

SECOND EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

Paper No. 9

DEVELOPMENT, FABRICATION AND TESTING OF A
HYBRID COMPOSITE TAILBOOM FOR BO 105

H. Bansemir
R. T. Schulz

Messerschmitt-Bölkow-Blohm GmbH
Munich, Germany

September 20 - 22, 1976

Bückerburg, Federal Republic of Germany

Deutsche Gesellschaft für Luft- und Raumfahrt e.V.

Postfach 510645, D-5000 Köln, Germany

DEVELOPMENT, FABRICATION AND TESTING OF A
HYBRID COMPOSITE TAILBOOM FOR BO 105

by

H. Bansemir,

R. T. Schulz

Messerschmitt-Bölkow-Blohm GmbH

Postfach 801140

8 München 80, Germany

SUMMARY

This paper describes a national program pursued by MBB for the design, manufacture, and testing of an advanced composite tailboom for the BO-105 helicopter. The program was undertaken to gain experience in design and manufacture of a major primary structure produced by the filament winding process. A special net-sandwich configuration was chosen, because of cost reduction, weight saving, stiffness and strength. Kevlar 49, Graphite type II (HT) was selected for the design.

Two tailbooms were fabricated, one for structural test and one for flight test. It was found that the composite boom was considerably stiffer than the standard production tailboom of the same weight. It failed at 180 percent ultimate load with failure occurring in the compression and torsion area. The paper describes the analytical work, the fabrication process, and the test program.

1. INTRODUCTION AND DESIGN REQUIREMENTS

The tailboom, which is the structural element between the main airframe and the tailrotor of the BO 105 helicopter, is a conventional aluminium alloy sheet-stringer structure. The design requirements for the tailboom made of high-strength and stiff advanced composite are:

1. bending and torsional stiffness at least as large as that in the standard tailboom
2. sufficient strength
3. interchangeability with the standard tailboom for the purpose of flight tests
4. as little weight as possible

Depending on the choice of fiber material the different designs differ in respect to weight, as well as fail safe behaviour, hit-sensitivity, radar-detectability, production repair costs. Because of the small diameter, a high torsional stiffness of the composite is required. Furthermore, because the tailboom had to be designed without frames a stiff sandwich construction was considered.

The replacement of foam and honeycombs with a grid system made of very stiff material was considered for this construction. This grid can be set at an angle of ± 45 degrees, so that the shear stiffness requirement is met. When the automatic method of production, like the filament winding process is taken into account a 5 layered "net-sandwich" design results.

2. FABRICATION AND DESIGN PRINCIPLES

The construction of the conical shell of the tailboom depends primarily on the fabrication method and the strength and stiffness specifications. The other characteristics, such as hit-sensitivity, radar detectability and IR-radiation are determined by the choice of the fiber materials. The filament-winding process, in which unidirectional fibers are wound around

a positive mandrel, was chosen as the method of fabrication.

The conical shape of the tailboom requires a so-called non-linear filament winding process, in which the fibers are laid up on geodesic lines. These lines, being the shortest, prevent slippage of the fibers. The forward speed at the delivery eye in the non-linear filament winding process in relation to the rotating speed of the mandrel must be different for each point of the layered fibers. The result is a structure with different fiber orientations over the length of the conical shell. In addition, a different wall thickness over the length results from the geodesic lay-up and the conical shape.

The wall of the shell is subdivided into 5 layers, where each layer meets special strength and stiffness requirements which correspond to the fiberorientation.

A layer is set up $\pm 45^\circ$ in order to take up the torsional moments and is located between the longitudinal layers. In contrast to the usual method, which consists of laying the single fibers close together, this torsion layer is fabricated as a net with a special mesh pattern.

Instead of laying up each band close together, they are stacked on top of each other and form the core of the sandwich, the so-called "netsandwich".

The lay-up, shown in fig. 1 and table 1, was chosen for the design.

3. MATERIAL SELECTION

In the early program stage the choice of materials was narrowed down to glass, Kevlar 29 and 49 as well as graphite-epoxy HT and HM.

Because of the high stiffness requirements only Kevlar 49 and graphite-epoxy HT and HM were considered. Kevlar is hygroscopic, and matrix-fiber-bonding is insufficient. But for the "netsandwich" structure this matrix-fiber-bonding is essential. Thus the

solution was the selection of the graphite-epoxy, leading to the final decision between the fibers HM Toray M-40 A and HT Toray T300 A. In the tables 2 and 3 the main characteristics of the two fibers are described.

The high stiffness values of the M40A result in high buckling values and stiffness of the conical shell. The high strength values of T300A result in high strength of the load-introduction and load-diffusion-areas.

4. STRESS ANALYSIS OF SPECIAL COMPONENTS

The main loads which effect the tailboom are described in figure 2.

The sum of the loads for each loading condition is given in figure 3. The points refer to limit- and ultimate loads on the different parts of the tailboom. The main loadcondition of the tailboom consists of the maximum bending moment together with the maximum torsional moment.

The tailboom was expected to fail in buckling adjacent to the fuselage attach fitting. Another critical part of the tailboom is the cutout for the attachment of the vertical stabiliser. It had to be found a suitable method to reinforce the cutout.

For studying the reinforcement of the cutout to find the ultimate buckling stress a series of elementary tests with cylinders were performed. The load condition on these small cylinders were shear and uniform pressure. It was cost efficient and suitable for studying different types of cutout reinforcements.

