DOCUMENT CONTROL SHEET

	ORIGINATOR'S REF.		SECURITY CLASS.
	NLR TP 97068 U		Unclassified

ORIGINATOR
National Aerospace Laboratory NLR, Amsterdam, The Netherlands

TITLE
Design, fabrication and testing of a composite bracket for aerospace applications

PRESENTED AT
The Ninth International Conference on Composite Structures, 8-10 September 1997.

AUTHORS	DATE	pp	ref
H.G.S.J. Thuis and C. Biemans	970213	11	3

DESCRIPTORS
Aircraft construction materials
Brackets
Carbon fibers
Compression tests
Epoxy matrix composites
Fabrication
Finite element method
Laminates
Ply orientation
Preforms
Resin transfer molding

ABSTRACT
In this paper the results of a program, in which a composite bracket as replacement of a metal forging was developped, will be presented. The finite element method in combination with an optimization module was used to design the bracket. Compared to its metal counter part, the composite brackets were fabricated by RTM. One bracket was loaded statically to 1.38 x Design Ultimate Load. The bracket dit not fail at this load level.

217-02

NLR TECHNICAL PUBLICATION

TP 97068 U

DESIGN, FABRICATION AND TESTING OF A COMPOSITE BRACKET FOR AEROSPACE APPLICATIONS

by

H.G.S.J. Thuis and C. Biemans

Paper prepared for the Ninth International Conference on Composite Structures, 8 - 10 September 1997.

Division	: Structures and Materials	Completed	: 970213
Prepared	: HGSJT/13/2/3 CB/13/2/3	Order number	: 542.401
Approved	: HHO/HO 12/3	Typ.	: MM

Contents

(11 pages in total)

Design, fabrication and testing of a composite bracket for aerospace applications

H.G.S.J. Thuis and C. Biemans

National Aerospace Laboratory, Voorsterweg 31, 8316 PR Marknesse, The Netherlands

In this paper the results of a program, in which a composite bracket as replacement of a metal forging was developed, will be presented. The finite element method in combination with an optimization module was used to design the bracket. Compared to its metal counter part, the composite bracket demonstrated a weight reduction of 43%. Two composite brackets were fabricated by RTM. One bracket was loaded statically to 1.38 x Design Ultimate Load. The bracket did not fail at this load level.

1 INTRODUCTION

The use of composites in primary aerospace structures is increasing gradually. Until recently one of the most important reasons for using composites instead of metals for these structures was the reduction of weight. However, the last few years a change from "Design for Minimal Weight" to "Design to Cost" can be observed. The main goal of this "Design to Cost" approach is to achieve a reduction in total life cycle costs of a structure. A way to realise this cost reduction, among others, is to develop new composite materials and fabrication concepts for these materials. One of these 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 cavity is being replaced by resin and the fibres are impregnated. The RTM process has been in use within the automotive industry for many years for limited production run parts where the cost of tooling for pressed steel construction would be prohibitive, e.g. for sports cars and special purpose vehicles. RTM has also been in use in the aerospace industry for many years for secondary parts as radomes and flap track fairings. However, until recently, RTM has not been used routinely in the aerospace industry for primary structures by the lack of high quality RTM resins and the lack of available material data bases adequate for structural substantiation and certification.

Now that high quality RTM resins are becoming commercially available, RTM is becoming increasingly popular in the aerospace industry. The main improvement of these new RTM resins (besides their improved mechanical properties) is that they have a low viscosity for a reasonable time, enabling large products with high fibre volumes fractions without excessive high injection pressures. Although RTM moulds often are very complex and expensive, RTM has several advantages compared to autoclave prepreg fabrication concepts which, at this moment, are the standard used in the aerospace industry. Some of these advantages are:

- Net shaped products can be made, reducing the amount of trimming of the cured product.
- Two-sided tooling concepts can be used assuring tight outer dimensional tolerances, reducing the amount of shimming during assembly.
- No high capital investments (for instance an autoclave) are required.
- Both resin and fibres can be stored for long periods at room temperature.
- 3-D double curved products can be fabricated which can not be made with standard autoclave fabrication techniques.

An example of a 3-D double curved composite component is a bracket as replacement of a metal forging. The potential advantages of these composite brackets are (beside a reduction in weight) a reduction in fabrication and maintenance costs. A major reduction in fabrication costs can be achieved because an RTM mould for such a part can be relatively simple in comparison to an often very complex and expensive forging die. The reduction in maintenance costs can be attributed to the excellent fatigue properties of composites.

