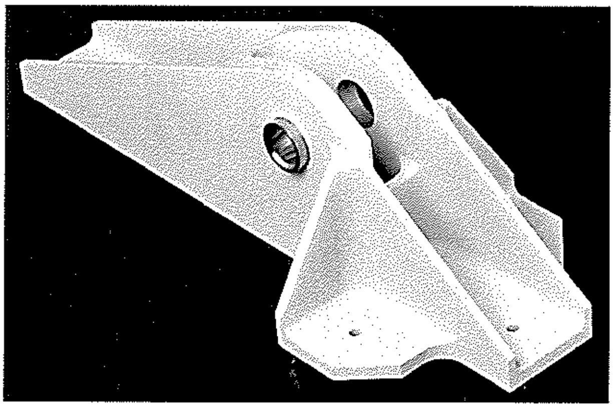

Figure 1 Metal bracket

[1] To be presented at "Weight watching, a new approach", organised by ISAAC Newton at the University of Twente, Enschede, The Netherlands, April 22nd, 1999.

nium bracket that was used as a reference in this study. The bracket is incorporated in the Ariane IV launcher. This metal bracket is made out of aluminium and has a weight of 314 grams.

Materials used for the composite bracket
As the bracket has a complex 3 D shape, it was decided to use the RTM technique for this component. The composite bracket was composed from carbon fabric with HTA fibres and epoxy resin to impregnate the fibres. The resin used, has a reasonably low viscosity for a long period to allow flow through the fabric and has a low curing temperature of 80°C.

Design of the composite bracket
The composite bracket was designed with the finite element code B2000 [Ref.2], which is in use at NLR as a testbed for developments in computational mechanics. It was decided to keep the interface between the bracket and the backing structure the same as for the metal bracket in order to make a retrofit possible. Therefore the same kind and number of pin-loaded holes, hi-locks and bolts were used in the composite bracket as in the metal reference bracket. However, the general layout of the composite bracket was allowed to be different from that of the metal reference bracket. The bracket was optimised for minimal weight with the optimisation module B2OPT [Ref.3] within B2000. This optimisation code minimises the weight of the bracket while the design is subjected to constraints on stresses. In order to perform an optimisation of the bracket, a number of design variables were defined such as height and width and number of plies in the different orientations. After optimisation, a buckling analysis was performed to check the stability of the bracket.
The weight of the optimised composite bracket was 173 gram. The weight of the aluminium bracket was 314 gram. This means that a weight reduction of 43% has been achieved.

Fabrication of the bracket
Figure 2 presents an exploded view of the mould that was developed to fabricate the composite bracket by RTM. All mould elements were made of aluminium with the exception of the central part that was made of the elastomer Techtron HPV. The modular character of the mould is apparent from Figure 2 . Because of this modular concept, sub-preforms could be prepared very easily on the tapered mould elements and the Techtron central part. When the sub-preforms were positioned in the mould, the mould was closed and resin was injected through a central injection hole.
Based on a cost estimation it was decided not to fabricate the bracket net shaped but to machine the cured bracket to the required dimensions because cutting the sub-preforms to the net-shaped dimensions without fibre distortion at the edges would become very difficult, time consuming

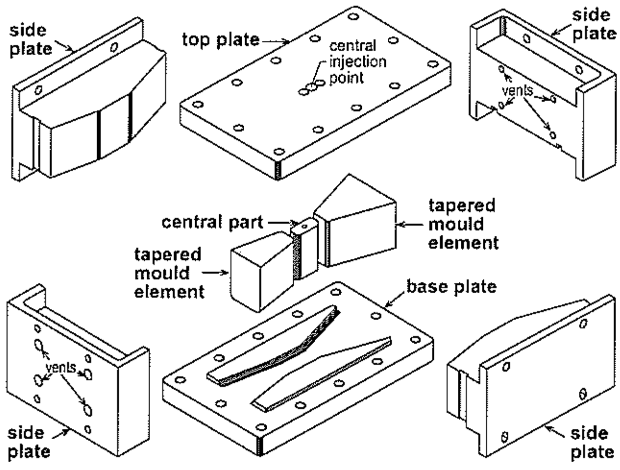

Figure 2 Elements of the RTM mould

and therefore expensive due to the small dimensions of the bracket. Figure 3 shows the resulting composite bracket.