Test cylinders without cutouts, with cutouts and with Kevlar cloth reinforced cutouts were tested under torsional moments.

Failure modes and reinforcements are represented in figure 4 and 5.

The effect of the cutouts on the ultimate torsional moment was studied in a finite element analysis with the structure program, NASTRAN. The tests of specimens with Kevlar cloth reinforced cutouts showed, that a remarkable increase of the ultimate torsional moment was possible. The torsional moment for the specimen with reinforced cutout was even higher than the ultimate load for the specimen without cutout. The frame-like reinforcement showed to be a very efficient stiffener, which prevents the structure from shear buckling. The performed tests were used to find the ultimate bending- and torsional moment for the tailboom.

As shown in [1], it is possible to find the ultimate buckling moment from the ultimate buckling pressure. Usually the bending stress σ_{bd} is set equal to the axial pressure σ_d . According to [1] the relation

$$\sigma_{bd} \cong 1,4 \sigma_d \text{ is valid} \quad (1)$$

$$\text{with } \sigma_d = \frac{P}{A}$$

$$\text{and } \sigma_{bd} = \frac{M}{W} \text{ with } W \approx \frac{A \, dm}{4}$$

and therefore

$$M \cong 1,4 P \frac{dm}{4} .$$

According to [2] for the superposition of shear and pressure we get the equation:

$$\left(\frac{\tau_{br}}{\tau} \right)^2 + \left(\frac{\sigma_{br}}{\sigma} \right) = 1 \quad (2)$$

According to [3] we can change this relation into

$$\left(\frac{\tau_{br}}{\tau} \right)^2 + \left(\frac{\sigma_{br}}{\sigma} \right)^{1,5} = 1 \quad (3)$$

A quite conservative relation is

$$\frac{\tau_{br}}{\tau} + \frac{\sigma_{br}}{\sigma} = 1 \quad (4)$$

With these relations and the test results we get for the ultimate bending moment of the tailboom

$$M_{br} \cong 2.16 \times 10^4 \text{ Nm}$$

With the equation(2) we get

$$\frac{\sigma_{br}}{\sigma} = 1 - \left(\frac{\tau_{br}}{\tau} \right)^2$$

$$\text{with } \tau_{br} = 0,185 \tau$$

$$\text{and } \sigma = 0,997 \sigma_{br}$$

This leads to an ultimate bending-moment of

$$M = 20900 \text{ Nm}$$

Possibilities for reinforcement of the cutout were studied with the NASTRAN finite element analysis with the model shown in figure 6 and 7. It was found that a combination of unidirectional and $\pm 45^\circ$ layers were the optimum reinforcement for the given shear- and bending loads of the tailboom. For the reinforcement a Kevlar 49 cloth was chosen, layered up under $\pm 45^\circ$, 0° and 90° . Thereby a very effective frame-like reinforcement was achieved (figure 8). The loads from the vertical stabiliser were transferred to the conical shell by two glass-fiber-reinforced plastic bulkheads (figure 9).

The load transfer from the advanced composite tailboom to the fuselage is made by a fuselage attachment bulkhead which is bolted to the reinforced composite tailboom.

5. FABRICATION OF THE TAILBOOM

Broadly speaking, load is carried by a particular filament, proportional to the tension developed within it during the winding process. Therefore it is necessary to lay up the filament on a geodetic path around the circumference and domed

ends of a mandrel, to achieve this a special program is required for the electronically controlled winding machine.

Prior to winding, the program was fed into the machine and the aluminium mandrel installed and tested to ensure true running. Domes made of a foam material were then bonded on to the ends of the mandrel.

To produce the first layer of the boom, rovings were hoop wound on to the mandrel forming a full cover over the entire mandrel. Because the speed of the delivery eye was very low, it was possible to remove excess resin which was squeezed out of the laminate due to high pre-tension in the roving. The rovings were impregnated directly before being wound.

On completion of the first process, the second layer was wound on to the wet first layer. The second layer consists of a carbon fiber ply wound with an alignment of 8° to 12° . This second layer forms one of the bending shells.

The major problem here was to lay up the helical windings at a winding angle of 30° to 45° . To produce a full cover with the required orientation was considered state of the art, but there existed little experience of winding a wide gap pattern. The gap width envisaged was $11d$ and the band width 3 mm at an angle of 30° - 45° , therefore the pitch had to be greater than the band width. That meant high carriage acceleration and because of high elongation rate of the driving chain, misorientation of the fibers.

Finally after many dry runs the rovings were laid-up on one another forming a torsion layer of high thickness.

Layers 4 and 5 were laid up by the same procedure.

The tube was cured for 15 h at $T = 80^{\circ}\text{C}$.

The cutout for the horizontal stabiliser, in a tailboom constructed from CFRP, had to be reinforced by several layers of Kevlar 49. This reinforcement was also drilled to carry the stabiliser attachments.

To introduce the loads from the vertical stabiliser two separate bulkheads were fabricated from GFRP and then bonded into the boom. The stabiliser was riveted to these two frames.

Finally all panels and rotor drive equipment were assembled to the tailboom to complete the manufacturing phase.

6. FULL-SCALE TEST PROGRAM

The tailboom was loaded as seen in figure 13 and in figure 2 and 3.

