Attachment B

"Development of the A300 Fin in Modern Composite Fibre Construction"
"Structural Certification of Airbus Fin Box in Composite Fibre Construction"

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DEVELOPMENT OF THE A300 FIN IN MODERN COMPOSITE FIBRE CONSTRUCTION

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Abstract

On the base of a research program sponsored by the German Government the companies MBB and VFW started developing the Airbus - fin box in fibre reinforced plastics in 1978. In 1984 one fin shall be certificated for airworthiness and be tested in airline service. In this paper, program and design aims are set up. Main results achieved during the first development phases are reported. Environmental conditions to be considered permit the use of 120°C - resin systems. As the result of analytical and experimental investigations with respect to weight, production costs, maintenance and reliability, a structure was chosen which is primarily reinforced by open - section stringers. By using a low cost production concept the increased composite material cost can be offset.

I. Introduction

Since 1976 there have been strong efforts within the partners of Airbus Industry for applying advanced fibre materials to the secondary structure of the Airbus A300 / A310. Essentially, this refers to spoilers, landing gear doors, floor struts, rudder, leading edges and fairings. The fin leading- and trailing edges and rudder (Fig. 1; 2; 3) will be brought into commercial airline service in 1983. While for the existing leading - and trailing edge sandwich structure a simple material exchange of glass to carbon fibre reinforced plastic (GFRP/CFRP) could be realized, the rudder had to be totally redesigned. The rib - stiffened metal rudder will be replaced by a CFRP - sandwich structure without inner ribs. The simple configuration of the new rudder allows an additional 18% weight saving and a reduction of the total production costs. On the basis of this preparatory work which generates special experience with fibre constructions in the fields of design, production, quality assurance and later in actual airline service, the companies MBB and VFW began to develop the Airbus - fin box in CFRP in 1978. The research program is sponsored by the German Ministry of Research and Technology (BMFT). The fin will be the first piece of composite primary structure for the Airbus. This structural part is especially suitable for demonstrating the applicability of advanced fibre materials in civil aircraft constructions. It distinguishes itself by being removable and therefore easily interchangeable. The large area structure ($A = 45m^2$) is typical for wings and tail units. The development program is divided into six stages (Fig. 4) Preparation, conception and definition stages ended in March 1980 with the completion of the preliminary design work. At the end of the following developmental and testing stages, five fin boxes will be produced. The program will be completed in 1984/86 with flight service.

II. Objectives and Design Principles

The design principles are mainly induced by the research program objectives and the requirements derivable from the Airbus program.

Research Program Objectives

- o Demonstration that the application of composite material to primary structures is a suitable step to reduce the direct operating costs of civil aircraft without any loss of safety.
  - reduction of the structural weight by approximately 20%.
  - comparable production cost
  - acceptable maintenance costs in relation to the existing metal structure.
  - preparation of the basis for a medium - term economic series introduction of the CFRP - fin.

Airbus Requirements

- o The outer geometry of the fin is clearly defined.
- o The fin box must be interchangeable.
- o The fin structure must meet the airworthiness requirements FAR 25, amendment 45 and special conditions.
- o Economic repair life:
  48 000 flights for A300
  40 000 flights for A310
  as a design aim.

Conventional Fin Structure

The fin can be divided into the following main components (Fig. 1)

- fin box
- fin leading edge
- rudder
- fin fairings

Its main dimensions are:

height	8.3m
chord depth at the root	- 7.8m
chord depth at the tip	- 3.1m

The fin box is the main structural part of the fin. It takes all airloads acting on the box area itself and the joining loads coming from the leading edge, rudder and trailing edge. The resulting loads are transfered to the fuselage structure by 3 transverse load - carrying fittings and 6 fittings acting mainly in the vertical/longitudinal plane. These 9 fittings guarantee full fail - safety. The interchangeability of the fin is achieved by detachable bolts. The box is designed with 3 spars in the lower and 2 spars in the upper part. Normal rib pitches vary between 420mm and 500mm. The ribs are of a trusswork and shear web design. The skin is made from sheet material mechanically and chemically milled to varying thicknesses due to loading requirements and is stiffened by Z - shaped stringers with a pitch of 115mm. At the rear spar 7 aluminium fittings are attached to pick up the rudder hinge fittings and 3 actuators for performing rudder deflection. The general assembly is joined by riveting and bolting.

Design Principles

The before - mentioned aims and requirements lead to the following design principles for the CFRP - fin box

- o The fin box shall be applicable to A300 and A310 as well.
- o The outer geometry has to be identical to the metal one at room temperature; the same lofting has to be used.
- o All interface points to the fuselage, leading edge and rudder must be identically positioned and shaped.
- o The structural design must meet the requirement that interface forces must not increase more than 5%, which is within tolerance with respect to the

strength of the adjoining parts.

- The structural design must have fail safe features and guarantee an economic repair life of 48 000 flights.
- Environmental conditions have to be considered.
- The structure must allow the application of simple inspection methods.
- Number of components has to be reduced.
- The design must allow the application of cost competitive manufacturing processes and materials.

III. Production Conception

Considering the program objectives it becomes obvious that the success of the program depends strongly on the possibility of using cost competitive manufacturing processes. Medium - term economic series introduction means later than 1986. By then several hundred metal fins will have been built and the production costs will have been reduced to a major extent. It must be shown that the production costs of the CFRP - fin box shortly after the beginning of series production will decrease 80% of the metal fin costs (Fig. 5). Since the material costs at the end of the 1980's will be higher for CFRP than aluminium, in order to achieve this considerable cost reduction, advanced structural concepts and manufacturing processes had to be considered. An analysis of the production costs for the existing metal fin box is shown below:

Work Package	% of Total Production Costs
Panels & Fittings	63%
Spar Webs & Fittings	4%
Ribs & Fittings	19%
Assembly	14%

Table 1

This shows that special efforts on the panels, ribs and assembly could be profitable. During the concept stage a configuration study showed that an orthogonal stiffened panel concept was the best compromise based on the criteria:

- production cost
- weight saving
- reliability
- maintenance
- inspection

It was decided that such panels have to be designed and manufactured as integral parts. Skin, stringers and rib clips will be "one - shot cured".
The cost reduction for the rib production can be mainly achieved by reducing the number of ribs. Considering the necessity of having ribs at the rudder hinge fitting positions and studies concerning rib pitch optimization, the number of ribs for the composite fin box could be reduced as follows:

metal fin box - 26 ribs
composite fin box - 18 ribs

Both afore mentioned measures, the integral panel concept and the reduction of the number of ribs, bring down the assembly costs accordingly.
For realizing the cost effective "one-shot curing" production of the panels, two concepts were developed:

a) mat production process (Fig. 6)
b) module production process (Fig. 7)

The Mat - Concept is preferable in the production of closed sectioned stringers. Shaped rubber mats reaching from rib to rib are laid on a compact substructure that is the female mold for the ribs and stringers. Rib laminates are brought between the shaping blocks and A - section - stringer laminates are laid directly in the shaping mat. The inner volume of the stringers is filled with a rubber pipe which is formed according to the inner surface of the stringers. This grid - work is than covered by the skin laminates. During the curing process within the autoclave, the pressure is achieved for all parts of the skin, ribs and stringers by the flexible mat and rubber pipes. After the curing process has been finished, the mats can be dismantled easily. Implosion techniques can be used in the case of the rubber pipes.