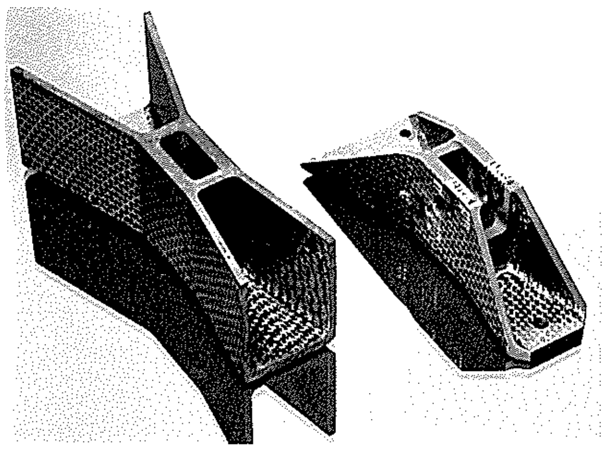

Figure 3 Composite bracket before (left) and after (right) machining

Testing the composite bracket
One of the brackets was tested in tension and compression. The loads were applied by a pin in the holes. The bracket was loaded up to 1.2 times the Design Ultimate Load. The bracket did not fail during these tests and the measured strains corresponded well with the predicted FEM results. Based on these static tests it can be concluded that it is possible to replace the aluminium bracket with a composite one and to gain a weight reduction of 43% for each bracket.

3 A COMPOSITE TORQUE LINK FOR A LANDING GEAR

The second case presented is the development of a composite torque link for landing gear applications [Ref.4]. The composite torque link was developed in the framework of a landing gear technology program. NLR made the preliminary design, developed the preforming and RTM tooling concept, fabricated several torque links and carried out static tests.

The metal reference torque link
Figure 4 presents the metal (aluminium) torque link. The torque link is composed of two elements: an Upper Torque Link and a Lower Torque link. In landing gear applications a torque link is used to prevent the landing gear wheel from shimmying during landing operations. The weight of the metal torque link was: 182 gram for the Lower Torque Link and 175 gram for the Upper Torque Link.

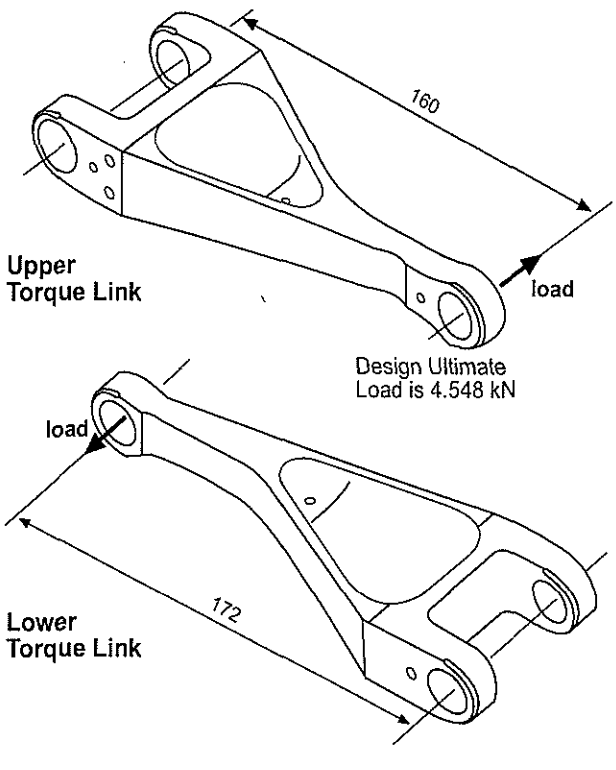

Figure 4 Aluminium torque link

Fabrication concept and materials used
For this component RTM was also used. The composite torque link was composed of carbon fabric with HTA fibres and RTM-6 epoxy resin. The material properties of the materials used (needed as input for the finite element calculations) were determined by testing small specimens in tension and compression loading.