The tailboom was first loaded with the limit load conditions of points 1,2,3 in figure 3. The stresses measured by strain gauges for these conditions were nearly the same, as predicted by the elementary theory. Following the limit load tests, the structure was loaded with the failure of points 4,5,6,7 and 8 of figure 3.

It was found that the glassfiber bulkhead (figure 9) buckled just below the failure torsional load, so the bulkhead was reinforced. After the reinforcement of the bulkhead the loads P_y on the vertical stabiliser and the P_y on the T/R bearing were maintained at failure load (point 4,5) and load P_z on the vertical stabiliser was increased until the tailboom failure occurred at $P_z = 9700$ N, which corresponds to a bending moment of $M_B = 27000$ Nm.

The tailboom failed at 180 percent ultimate load with the failure occurring in the compression and torsional area. No overall buckling was the failure mode (figure 14).

Flight Test

Testing the CFRP-tailboom in flight it could be shown that the general behaviour did not differ from the standard one.

The IAS was limited to 80 kts, although high speed manoeuvres were possible as well. The higher value of the rate did not influence the vibration levels.

The manoeuvrability was as good as the BO 105 equipt with the standard tailboom.

7. CONCLUSION

After the fabrication of two "netsandwich" tailbooms all the manufacturing problems could be solved, although at that time new aspects already led to new ideas, which possibly allows a higher rate of weight saving.

Although the CFRP tailboom and the aluminium tailboom have the same weight, it should be mentioned that the shell of the normal tailboom was heavier than the one manufactured in CFRP. But the fittings and attachments increased the weight of the complete tailboom to that of the aluminium one. Therefore it will be necessary for future tailboom to find a less conservative solution for it and especially for the position of the horizontal stabiliser.

REFERENCES

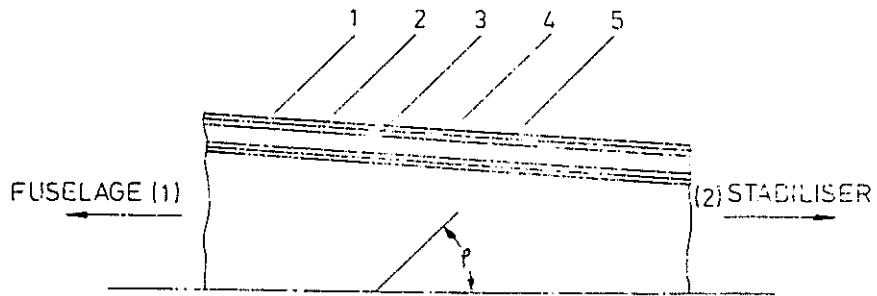
- (1) Reese, C.D.; Bert, C.W.
Buckling of Orthotropic Sandwich Cylinders under Axial Compression and Bending. *Journal of Aircraft*, Vol. 11, No. 4, 1974.
- (2) Bert, C.W.; Crismann, W.C.; Nordby, C.M.
Buckling of Cylindrical and Conical Sandwich Shells with Orthotropic Facings. *AIAA-Journal*, Vol. 7, No. 2 February 1969.
- (3) Bruhn, E.F.
Analysis and design of flight vehicle structures.
Tri-state offset company, Cincinnati, Ohio 45202 (USA).
- (4) Brunsch, K.; Jonda, W.; Och, F.:
Konstruktionsforschung für Drehflügelbauteile aus KFK.
MBB GmbH, Bericht UD-69-71 vom 28.12.71.
- (5) Jonda, W.
Weiterentwicklung der Fertigungstechnologie für Bauteile aus KFK
MBB GmbH, Bericht UD-70-71 vom 12.12.71.
- (6) Jonda, W.
Technik der kohleverstärkten Kunststoffe
MBB GmbH, Bericht UD-90-72 vom 29.12.72.
- (7) Jonda, W.
Technik neuer faserverstärkter Kunststoffe
MBB GmbH, Bericht UD111-73 vom 28.12.73.
- (8) R.T. Schulz
Neue Verstärkungsmaterialien, ihre Anwendungsmöglichkeiten an Beispielen ausgesuchter Bauteile
MBB GmbH, Bericht UD-126-74 vom 27.3.1975.

(9) Zinberg, H.

An Advanced Composite Tailboom for the AH-1G Helicopter.
Presented of the 29th Annual National Forum of the American
Helicopter Society

Washington, D.C. May 1973

Reprint No. 785



Skizze: Laminataufbau der Röhre

Figure 1 LAMINATE LAY-UP SEQUENCE

Ply	Thickness mm	Oriente- tion	Laminate	Fiber	Supplier
1	0,5	90	PRD-EP.	Kevlar 49-III	Dupont
2	1) 0,7 2) 0,8	$\pm 8^{\circ}$ $\pm 12^{\circ}$	KFK	Toray T 300 A	Torayca
3	1) 1,2 2) 1,5	$\pm 30^{\circ}$ $\pm 45^{\circ}$	KFK	"	"
4	1) 0,7 2) 0,8	$\pm 8^{\circ}$ $\pm 12^{\circ}$	KFK	"	"
5	0,5	90 ^o	PRD-EP.	Kevlar 49-III	Dupont

TABLE 1 : LAY-UP OF THE TAILBOOM

FIBER	$E_{ }$ dN/mm ²	$\sigma_{ }$ dN/mm ²	$\alpha_{ }$ ^x 1/°K	ϵ ‰
TORAY M40A	$4,0 \times 10^4$	225	-1×10^{-6}	6
TORAY T300A	$2,35 \times 10^4$	280	-1×10^{-6}	10,5