The Module - Concept is the result of applying a high degree of automation in production to the specific features of stringer- and rib - stiffened light - weight constructions. In principle, light - weight fibre structures can be realized by designing the different elements for internal forces as follows:

skin / for shear loads
stringer and rib-flanges / for end loads
stringer and rib-webs / for shear loads

While all flanges should be continuous, the stringer webs can be interupted at the grid points, but a shear load transfer to the adjoining webs must be available. Such a web design, shown schematically in Fig. 8 is applied in the module concept. The fin box panel is devided into a substantial number of small boxes shaped by stringer webs and rib webs. The design suggests that stringer- and rib webs of such an unit can be produced in a one step process by simply draping prepregs around rotating module cores, the geometrie of which is defined by the volume between two adjacent stringers and rib clips (Fig. 9). In another mechanized production step, all uncured module parts must be brought together with the layed-up skin and flange prepregs for co-curing. It is obvious that this procedure will save considerable assembly work later for joining rib- and stringer webs, since the stringer webs and rib clips are already joined in the module unit.

Production Development

During the definition stage of both previously discussed configurations, a number of panels were manufactured in order to establish process parameters. These investigations will be continued in the development stage, but preliminary results from compression tests demonstrate that both methods will lead to an acceptable standard of quality. Special attention was given to module core design to achieve a controlled manufacturing process with respect to pressure and temperature combined with a long core life. Test panels produced with aluminium cores showed good geometry and strength but for the production of more complex structures more elastic cores are preferable. For the mat processing, special attention was given to reproducibility of the general geometry and flatness of all parts with the use of soft tooling and the accomplishment of long life behavior of the rubber mats. Different rubber materials are under investigation.

Selection of Final Concept

As the result of paper studies [1] during the concept phase, a decision was made to start preliminary design of an I - section stringer configuration having in mind the application of module technology. It was hoped that hardware built in the definition stage would verify this assessment. At the end of the definition phase a review was made on this subject. An evaluation was carried out according to a method given in "Luftfahrttechnisches Handbuch für Konstruktion" [2] for both stringer configurations, considering six criteria of varying importance (Table 2). As it can be seen from Table 2, the profitable values for both conceptions are almost equal, which led to the decision not to change the design work but to continue with I - section stringers.

Criteria	Factor of Importance	I-Stiffened Structure		⎍-Stiffened Structure	
		Relative Value	Profitable Value	Relative Value	Profitable Value
Production Cost	1.0	1.0	1.0	0.8	0.8
Risk for Program	0.7	0.95	0.665	1.0	0.7
Weight	0.63	0.94	0.59	1.0	0.63
Transferability	0.5	0.85	0.425	1.0	0.5
Maintenance	0.45	1.0	0.45	1.0	0.45
Potential Improvement	0.4	0.95	0.38	1.0	0.4
Profitable Value	-	-	3.51	-	3.48

(Profitable Value) = (Factor of Importance) x (Relative Value)

Table 2. Valuation of I- and ⎍-stiffened Structures

Series Production Concept

In Fig. 10 a possible series production line on the basis of module conception is pictured. As outlined before, such a concept must be able to compete on a cost basis at the end of the eighties. The main principle for this production line is minimizing man power and applying automation to the utmost justifiable degree. Almost all production steps are numerically controlled ① .
The production starts by water jet cutting ② the module prepregs, which will be draped on module cores on a bandage machine ④ with the aid of a manipulator ③ . The transport of naked module cores from storage ⑥ to the bandage machine ④ and the draped cores from the bandage machine ④ to the module control box ⑦ will be carried out by a second manipulator ⑤ .
After being controlled, the draped module cores will be transported from the control box ⑦ to the module grating platform ⑧
The grid being complete and pressed together will be positioned on the laminated skin which has been prepared by a layer machine ⑨ . After that, the stringer flanges will be layed upon the bordered stringer webs ⑨ . Autoclave curing will join ⑩ , ⑪ . The dismantling ⑫ , transporting ⑬ , ⑮ and cleaning of the tools and module cores ⑭ is a highly automated procedure.

IV. Structural Development

Material Selection

Environmental conditions, especially humidity and temperature, affect the strength and stiffness properties of the composite structures.
The composite structures must be designed for the worst applicable conditions which are influenced by aircraft mission spectrum, surface coloring and material behaviour. Evaluations of test programs and calculations [1] resulted in the specification statements for extreme structural temperatures being -70°C and +70°C. For the maximum humidity contents a first prediction was made, that the long time value will be 0.9 weight percent. The decrease of the material properties at 0.9% RH and 70°C for the composite T 300 / CIBA 913C is shown in Table 3.
These values were used for preliminary calculations. Since the maximum fin box temperature does not exceed 70°C under

high loading conditions, and the fin structure is dimensioned mainly for stiffness requirements, resins with curing temperatures of 120°C can be used. Compared with 180°C - curing systems the following advantages on the production side can be outlined:

- less problems with curing tools due to thermal expansion
- reduced time and energy extent
- reduced thermal stresses
- easier machining

As fibre material KC 20 fibre type according to LN 29694 has been selected. It represents a good combination of stiffness, elongation, costs and workability. The product T300 of TORAY/UCC belongs to this class.
For the production of the fin box 8H - satin fabrics and tape prepregs are used, preferable with a surface weight of 400g/m². Suitable resin systems are Hexcel F 550, CIBA GEIGY 913C, NARMCO 5209; Fiberite 948 and CODE 95. Hexcel F 550 was designated as the primary resin system for the fin during the definition stage.

	ambient	0.9% RH; 70°C
$E_{\parallel}$	1.26×10^5 N/mm²	1.26×10^5 N/mm²
$E_{\perp}$	9.5×10^3 N/mm²	6.7×10^3 N/mm²
G	4.8×10^3 N/mm²	3.4×10^3 N/mm²
γ	0.3	0.3
$\sigma_{\parallel t}$	1250 N/mm²	1250 N/mm²
$\sigma_{\parallel c}$	1250 N/mm²	750 N/mm²
$\sigma_{\perp t}$	50 N/mm²	35 N/mm²
$\sigma_{\perp c}$	210 N/mm²	100 N/mm²
τ	80 N/mm²	50 N/mm²

E / G	Young / shear modulus
σ / τ	normal / shear stress
ν	Poisson's ratio
t / c	tension / compression
$\parallel$ / $\perp$	in / transvers to fibre direction

Table 3 Material B-Values for T 300 / 913 C

Material Testing

A principle question for material testing is how to get realistic humidities for the different materials. The problem can be solved by calculation for specified flight mission if the diffusion coefficients are known. For selected materials the diffusion coefficients were found by tests at the DFVLR in Braunschweig.
On the other hand, the service humidity can be evaluated by comparable tests if for one composite material experience on aircraft with a comparable mission is available. At spoilers of Boeing 737 made of carbon fibre NARMCO 5209 composite, a relative humidity of 0.65% after long time Lufthansa service was found. Recalculations for extreme climates indicated that a humidity content of 0.85% could have been expected.
In order to find a laboratory service climate, specimens made of T 300/NARMCO 5209 - composite were exposed to different climates. It was found that laboratory climate of 70°C and 70% RH led to the desired stabilized humidity of 0.9%. Other composite materials were exposed to the same climate up to a stabilized humidity content. First results are given in Table 4, which due to the comparable flight missions also are valid for the Airbus.