In the investigation described in this paper a composite bracket for aerospace applications has been developed. The bracket was fabricated by RTM. To evaluate the composite design it was compared with an existing metal bracket as counter part. The main goal of the investigation was to demonstrate the feasibility of a composite bracket as replacement of a metal version.

2 THE METAL BRACKET

The metal bracket which was used as reference for this study is presented in figure 1. The bracket is made of aluminium and has a weight of 314 gram. In service the bracket will be connected to a backing structure by two 5/16" steel bolts and four 1/4" titanium Hi-Locks (see fig. 2). Design Ultimate Load (D.U.L.) for the metal bracket was 33.3 kN in tension and 34.0 kN in compression (see fig. 2). These tension and compression loads are introduced via two pin loaded holes with a diameter of 14.0 mm.

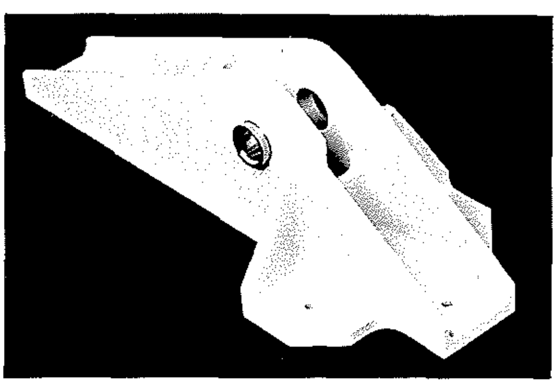


Fig. 1 Metal bracket

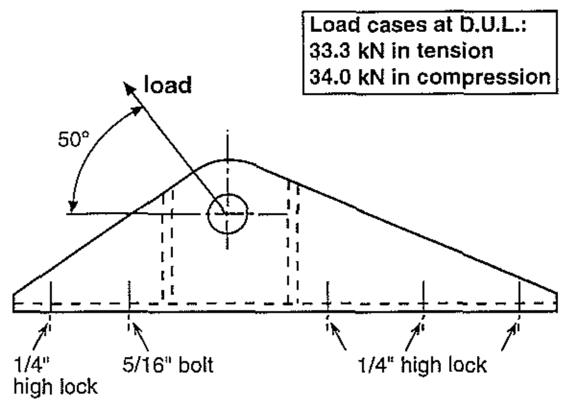


Fig. 2 Static load cases for the metal bracket

3 COMPOSITE MATERIALS USED

The following materials were used for the composite bracket:

a) SA Injectex GF420-E01-100 2.5 D (420 g/m^2) carbon fabric with HTA fibres
This balanced fabric has an equal amount of fibres in the warp and weft direction. The mechanical properties of this fabric are not as good as for an unidirectional fabric but it has excellent drapability characteristics and will therefore be used in double curved areas of the bracket.

b) SA Injectex GU230-E01-100 unidirectional (230 g/m^2) carbon fabric with HTA fibres.
This fabric has 90% of its fibres in warp and 10% of its fibres in weft direction. Because of the unidirectional character of the fabric, the mechanical performance is excellent but drapability characteristics are poor. Therefore this fabric will be used in single curved areas of the bracket.

Low temperature curing epoxy resin LY5052 and hardener HY5052 were used to impregnate the fibres.

The material properties of the materials used (needed as input for the finite element analysis) were determined by testing tension (250 mm x 25 mm x 3.5 mm) and compression (45 mm x 40 mm x 3.5 mm) specimens. The specimens were fabricated by RTM and had a fibre volume fraction of 58%. All tests were performed at ambient conditions. The results of these tests are presented below.

	GU230	GF420
E_{1t}	110.0 GPa	59.0 GPa
E_{2t}	3.4 GPa	59.0 GPa
E_{1c}	110.0 GPa	57.0 GPa
E_{2c}	3.4 GPa	57.0 GPa
G_{12}	4.5 GPa	4.5 GPa
σ_{1t}	1500.0 MPa	591.0 MPa
σ_{2t}	70.0 MPa	591.0 MPa
σ_{1c}	633.0 MPa	388.0 MPa
σ_{2c}	70.0 MPa	388.0 MPa
ν_{12}	0.300	0.035
τ_{12}	89.0 MPa	89.0 MPa

4 ANALYSES AND OPTIMIZATION OF THE COMPOSITE BRACKET

The purpose of the program described in this paper was to demonstrate, in a relatively short time period, the feasibility of a composite bracket as replacement of a metal version. It was decided to use the same kind and number of pin-loaded holes, High-locks and bolts in the composite bracket as were used in the metal bracket. The pin-loaded holes, used for load introduction, and the holes for the bolts and high-locks, were not modelled in detail to keep the FEM model as simple as possible in order to minimise the time needed for modelling and post processing.