Table 2 MATERIAL PROPERTIES (FIBER)

FIBER / RESIN ^{xx}	$E_{ }$ dN/mm ²	$\sigma_{ }$ dN/mm ²	$\alpha_{ }$ 1/°K	ϵ ‰
M40A CY209	$2,3 \times 10^4$	142	$0,7 \times 10^{-6}$	6
T300A CY209	$1,2 \times 10^4$	165	$0,7 \times 10^{-6}$	10,5

++ for 60 V/O fibercontent

Table 3. MATERIAL PROPERTIES OF THE UNIDIRECTIONAL LAYER

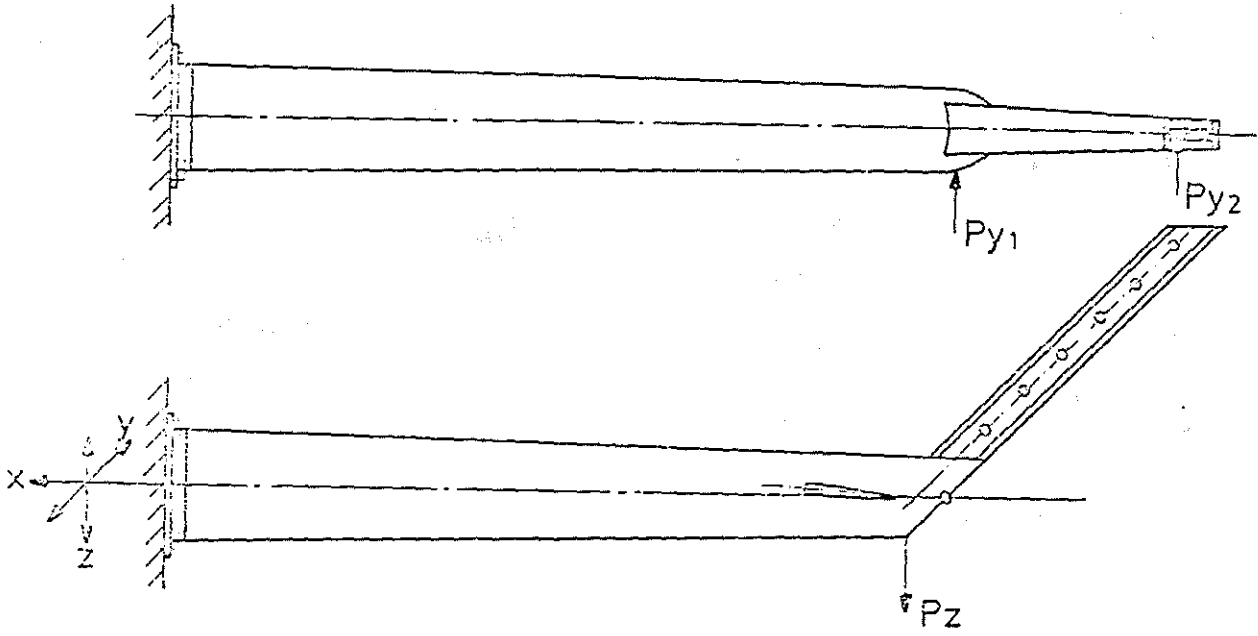


Figure 2 LOADING POINTS ON THE BO 105 T/B

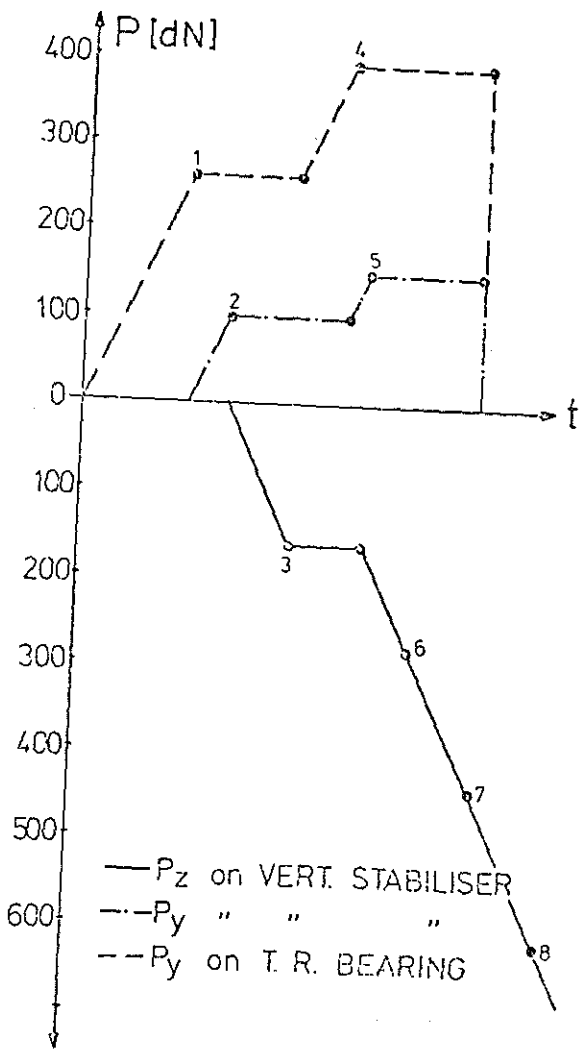


Figure 3
LOAD APPLICATION
SEQUENCE BO 105 T/B

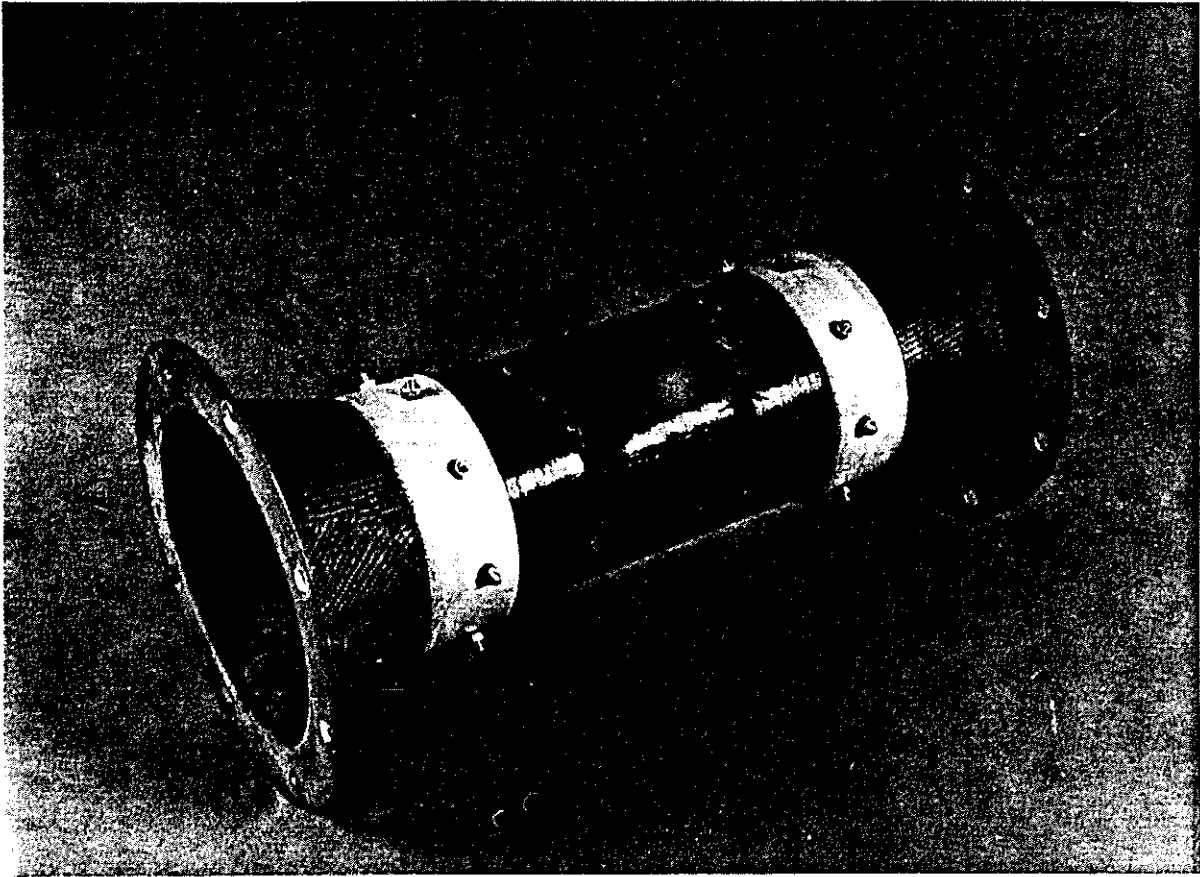


Figure 4 TEST CYLINDER WITH CUT-OUT AFTER TEST