Graphite Composite	Service Humidity
Hexcel W3T - 584 - F 550	0.74%
Hexcel T6T - 262 - F 550	0.75%
Fiberite HY - E 1048 A 1 E	0.85%
Fiberite HMF - 133	0.86%
NARMCO 5209	0.90%
Fibredux 913C - TS - 5	0.98%

Table 4. Relative Humidity in Composites at the Airbus

Strength tests with "service - climate" - conditioned specimens are under preparation.

Dimensioning Criteria

The main dimensioning criteria are derived from the requirements that the composite fin box must be applicable to the unchanged A300 and A310 aircrafts. As the weight of the total composite fin is reduced by approximately 20%, the stiffness of the fin box can be reduced by 20% in bending, shear and torsion accordingly. By this a comparable fin box -Eigenvalue and a similar level of safety for flutter onset can be achieved as for the certified aircrafts with metal fin boxes. In addition, all interface loads with fuselage and rudder must remain the same as for the metal fin. For composite structures, the effects of buckling on strength, especially on fatigue, is not completely understood. Therefore, it was decided for the fin box design that local buckling may not occur below limit loading. The same limit was set up for resin matrix cracking. For all strength and stiffness calculations ambient and conditioned material properties must be used.

Preliminary Strength Calculations

On the basis of the dimensioning criteria and preliminary material data, first calculations for optimizing I - and ⎍ - stringer stiffened structures were carried out. The rib pitches were found to be identical for both stiffener configurations, 700mm at the root and 1000mm at the tip of the fin. The overall dimensions of the stringers and the stringer pitches shown schematically in Fig. 11 are constant over the span. On the other hand, the skin and stringer thicknesses decrease from root to tip. For the preferred I - stringer configuration thicknesses are given at three rib stations in Fig. 12.

Panel Tests

In the course of the definition stage, compression tests were carried out with 1000mm long panels stiffened by different shaped stringers. All panel configurations were designed for the same stiffness per unit width. The ends of the panels were cast in resin and rib structures were simulated by supporting plates. In Fig. 13 a failed test specimen is shown in the test rig. The test results are depicted in Fig. 14. The ultimate stress σ_u is here understood as the ultimate load divided by the total cross - sectional area. In relation to I - section stringer panels it is shown that the ultimate strength is 13% lower for [- and Z - section stringers and 6% higher for ⎍ - section stringers.

Further it is shown that by the use of ±45° tapes instead of fabrics an increased strength of 6% can be achieved.

A comparison of the weight related stresses $\sigma_u \cdot \rho_{CFRP} \cdot \rho^{-1}$ for CFRP I - stringer panels and aluminium Z - stringer panels indicates a weight saving of 26% for the composite structure.

At the DFVLR for short I - stringer panel sections comparative tests are under preparation to define the influence of moisture and temperature on compression strength.

As the next step, panels with a size of 2300mm x 700mm are to be tested in combined shear and compression loading. Fig. 15 shows a module panel prepared for testing in a test rig described in Fig. 16. A preliminary shear test with such a panel showed that the shear strength will be higher than 120 N/mm² at all stations of the fin box.

Preliminary Design

As outlined before in the definition stage, the preliminary design for the I - section stringer configuration was accomplished. It resulted in drawings for all main components of the composite fin box [3] .

Selected points shall be discussed in this paper.

- Structural System
  According to the design principles all interface points to the fuselage, leading edge and rudder must be identically positioned and shaped. That means identical positioning of the 3 spars and the 7 main ribs supporting the rudder hinge fittings in relation to the metal structure (Fig. 17). The length of the middle spar could be changed.

- Panels
  As outlined before the panels consist of skin, stringers, spar flanges and rib clips made of carbon fibre fabrics and tapes (Fig. 15). Because these parts are co - cured no further assembly work is necessary. The approximately 40mm high I - stringers (height varies with flange thickness) run parallel to the rear spar with a pitch of 100mm. Special features for assembling the panels to the ribs and fittings can be seen at Fig. 17.2; 17.3.

- Spars
  The spar webs consist of flat fabric laminates stiffened by co - cured composite stiffeners. In the upper part of the front and rear spar, holes are incorporated to make the fin box accessible for assembly and maintenance reasons. At the lower end the shear fittings are co - cured with the spar webs. The spar webs are riveted to the panels by titanium rivets. To the rear spar, aluminium fittings are bolted for supporting rudder hinge fittings and actuators (Fig. 17.3). The principle load transfer is shown on Fig. 18.

- Ribs
  While the upper and lower end ribs and the 7 main ribs supporting the rudder hinge fittings are designed as flat stiffened webs, mainly made of fabric composite (version I on Fig. 17.3), the 9 ribs supporting the panels for stability reasons can be designed as composite truss work, which leads to a lighter structure (Fig. 17.2). It is under investigation if the inner rib flange can be co - cured with the panel.

- CFRP - Fittings
  In Fig. 17.1 the mid spar/fuselage attachment fitting for load transfer in the vertical/longitudinal plane is shown assembled to the fin box. The fitting consists of 2 separate cured parts laminated from fabrics. During the panel curing the 2 fitting parts will be bonded to the fin box panel, achieving a multiple shear connection. Additional bolting is foreseen for safety reasons.

- Weights
  At the end of the preliminary design stage a weight calculation was carried out. The results are presented in Table 5.

Components	CFRP (kg)	METAL (kg)
Panels & Fittings	341	404
Spar Webs & Fittings	75	112
Ribs & Fittings	84	136
	500	652

Table 5. Weights of the Fin Box

Finite Element Analysis

In order to meet the requirements of the design and dimensioning criteria with special respect to the interface forces and fin box stiffness, a detail structural analysis has to be carried out to obtain a reliable comparison of the structural aspects of the metal and composite fin. On the basis of the preliminary design work and stress calculations, a structural analysis with the finite element program NASTRAN is prepared. As shown on Fig. 19 the structural idealisation incorporates all stringers, ribs and spars. The rudder is idealized as a flexible beam. The elasticity of the fuselage structure is taken into account by a special super-element. Effort is made for getting a suitable idealisation of the module stringers by splitting the stringer area into 3 elements: the module webs, the inner flanges and the outer flanges. By this means the strength analysis can be carried out separately for the different laminates of the stringers.

The loading is applied at the grid points of the idealized structure. In Fig. 20 typical loadings are shown for gust and maneuvre cases.

At the end of the definition phase the calculations were not completed so that results cannot be presented in this report.

V. Component and Full Scale Tests

Aging of Test Specimens

Tests for the verification of static, residual and fail-safe strength will be carried out under the most unfavorable applicable climate conditions, which normally means maximum service moisture content combined with maximum structural temperature. As outlined in chapter IV, for the Airbus the maximum structural temperature is +70°C and the maximum service moisture content can be achieved by conditioning the composites at 70% RH and +70°C until weight equilibrium.