Design of the composite torque link
The composite torque link was designed in a way that both the Upper Torque Link as well as the Lower Torque Link can be produced in the same mould in order to limit tooling costs. During the preliminary design phase the torque link was optimised for minimal weight by the finite element code B2000 (Ref.2) and the optimisation module B2OPT (Ref.3). To make the optimisation possible, a number

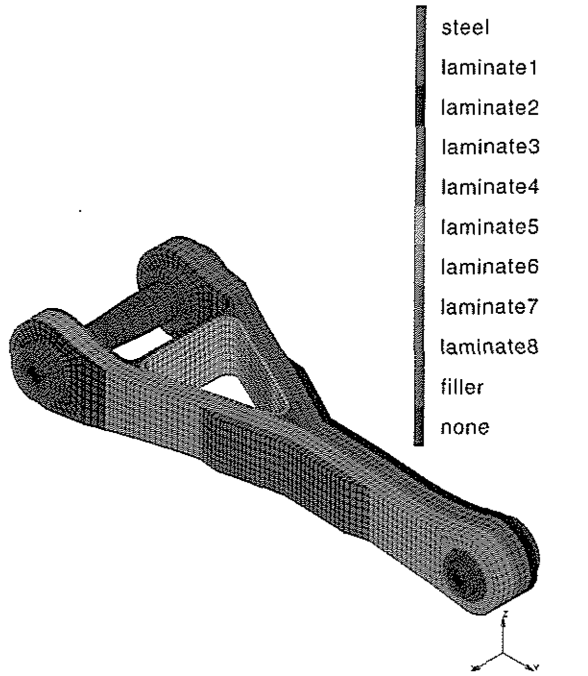

Figure 5 Composite torque link design

of design variables were defined as width, height and number of layers for each orientation. A detailed finite element analysis was made of the optimised torque link by MARC Analyis [Ref. 5]. Figure 5 presents the finite element model. The full three dimensional models consisted of brick elements. An automated contact algorithm was used to describe the contact between the bolts and the pin loaded holes. Stresses and strains were calculated to be compared with the test results.

Fabrication of the composite torque link
Both the Upper and Lower torque link were produced in the same mould. Figure 6 shows the exploded view of the

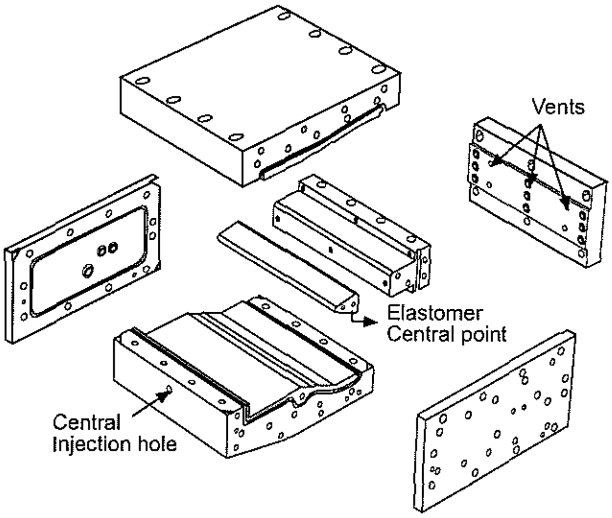

Figure 6 Exploded view of RTM mould

RTM mould. The mould was composed of aluminium elements in combination with an elastomer (Techtron) core element. With this mould six torque links (both Upper and Lower) were produced simultaneously by cutting the cured component into six slices. Resin was injected through the central injection hole.
The weight of the final composite Upper Torque Link is 121 gram (Figure 7). In comparison to the weight of the aluminium torque link (175 gram) a weight reduction of 31% has been achieved. The weight of the final composite Lower Torque Link is 129 gram. In comparison to the weight of the aluminium torque link (182 gram) a weight reduction of 29% has been achieved.