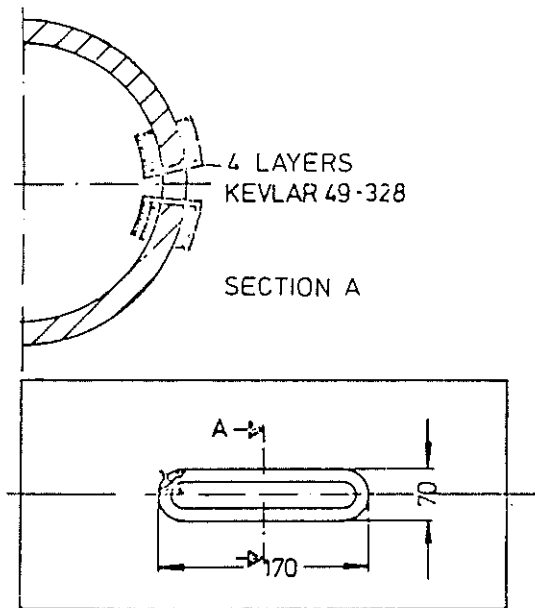


Figure 5 REINFORCEMENT OF TEST SAMPLE CUT-OUT

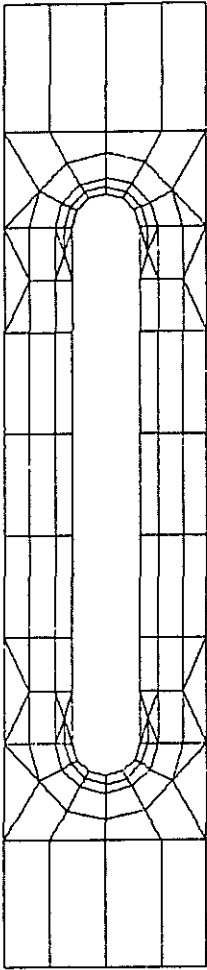


Figure 6

NASTRAN MODEL OF ADVANCED
COMPOSITE CUT-OUT

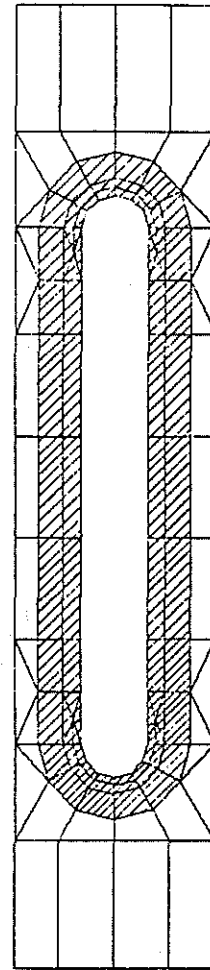


Figure 7

NASTRAN MODEL OF ADVANCED
COMPOSITE CUT-OUT REIN-
FORCEMENT