The composite bracket had to be a functional replacement of the metal bracket. However, it was allowed that the global geometry of the composite bracket differed from the metal bracket. The Finite Element code B2000 (ref. 1) was used for the analysis. The bracket was modelled using 354 nine-node an isotropic shell elements Q9.st (see fig. 3). The pin-loaded holes were modelled by introducing the load in

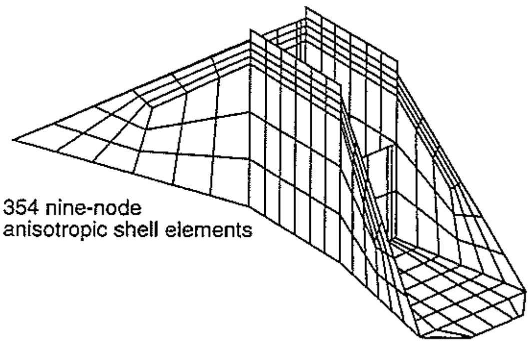


Fig. 3 Finite element model

two nodes, one node on each side of the bracket. The bolts and high-locks were modelled using boundary conditions which lock all six degrees of freedom in the corresponding nodes in the base of the bracket. Because it was not certain whether a fibre volume fraction of 58% (which was used to determine the material properties) could be realised in the bracket the Design Ultimate Load levels were multiplied with a factor of 1.15.

The bracket was divided into six sections (see fig. 4) with the following sublaminates:

Section 1 and 6:

$[45,0,45]_{sublaminate1}[0,90,0]_{sublaminate2}$
$[45,0,45]_{sublaminate5}$

Section 2:

$[45,0,45]_{sublaminate1}[45,0,45]_{sublaminate5}$

Section 3:

$[45,0,45]_{sublaminate1}[0,90,0]_{sublaminate2}$
$[0]_{sublaminate3}[90]_{sublaminate\ 4}$
$[45,0,45]_{sublaminate5}$

Section 4:

$[45,0,45]_{sublaminate1}[0]_{sublaminate\ 3}[90]_{sublaminate4}$
$[45,0,45]_{sublaminate5}$

Section 5:

$[45,0,45]_{sublaminate1}[0]_{sublaminate3}[90]_{sublaminate4}$
$[45,0,45]_{sublaminate5}$

The optimization module B2OPT (ref. 2) within B2000 was used to optimize the composite bracket. The optimization code minimizes the weight of the bracket while the design is subjected to constraints on: stresses and geometric-limits. For the optimization the following ten design variables were defined (see fig. 4):

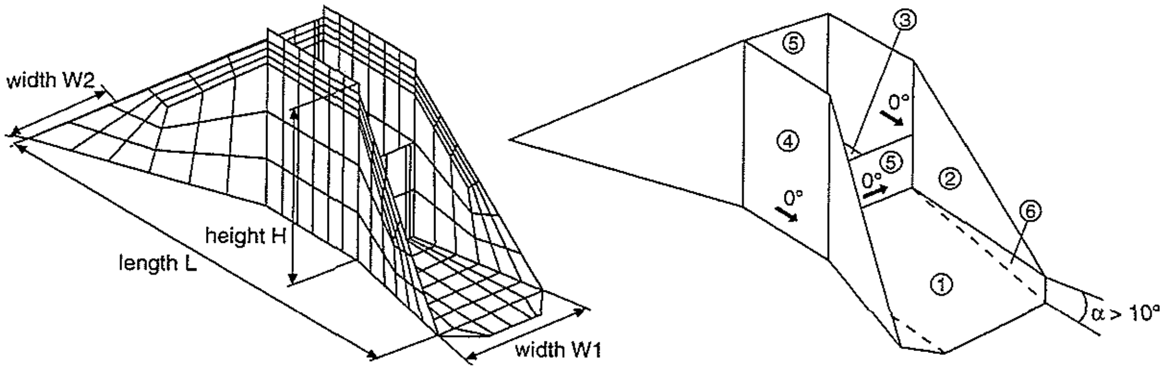


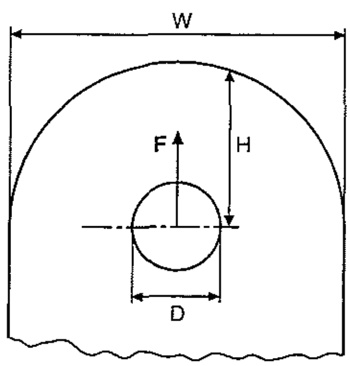
Fig. 4 Geometric design variables and sections 1 to 6