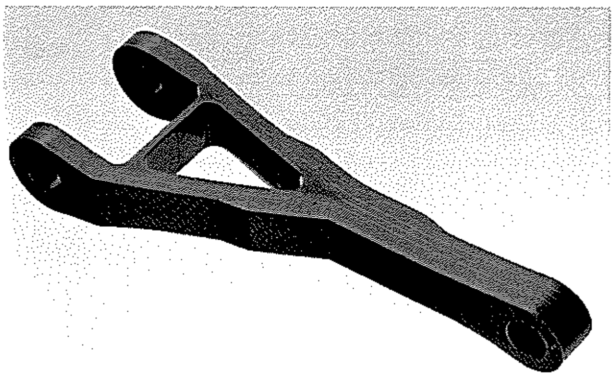

Figure 7 Torque link fabricated with RTM

Testing the composite Torque Links
All torque links were tested and failed beyond their Design Ultimate Load Level. At the time this paper was prepared, no comparison between measured and calculated strain levels had yet been made.

4 A COMPOSITE MAST FOR A YACHT

It is a "new trend" to replace the aluminium mast on sailing boats by composites ones. Manufacturing of these masts is more expensive, but a composite mast can result in a weight saving of 30%. Moreover, using carbon epoxy materials, higher stiffness can be obtained than in aluminium. The combination of reduced weight and increased stiffness, results in more speed and better sailing performance. The reduced mass of the mast results in a lower point of gravity of the mast and the yacht. This lower point of gravity requires less ballast, which can run up to 10 times the weight saving in the mast!
The current technology for composite masts is based on small masts built from several parts up to a length of 30 meters. Large sections are compiled from separate sections introducing joints that are possible failure locations but also undesirable from an architectonic point of view. Therefore Royal Huisman Shipyard in co-operation with

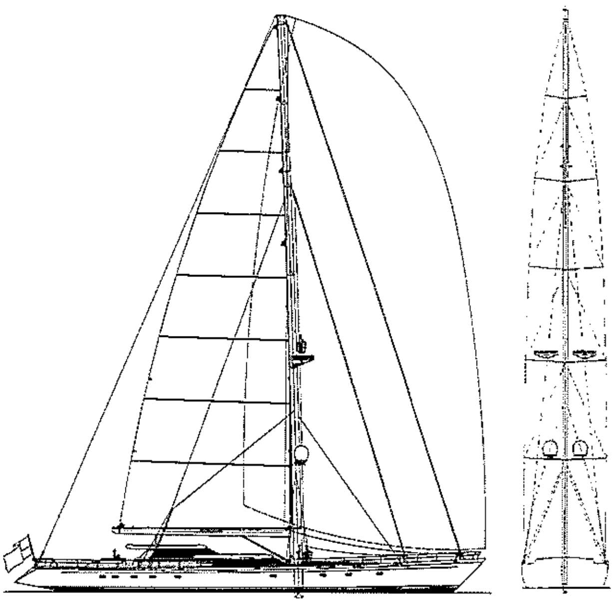

Figure 8 Yacht with 57 meters carbon/epoxy mast

NLR developed a technique to manufacture composite masts up to 60 meters in once piece [Ref.6].