When achieving the service moisture content for larger test specimens the following problems can result:

- There is natural aging during the time between production and test. This initial moisture absorption must be taken into account when obtaining the desired moisture value for testing.
- The test specimen might have different thicknesses. Each structural thickness should contain the same moisture content when tested.

The solution to these problems is the following:

Reference specimens for determining the moisture absorption with different thickness will be produced at the same time as the test specimen, weighed, and travel with it until the static test begins. These reference specimens will be weighed periodically before and during the artificial aging.

In order to accelerate the aging process it can be split into two steps (Fig. 21):

1st step:

Temperature: 60°C; RH: 96% - 98%

Duration: Until the thickest reference specimen reaches the desired service moisture content (0.9% for NARMCO 5209). After this the environment is changed to laboratory service climate.

2nd step: Service Climate

Temperature: 70°C; RH: 70%

Duration: Until the moisture content of the thinnest reference specimen has fallen to the service moisture content. The strength test can then be started.

Component Tests

In the development stage for critical and complex components such as spars, composite fittings, panels and their interfaces, test specimens will be designed, built and tested in order to get an early verification of the applied design features. For the production and quality control of the specimens, those techniques are applied which have been developed or checked by previous tests with respect to applicability to the full size fin structure.

Full Scale Static Test

For demonstrating stiffness, fail-safety and ultimate strength, a full scale test specimen consisting of the total fin box and dummy structure for the leading edge and rudder will be tested for gust and manoeuvre cases (Fig. 22). As outlined before the test will be carried out at service moisture and 70°C temperature. The aging can easily be realized by using the fin box itself as an environmental chamber.

For this reason the openings of the fin box will be sealed and the aging will be done from within.

Full Scale Fatigue Test

The fatigue test specimen consists of the lower part of the fin box (Fig. 23). Loads acting at the tip will be applied by a dummy structure. The test will be carried out to demonstrate that 48 000 service flights can be achieved without major failures. Therefore 96 000 test flights of the fin load spectrum must be applied. After 96 000 test flights, artificial cracks shall be saw-cut in the structure and an additional 24 000 flights applied in order to demonstrate that the crack propagation will not become critical with respect to proposed inspection intervals and methods. Over the test life the stiffness will be checked periodically. It is expected that the fatigue life of the fin box is not influenced significantly by the effects of temperature and moisture. Therefore the fatigue test shall be carried out at ambient conditions. This procedure shall be justified by fatigue tests on smaller components. The fatigue test will be completed with residual strength tests after 120 000 test flights. These tests will be carried out at service moisture and a temperature of +70°C.

Acknowledgement

The author would like to thank all members of the CFRP-fin-team for their work which is the basis of this paper.

References

[1] CFK - SLW - Team MBB / VFW
Airbus - Seitenleitwerk in Faserverbundwerkstoff, Meilensteinbericht vom 30.4.79, Konzeptphasenabschluß

[2] Arbeitskreis Konstruktion
Luftfahrttechnisches Handbuch für Konstruktion

[3] CFK - SLW - Team MBB / VFW
Airbus - Seitenleitwerk in Faserverbundwerkstoff, Meilensteinbericht vom 31.3.80, Abschluß der Definitionsphase