Design variable 1: Height H
Design variable 2: Width W1
Design variable 3: Width W2
Design variable 4: Length L
Design variable 5: Number of 45^0 plies in sublaminates 1 and 5 of sections 1 to section 6
Design variable 6: Number of 0^0 plies in sublaminates 1 and 5 of sections 1 to section 6
Design variable 7: Number of 0^0 plies in sublaminate 2 of section 1, section 3 and section 6
Design variable 8: Number of 90^0 plies in sublaminate 2 of section 1, section 3 and section 6
Design Variable 9: Number of 0^0 plies in sublaminate 3 of section 3, section 4 and section 5
Design variable 10: Number of 90^0 plies in sublaminate 4 of section 3, section 4 and section 5

Sublaminates 1 and 5 were composed of the 2.5 D fabric GF420-E01-100 (because this fabric is symmetric and balanced a 45^0 layer also can be regarded as a -45^0 layer see design variable 5). Sublaminates 2 to 4 were composed of the unidirectional fabric GU230-E01-100.

The composite bracket had to be a functional replacement of the metal version. Therefore side constraints for the optimization were defined to ensure that the optimized bracket stayed within the available assembly window of the metal bracket. In order to avoid fibre wrinkling and ease fabrication of the bracket preform an experimental drape study was carried out to determine the drape limit of the fabrics used. This drape limit was transformed into a side-constraint for the optimization which defined that the angle between section 1 and 2 of the bracket (see fig. 4) had to be larger than 10^0.

As mentioned before the pin-loaded holes and holes for the High-locks and bolts were not modelled in detail. To design these holes in the bracket the following design stress levels were used (ref. 3): $\sigma_{bearing}$ 400 MPa, $\tau_{shear\text{-}out}$: 90 MPa and $\sigma_{tension}$: 388 MPa. These stress levels in combination with the diameters of the different holes determine the dimensions required of the bracket near the holes (see fig. 5). These minimum dimensions were used as side-constraints for the optimization. The side constraints were set to values which ensured a bearing failure mode since this failure mode has a fail safe character (ref. 3).



For a given hole diameter D and load F:
Thickness t determined by bearings stress: $t = F/(D\times\sigma_{bearing})$
Width W determined by tensile stress: $W = (F/(t\times\sigma_{tension})) + D$
Height H determined by shear-out stress: $H = F/(2\times t\times\tau_{shear\text{-}out})$

Fig. 5 Global sizing of a pin-loaded hole

The Tsai-Hill stress criterion was used to predict laminate failure. A number of elements near the load introductions were left out in the determination of laminate failure as these elements were expected to give unrealistic high stresses as a result of the FEM model simplifications.

Figure 6a shows the stress distribution of the initial model before optimization. Note the stress concentrations near the load introduction areas. Figure 6b presents the stress distribution in the bracket after optimisation. Note the change in geometry of the bracket and the uniform stress distribution. Figure 7a shows the (uniform) thickness distribution in the bracket before optimization. Figure 7b presents the thickness distribution of the bracket after optimisation. Note the increase in thickness of the sub-laminates to realise the uniform stress distribution and satisfy the side constraints.

As a result of the optimization the sublaminates in sections 1 to 6 had changed as follows:

Section 1 and 6:

$[45_2,0,45_2]_{sublaminate1}[0_3,90,0,90,0_3]_{sublaminate2}$ $[45_2,0,45_2]_{sublaminate5}$

Section 2:

$[45_2\,,0,45_2]_{sublaminate1}$ $[45_2\,,0,45_2]_{sublaminate5}$

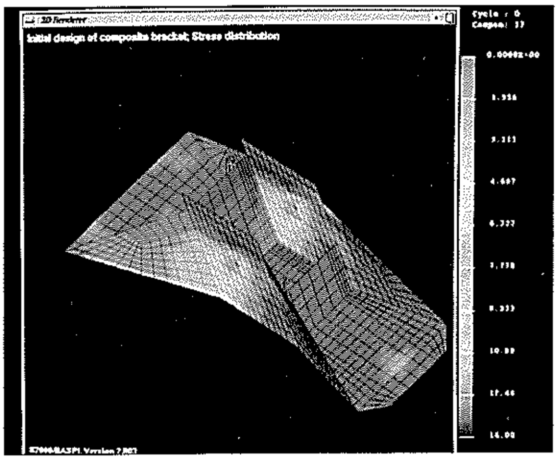


Fig. 6a Stress distribution before optimization

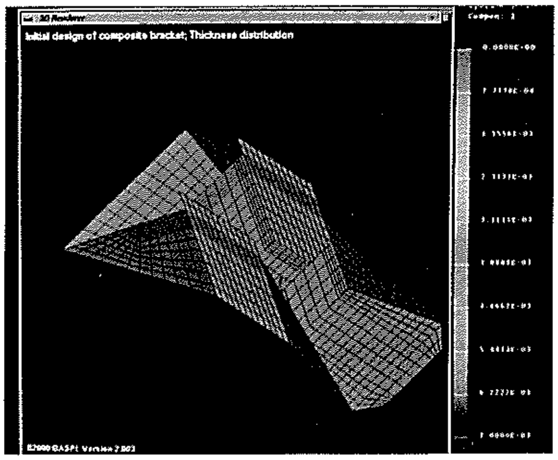


Fig. 7a Thickness distribution before optimization

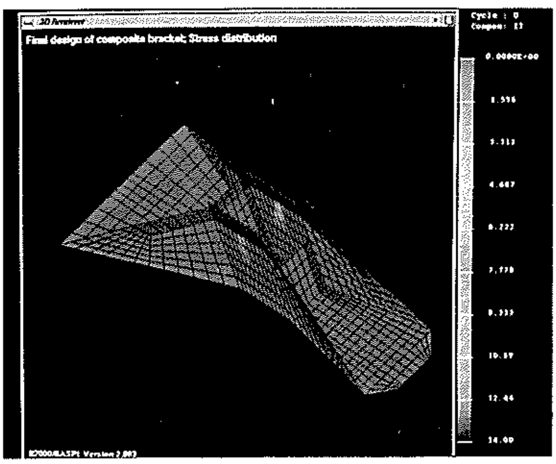


Fig. 6b Stress distribution after optimization

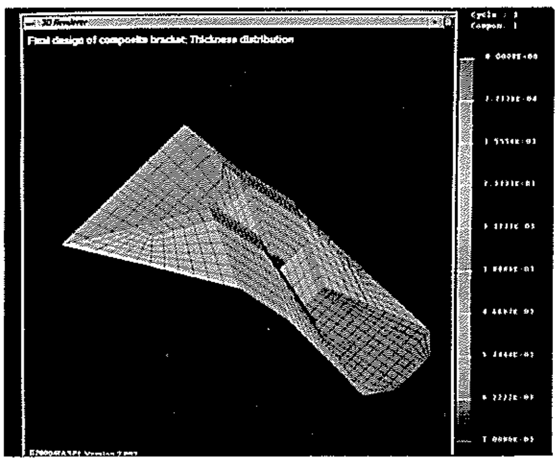


Fig. 7b Thickness distribution after optimization

Section 3:

$[45_2\ ,0,45_2]_{\text{sublaminate1}}$ $[0_3,90,0,90,0_3]_{\text{sublaminate2}}$ $[0_3,90,0\ 90,0_3,90,0_3]_{\text{sublaminates 3 and 4}}$ $[45_2,0,45_2]_{\text{sublaminate5}}$

Section 4:

$[45_2\ ,0,45_2]_{\text{sublaminate1}}[90_2\ ,0_3\ ,90_2\ ,0,\ 90_2\ ,03\ ,\ 90_2]_{\text{sublaminates 3 and 4}}[45_2\ ,0,45_2]_{\text{sublaminate5}}$

Section 5:

$[45_2\ ,0,45_2]_{\text{sublaminate1}}$ $[90_2\ ,0,90_2\ ,0,\ 90_2\ ,0,\ 90_2]_{\text{sublaminates 3 and 4}}[45_2\ ,0,45_2]_{\text{sublaminate5}}$

Figure 8 presents the dimensions of the bracket after optimization.