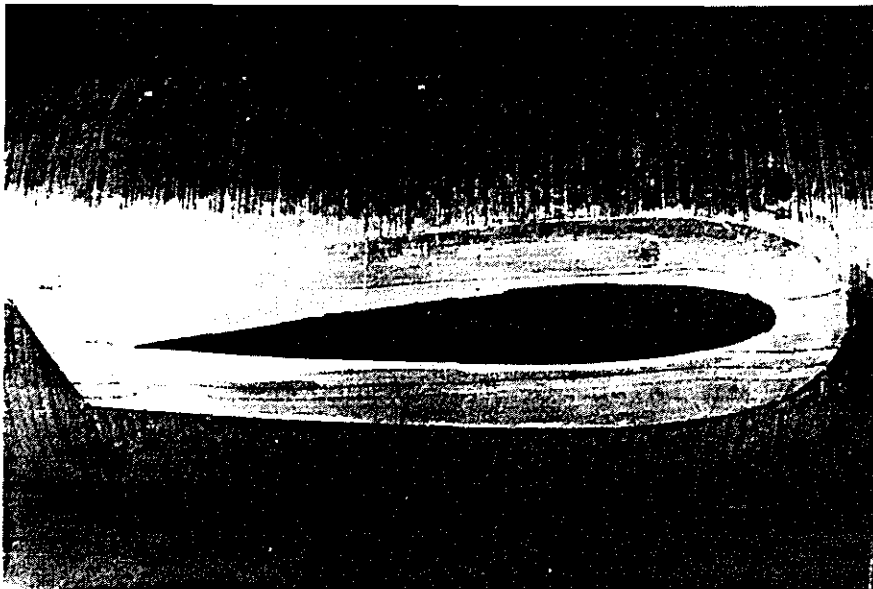


Figure 8 REINFORCED CUT-OUT FOR THE VERTICAL STABILISER

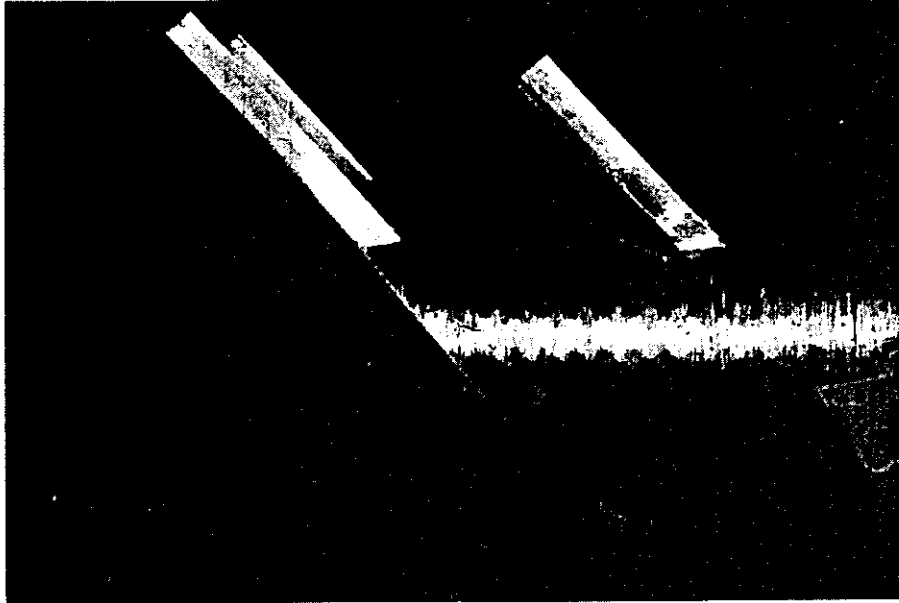


Figure 9 LOAD INTRODUCTION FRAMES

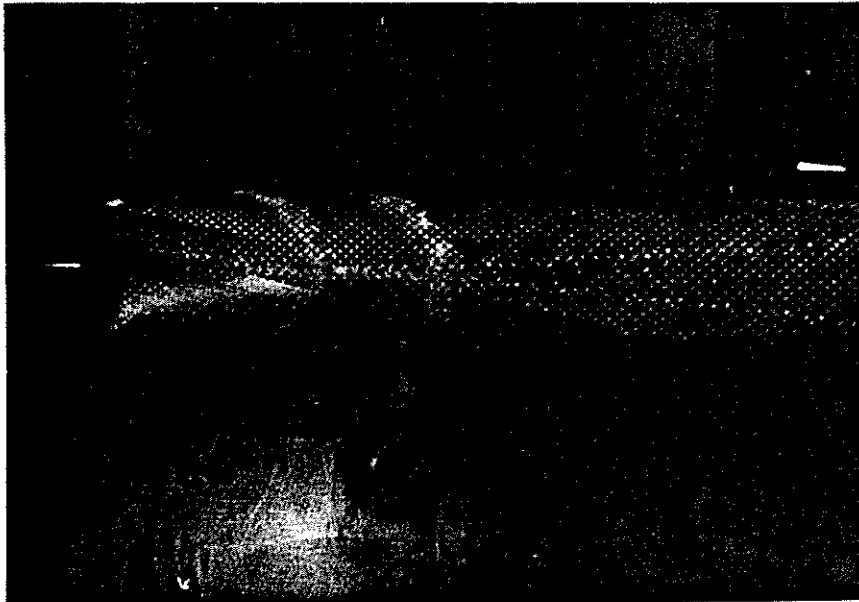


Figure 10 FIBER LAY-UP OF THE TAILBOOM

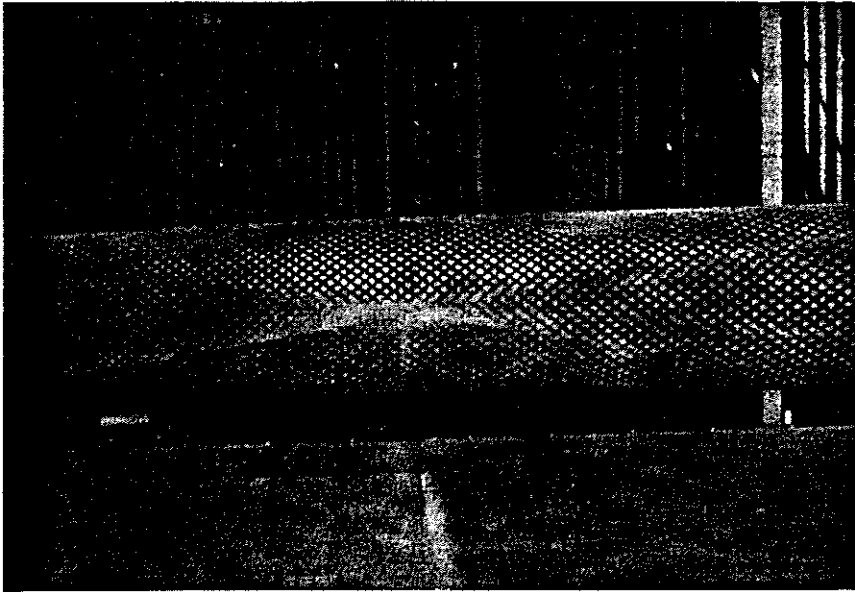