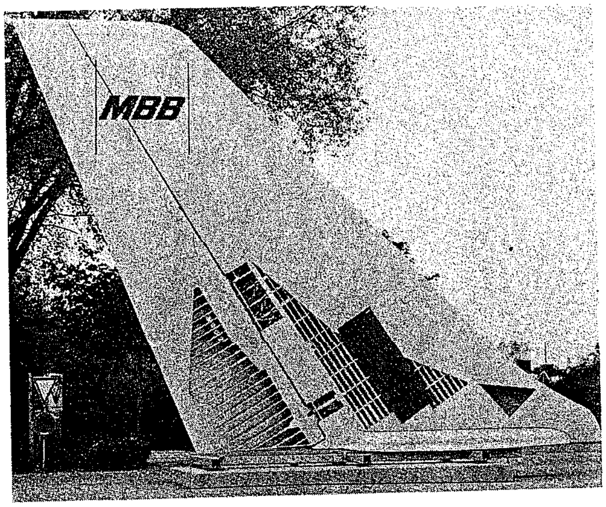


Fig. 1 Airbus Fin Structure and CFRP Test Panel

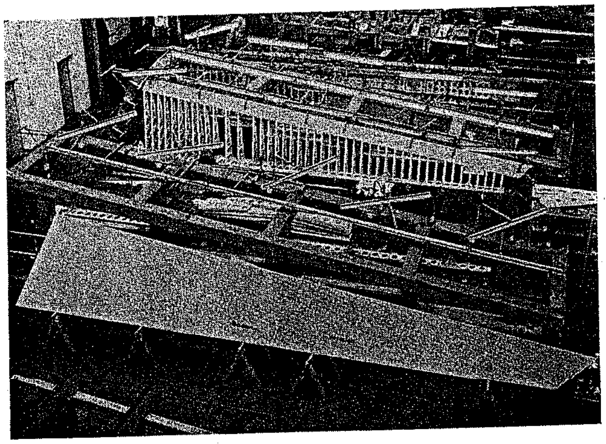


Fig. 2 Airbus Rudders in Metal and CFRP

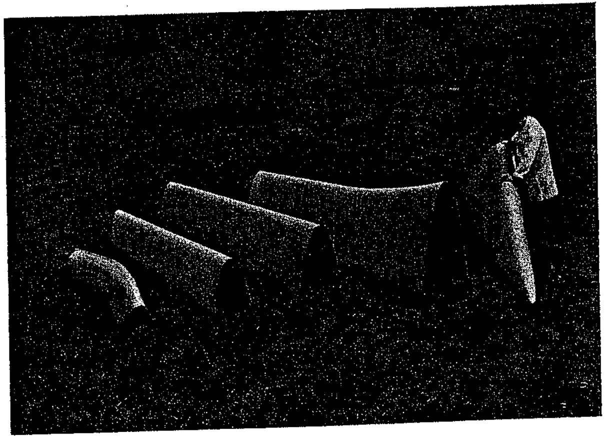


Fig. 3 Airbus Fin Leading Edge Sections in GFRP

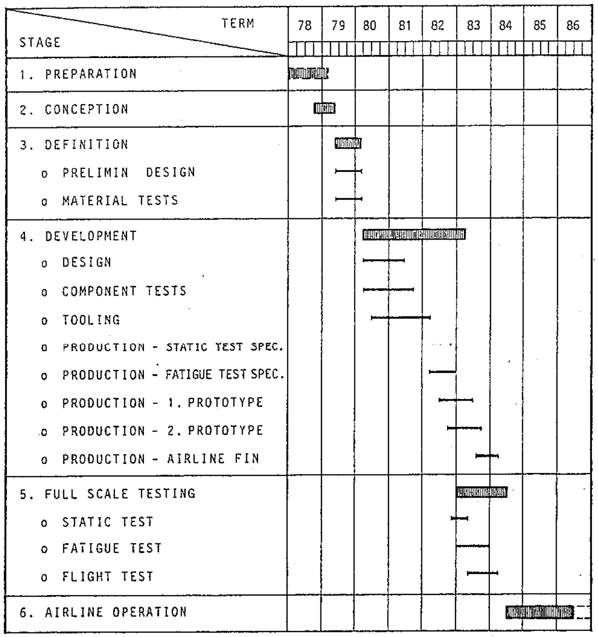


Fig. 4 Schedule of Development
- Airbus Fin in CFRP -

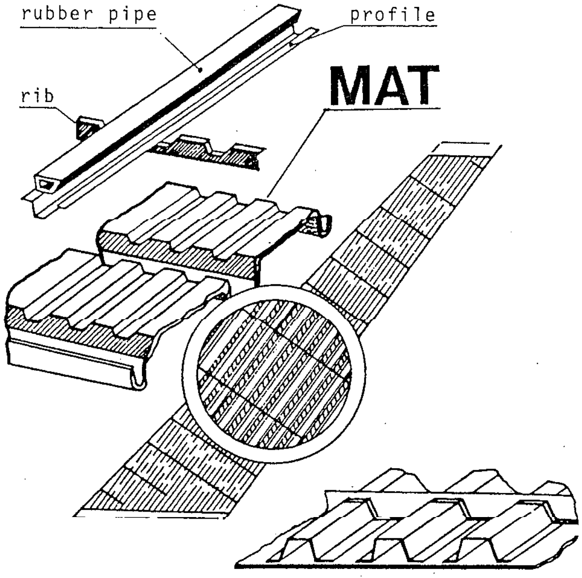


Fig. 6 Mat Production Process

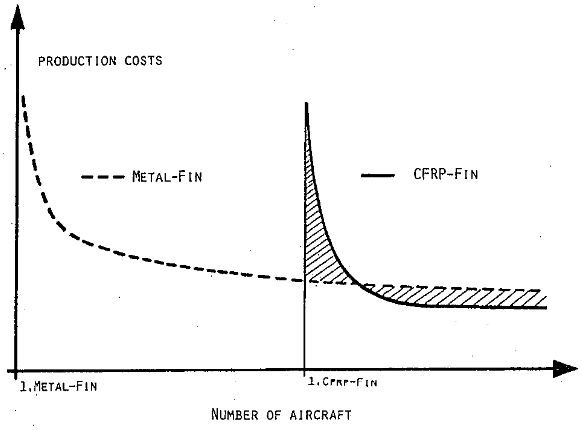


Fig. 5 Development of Series
Production Costs for
Metal and CFRP Fin
in Principle

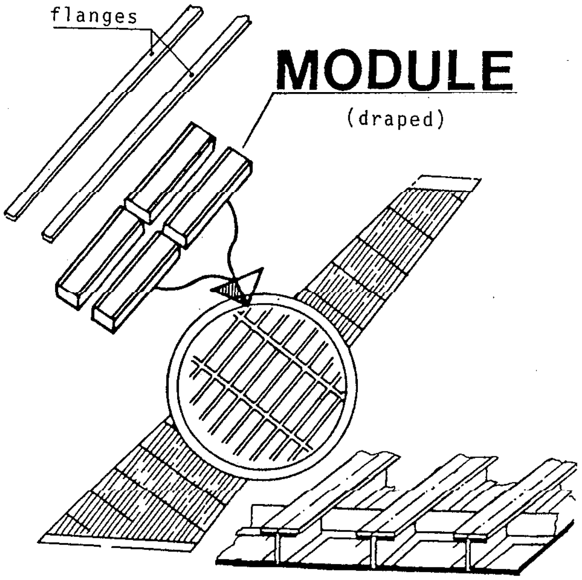


Fig. 7 Module Production Process

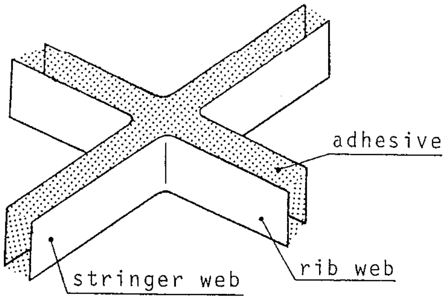


Fig. 8 Scheme of Web Assembly "Module Structure"