The selection of fabrication process and materials
Curing a single composite structure of 60 meters in an autoclave is not feasible. Therefore a new fabrication method had to be developed. As new low temperature/ vacuum curing pre-preg materials come onto the market, the oven technique was chosen as the most feasible concept for fabricating masts taller than 30 meters.
A simple fabrication concept was developed to reduce the tooling costs and maintain flexibility in re-using the tooling for new types of masts. The core of the mast is built from two thin shell halves (Figure 9). Around this core, the strength lamina is added and cured in several steps. The requirements for the materials used were included in a material selection program [Ref.7]. Based on the results of the selection program, a hot melt epoxy with a carbon fibre was chosen.

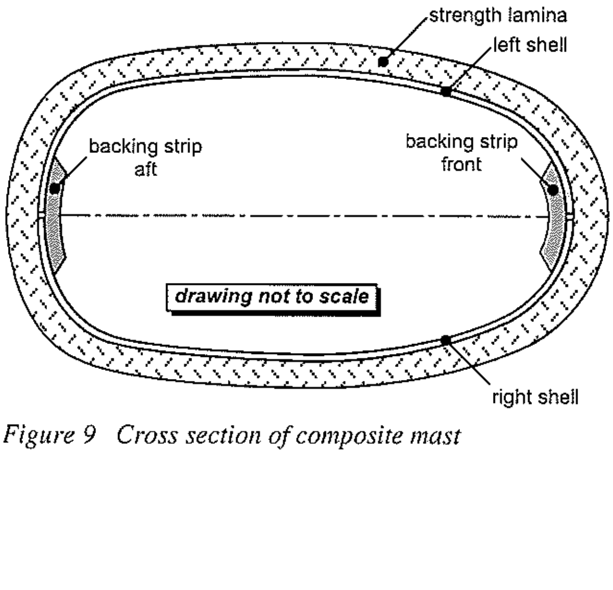

Figure 9 Cross section of composite mast

Numerical design of the mast
An initial design for the composite mast was numerically optimised with the use of a finite element code. During optimisation buckling loads and stresses were used as constraints while ply thicknesses of the mast shell were used as design variables. The optimisation resulted in a weight saving of 600 kg in the mast.

Actual fabrication of the mast
Because the production facility was set up as a laminating room (Figure 10), which is also used as a curing room, handling and transportation of the laminated structure was cut to a minimum. Due to the size of the component some problems with the vacuum tightness and the heat-up rate occurred. However, the overall results with the selected fabrication concept are satisfactory.

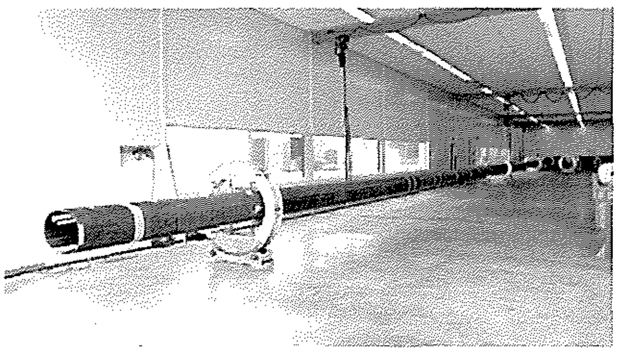

Figure 10 Fabrication of mast in oven

Figure 11 Yacht "Hyperion" with composite mast

Testing of the mast
The mast is not tested in a test set up. It is placed on the yacht (Figure 11) and it has sustained "wind-force 7" without failure. This corresponds with 1.7 MN compression load at the foot which is 80% of the design load.

5 CONCLUSIONS

The results of two case studies were presented in which complex shaped components with concentrated load introductions were fabricated by RTM. The studies demonstrated that such components can be made successfully. All components outperformed their specifications and weight savings of 29%-42% were achieved.
In case of the mast it is shown that the new generation materials allow the production of (extremely) large composite structures with good engineering properties at reasonable cost levels. The numerical optimisation actually pays off in terms of production cost savings and overall weight savings. These advances in fabrication and design technology made it possible for Royal Huisman Shipyard to actually build a 57 m composite mast in one piece and increase the performance of their yachts.

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