Figure 11 WOUND TAILBOOM WITHOUT HOOPWINDING



Figure 12 TAILBOOM STRUCTURE

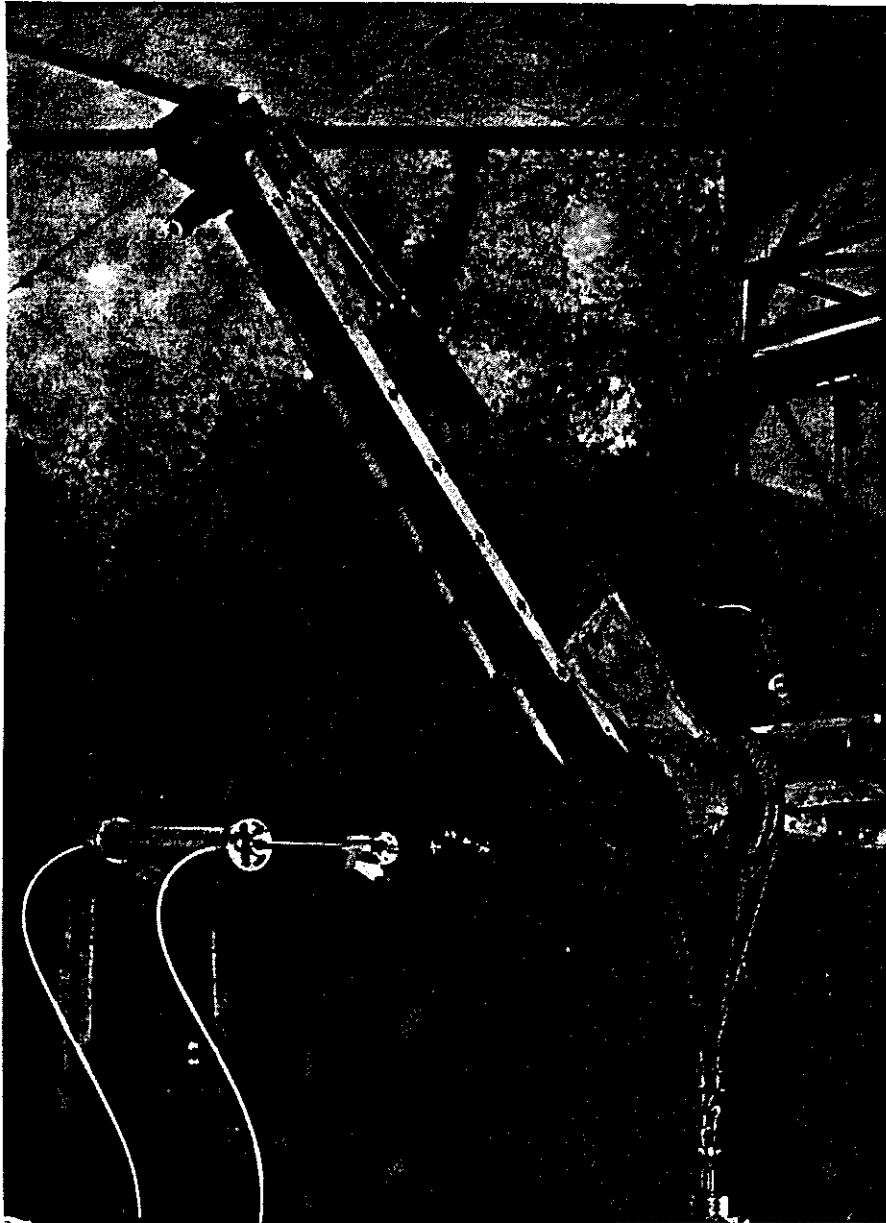


Figure 13 FULLSCALE TEST SET-UP

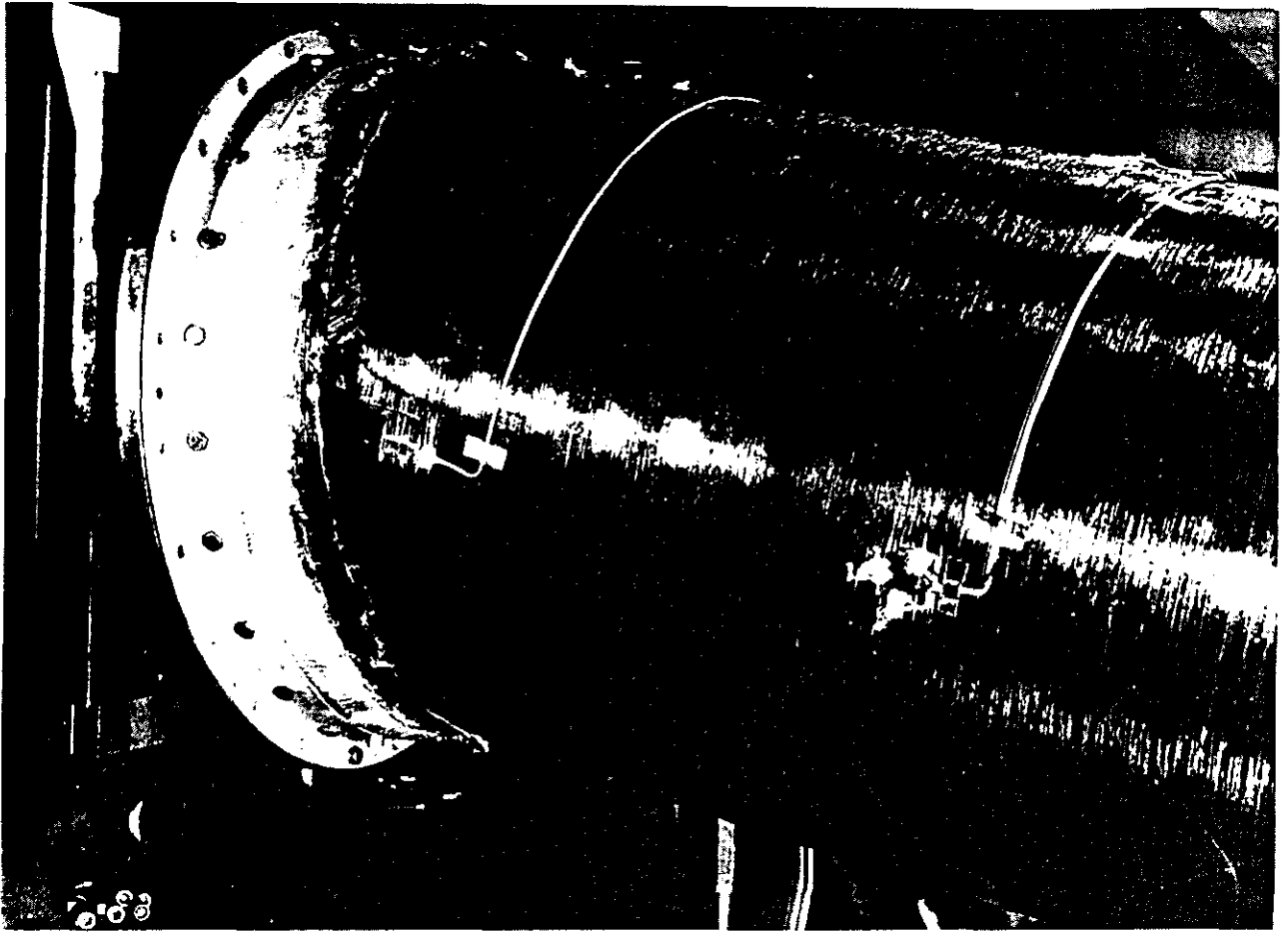


Figure 14 FAILURE OF STRUCTURE



Figure 15 ASSEMBLED ADVANCED COMPOSITE TAILBOOM
ON FLIGHT TEST