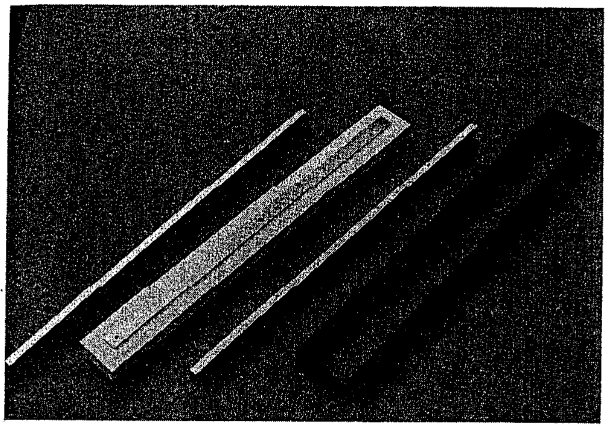


Fig. 9 Module Core made of 3 Sections and CFRP Module

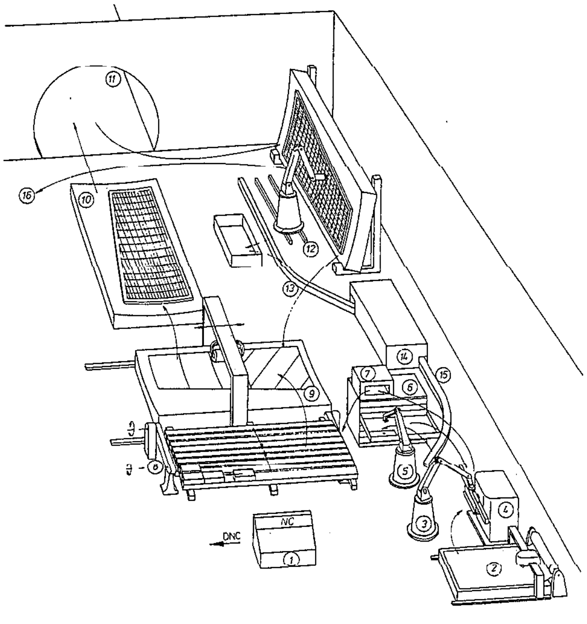


Fig. 10 Series Production Line for CFRP Fin Panels

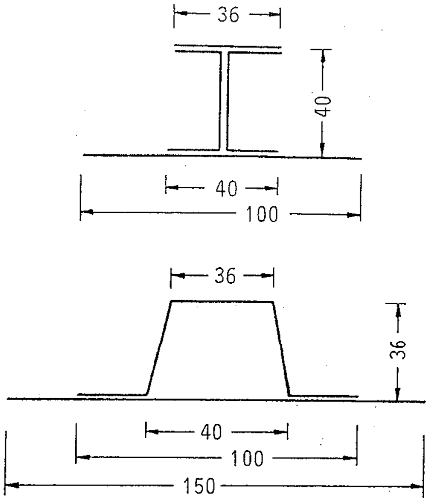


Fig. 11 Overall Dimensions of Stringers and Stringer Pitches for CFRP Fin Panels

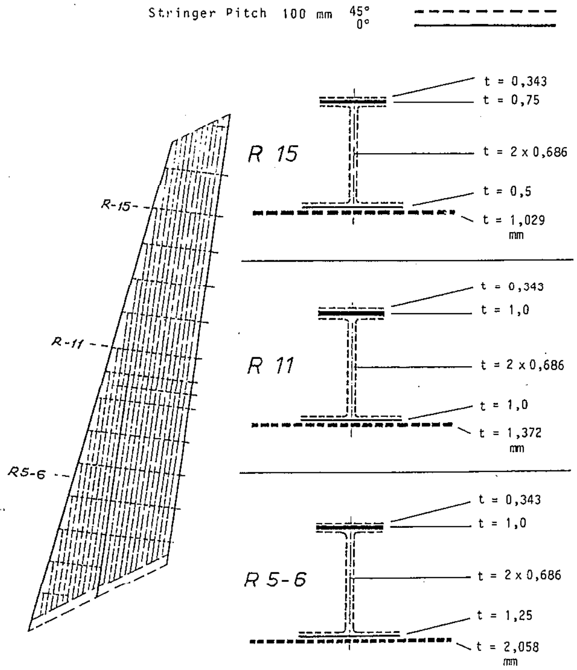


Fig. 12 Thicknesses of Stringers and Skin of CFRP Fin Panels

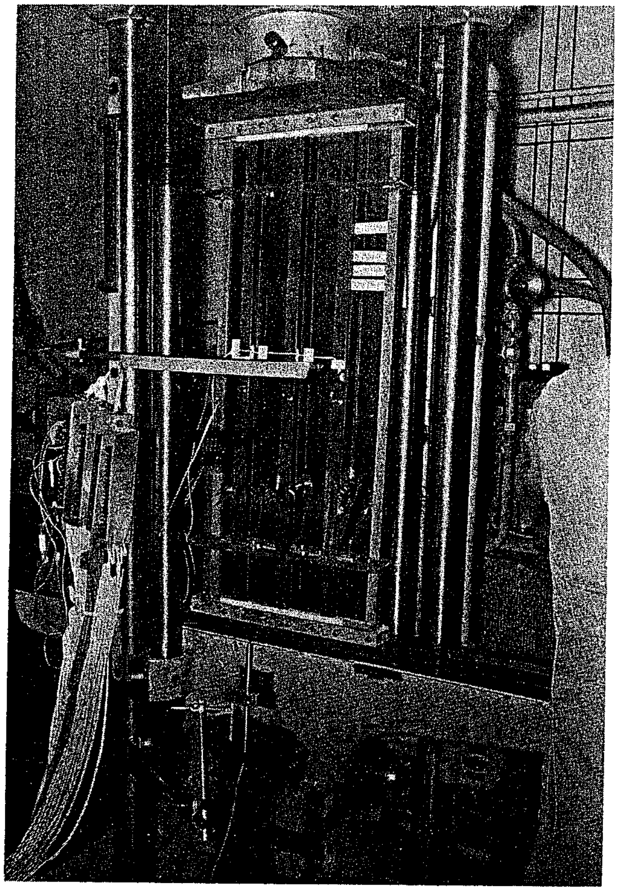


Fig. 13 Compression Test with I-Stringer Panel 1000 x 350 mm

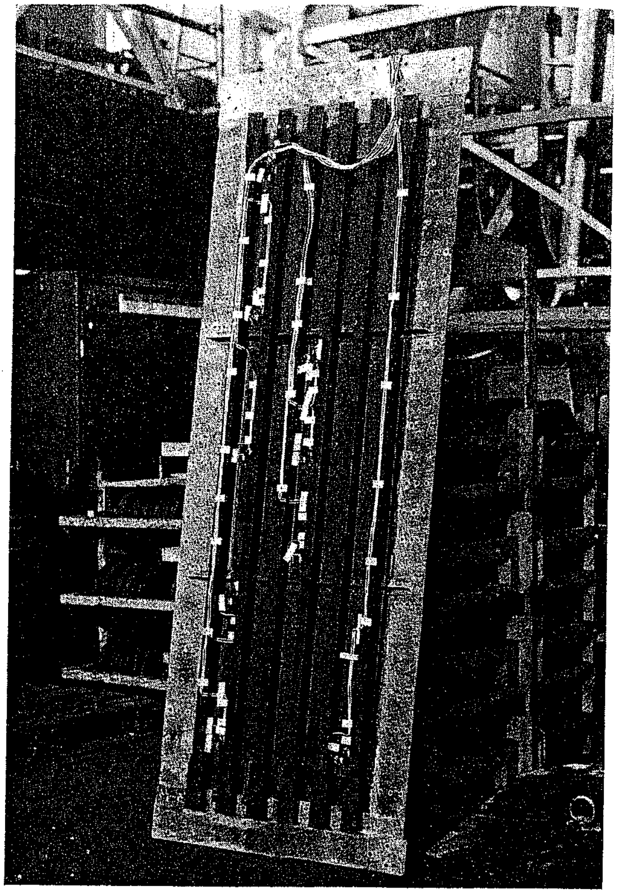


Fig. 15 "Module" Test Panel 2300 x 700 mm

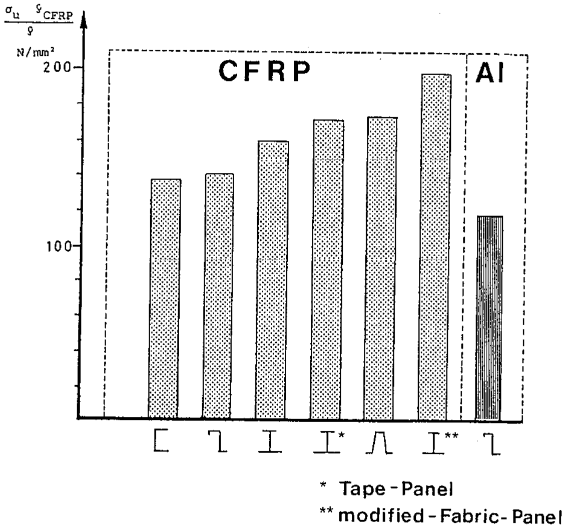


Fig. 14 Weight related Ultimate Stresses achieved by Compression Tests for Rib Station 6/7 of CFRP Fin Box