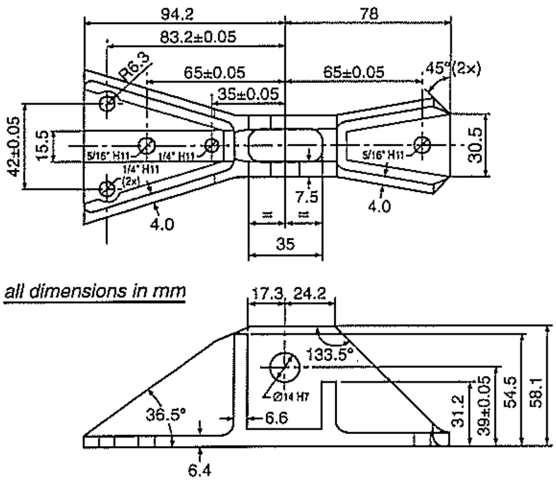


Fig. 8 Dimensions of the composite bracket after optimization

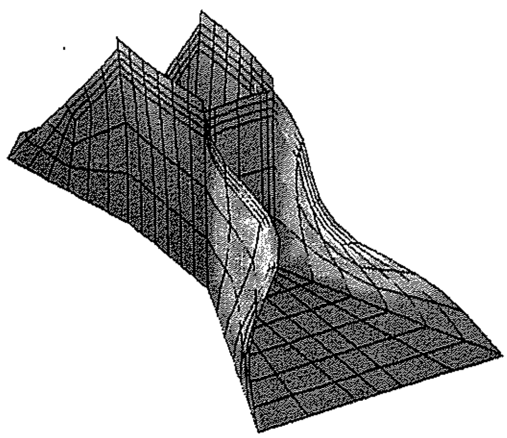


Fig. 9 First buckling mode at 8.5 Design Ultimate Load

After optimization a buckling analyses was performed to check the stability of the bracket. Figure 9 presents the first buckling mode which occurred at 8.5 x Design Ultimate Load.

5 FABRICATION OF THE BRACKET

Figure 10 presents the different elements of the RTM mould. All elements of the mould were made of aluminium with the exception of the central part of the mould which was made of the elastomer Techtron HPV. Techtron was selected because of its high coefficient of thermal expansion which eases demoulding of this mould element after post-curing the bracket. Because of the modular character of the mould, sub-preforms could easily be prepared on the tapered mould elements and the Techtron central part. Then sublaminate 5 was preformed on the subpreforms to complete the preform of the bracket. The final preform was positioned on the mould base plate. Then the mould was closed by bolting the side plates to the base plate and positioning the top plate. Resin was injected through a hole in the Techtron central part via a central injection point in the top plate. Eight vents, located in the side walls, were used to evacuate the air during resin injection.

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 and expensive due to the small dimensions of the bracket.

Two brackets were fabricated. During resin injection the mould had a temperature 50 ^{0}C. Resin was injected without vacuum assistance. The RTM pump pressure needed to inject the resin varied form 1.5 bar at the beginning to 3.5 bar at the end of the RTM process. After four minutes the preform was wetted. However, in order to ensure a complete impregnation of the fibres in the preform, resin injection was continued for 20 minutes. A fibre volume fraction of 55% was achieved with a good laminate quality. C-scans made, indicated no entrapped air or dry spots. Figure 11 shows the bracket before and after machining.