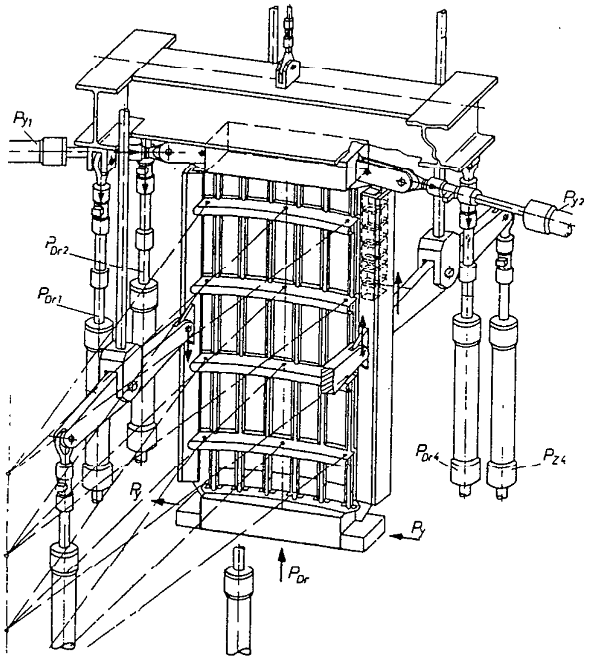


Fig. 16 Rig for Shear/Compression Test

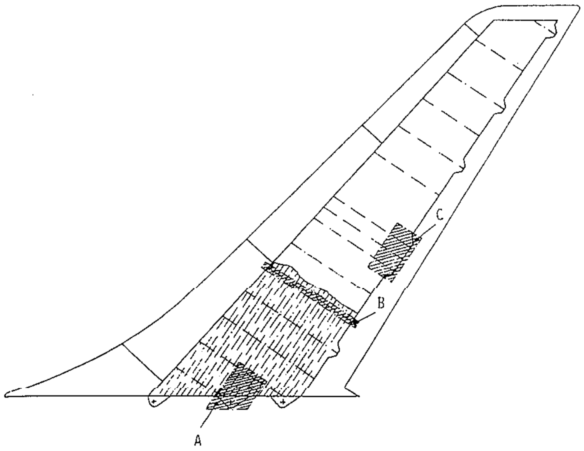


Fig. 17 Airbus CFRP Fin
Preliminary Design Work

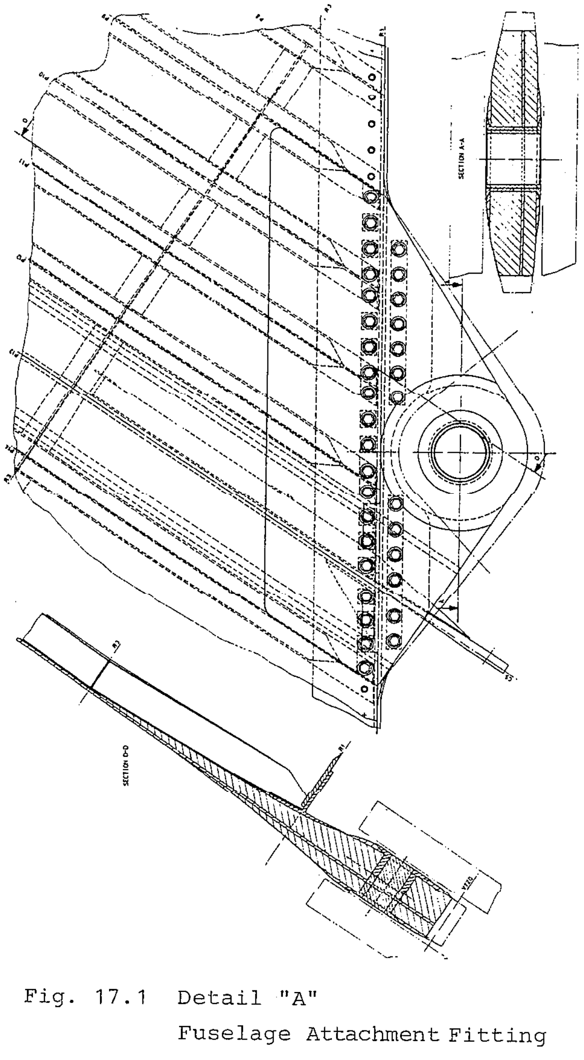


Fig. 17.1 Detail "A"
Fuselage Attachment Fitting

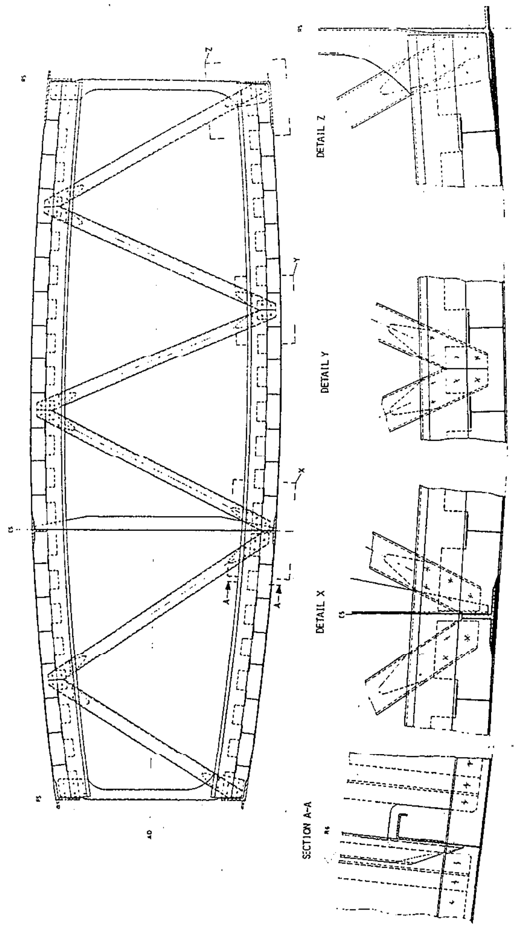


Fig. 17.2 Detail "B" - Rib 6

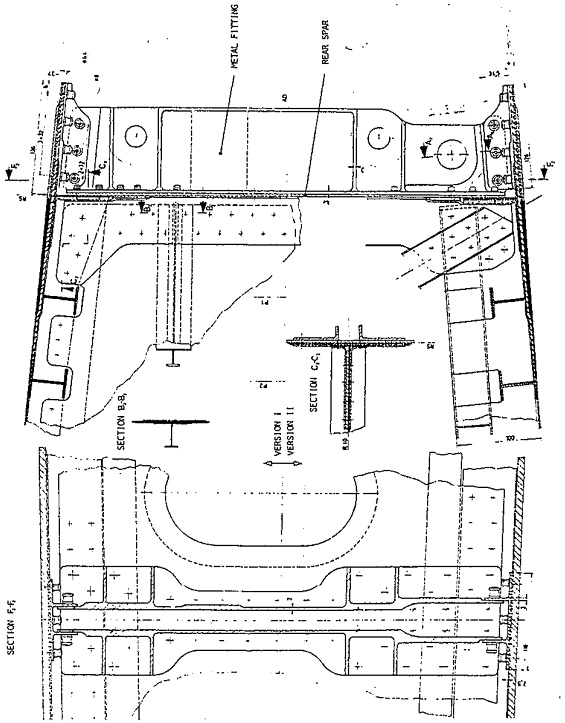


Fig. 17.3 Detail "C" - Rear Spar Area

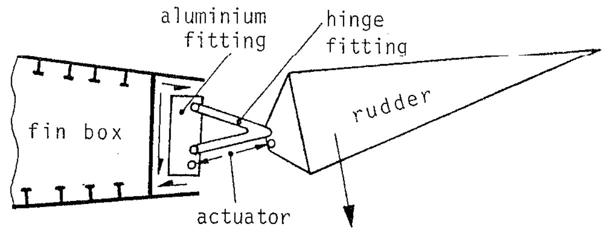


Fig. 18 Interface-Rudder/Fin Box

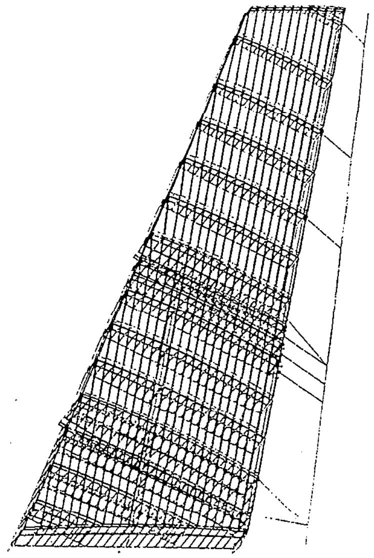


Fig. 19 Model for FEM Calculation

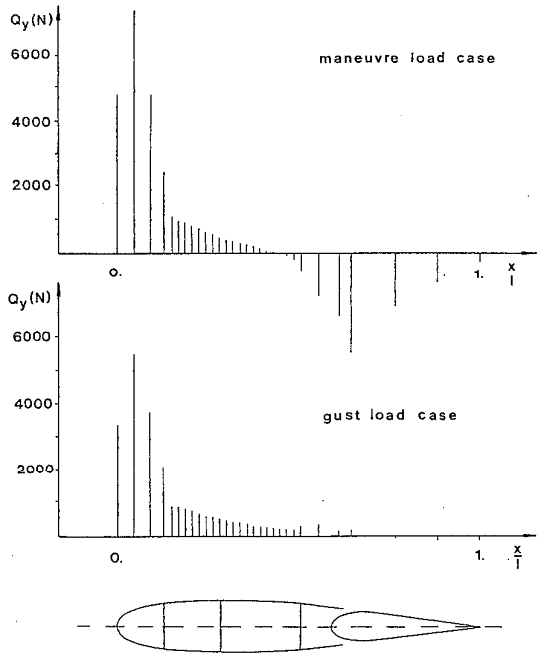


Fig. 20 Ultimate Node Forces at Rib 7

I. Aging Step with 60°C / 95 % RH
(Duration: Until the thickest ref.-probe reaches the service moisture content.)

II. Aging Step with 70°C / 70 % RH
(Duration: Until the thinnest ref.-probe reaches the service moisture content.)

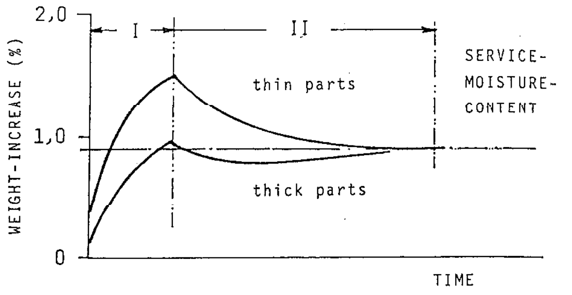
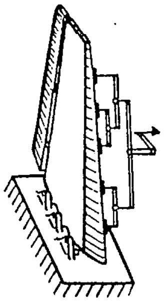
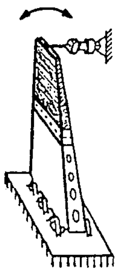


Fig. 21 Aging Process for Test Specimens



- O CHECK FOR STIFFNESS
- O FAIL SAFE-LOADING
- O ULTIMATE LOADING (J = 1,5)
- O T_{MAX} = 70° C;
- O MOISTURE CONTENT = 0,9 WT %

Fig. 22 Full Scale Static Test



- O 120 000 TEST FLIGHTS, AMBIENT HUMIDITY AND TEMP.
  - CHECK OF STIFFNESS AFTER FATIGUE LOADING
  - CHECK OF CRACKPROPAGATION
- O DEMONSTRATION OF FAIL-SAFETY AND RESIDUAL STRENGTH

T_{MAX} = 70° C; RH = 0,9 %

Fig. 23 Full Scale Fatigue Test

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STRUCTURAL CERTIFICATION OF AIRBUS FIN BOX IN COMPOSITE FIBRE CONSTRUCTION

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Abstract

In 1978 a government sponsored research program was launched by MBB for investigations about effective application of carbon fibre composites in primary transport aircraft structures. The task was exercised on the Airbus Fin Box and ends in 1985 with demonstration of static and fatigue strength and damage tolerance as well.

As 1983 a decision was made within Airbus Industrie to consider series application of the carbon fibre fin box for A310-300 in 1985, all structural development and testing has to be carried out in accordance with new airworthiness regulations for CFRP.

The report concerns the applied design and manufacturing principles, the test programs and some available results. The combined fatigue/static full scale test program is presented as a main subject.

I. Introduction