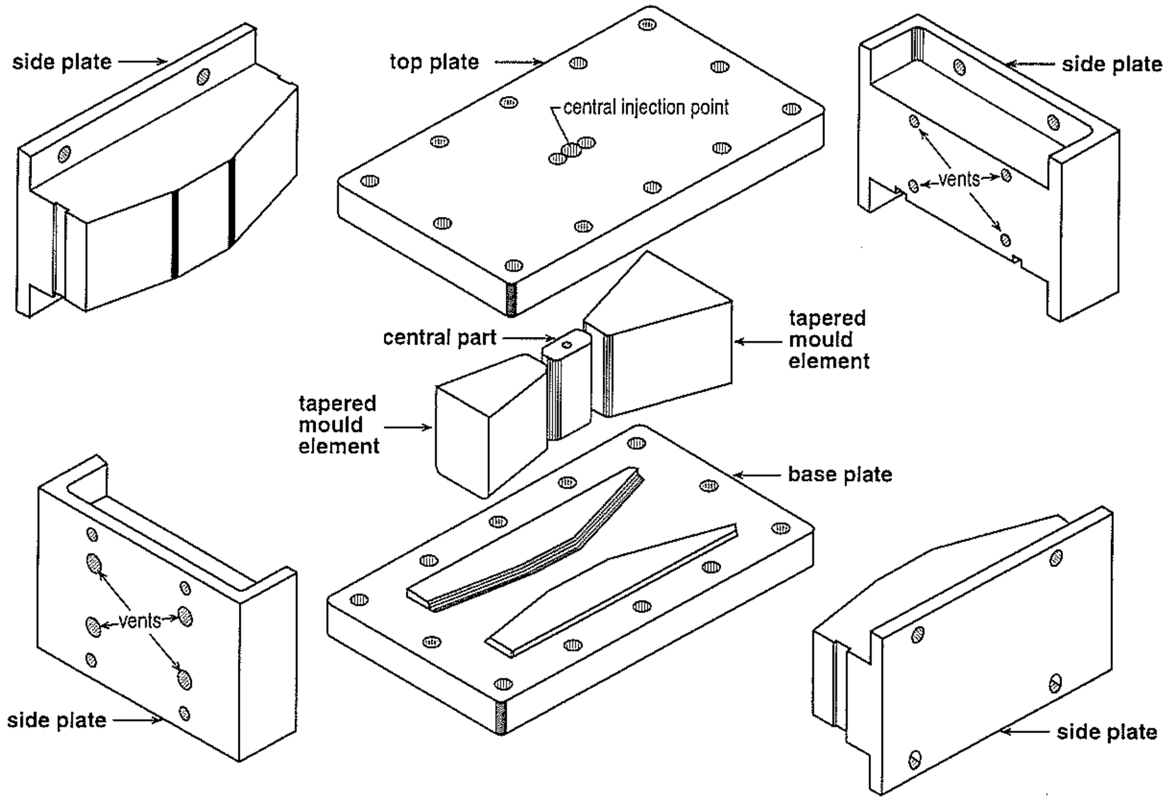


Fig. 10 Elements of the RTM mould

The weight of the bracket after machining was 173 gram whereas the aluminium bracket weighed 314 gram which means that a weight reduction of 43% had been realised. Unfortunately, because no data was available of the costs of the metal bracket no cost comparison between the composite and the metal bracket could be made.

6 TESTING THE BRACKET AND TEST RESULTS

One of the two brackets fabricated, was tested statically in tension and compression. During the tests the bracket was mounted in a test set-up on a slope making an angle of 40^0 (see fig. 12). Six rosettes (type HBM 6/120RY11) were

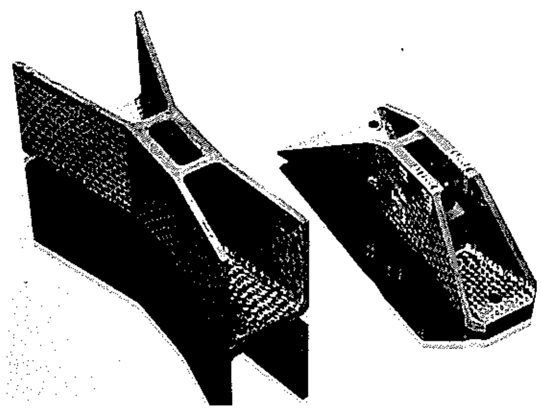


Fig. 11 Composite bracket before and after machining

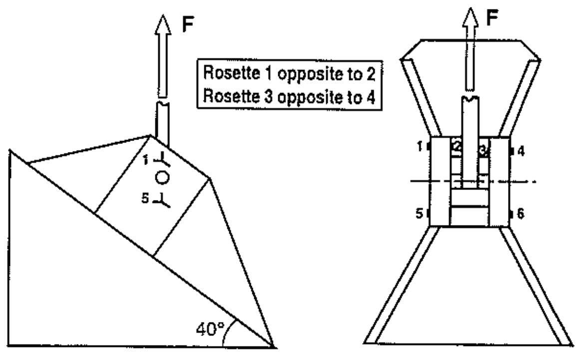


Fig. 12 Test set-up and instrumentation of the bracket

used to measure strains during the tests (see fig. 12). The tension and compression loads were introduced to the bracket by a metal bar connected to a screw driven test machine. Two steel bushes were positioned in the pin-loaded holes of the bracket to fix the metal bar. The tests were performed displacement controlled with a velocity of 0.1 mm per minute. The bracket was subjected to the following test programme:

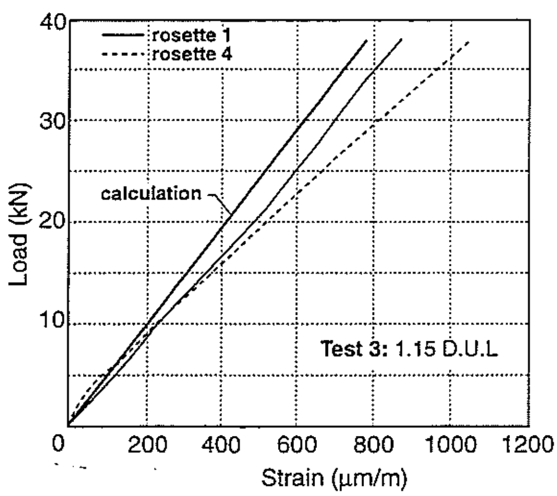
Test 1:0.575 x Tension Design Ultimate Load
Test 2:0.575 x Compression Design Ultimate Load
Test 3:1.15 x Tension Design Ultimate Load
Test 4:1.15 x Compression Design Ultimate Load
Test 5:1.38 x Tension Design Ultimate Load
Test 6:1.38 x Compression Design Ultimate Load

The bracket was designed for 1.15 x (Design Ultimate Load)$_{\text{metal bracket}}$. During tests 5 and 6 the bracket was loaded to 1.2 x (1.15 Design Ultimate Load)$_{\text{metal bracket}}$. The bracket did not fail at this load level. The bracket was not loaded to failure because it will be subjected to a fatigue program in the near future. Figure 13 presents the principle strains of rosettes 1 and 4 (see fig. 12) measured during test no. 3 (1.15 design Ultimate Load test in tension) and principle strains of rosettes 5 and 6 (see fig. 12) during test no. 4 (1.15 Design Ultimate Load in compression). The figure indicates that for a certain load level the calculated strains are somewhat lower than the measured strains. This may be caused by the mismatch in the fibre volume fractions between the specimens used to determine the material properties (58%), which were used as input for the FE analyses, and the fibre volume fraction of 55% obtained in the actual bracket.

7 CONCLUSIONS

A composite bracket for aerospace applications as replacement of a metal bracket has been developed. The finite element method in combination with an optimization module was used to design the bracket.
The weight of the composite bracket was 173 gram whereas the aluminium bracket weighed 314 gram which means that a weight reduction of 43% has been realised. Because no data was available of the costs of the metal bracket no cost comparison between the composite and the metal bracket could be made.

An RTM mould and modular preforming concept to produce the composite bracket has been developed. Two composite brackets were fabricated. One bracket was subjected to a test program in which the bracket was loaded to 1.38 x Design Ultimate Load both in tension and compression. The bracket did not fail at this load level.



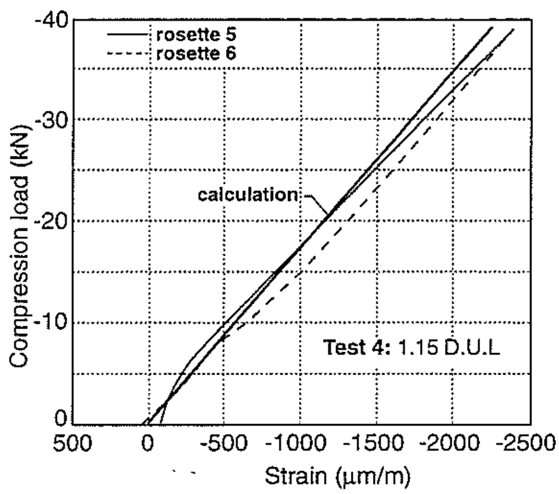


Fig. 13 Calculated and measured load-strain curves

REFERENCES:

1) Modular Finite Element Analysis Tools Applied to Problems in Engineering, PhD These no. 1251, Ecole Polythenique Federale de Lausanne, by Silvio Merazzi, Lausanne, EPFL 1994
2) The B2000 Optimization Module: B2OPT, by P. Arendsen, NLR Technical Publication TP 94116 L, published as part of the GARTEUR AG13 "Structural Optimization" action group report, March 1993
3) Design stress levels and rough design rules for CFRP structures with concentrated load introductions -an experimental study-, by H.G.S.J. Thuis, NLR technical report TR 97045 L, January 1997