As a result of the reduction in material costs for advanced composites during the seventies, aircraft manufacturers looked for the application of these materials in civil aircraft. Along with other aircraft manufacturers MBB started research, development and experimental programs to prepare for series introduction of advanced materials for parts under their responsibility on Airbus A310. Service experience was gained by experimental application of floor struts, fin leading edges, spoilers and rudder to aircraft of "Deutsche Lufthansa", before deciding on series application.(1)

During this phase airworthiness authorities formulated rules and advisory material for appropriate certification approach, which had to match the different properties of plastics compared with metals.

On the basis of the preparatory work consideration could be given to making use of the benefits of applying advanced composites to primary structures. Since 1978 MBB has run a research program for the development of the Airbus Fin Box in carbon fibre reinforced plastic (CFRP).(2) With the launch of the medium range version A310-300, Airbus Industrie decided to continue and to add a development program for series introduction. As shown in Fig. 1 certification of the new strutural component is intended to coincide with the type certification of A310-300 at the end of 1985.

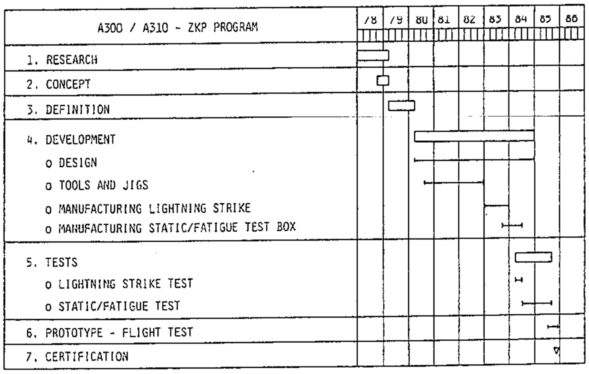


Fig. 1 Schedule of Development

The fin box will be the first primary structure of an European aircraft to be certified according to the respective authority rules from JAR airworthiness authorities and reflects especially to the STPA-Note Technique N 81/04 revision 2.

II. Design Criteria

The Airbus Fin Box was designed for general use on all versions of A300, A310 and A300-600. While the geometry is common for all versions, the load envelope of the whole wide body family had to be considered. Furthermore there should be no restrictions with respect to performance; world wide environmental effects had to be taken into account.

The main target of the program was to realize a minimum weight saving of 20%.

It was stated as a design aim that the use of CFRP should not result in a disadvantage in safety and maintenance. The use of metal parts was avoided as far as possible. From the very beginning of the program all efforts were made to realize a design which would allow cost effective production with a high degree of automation. Latest airworthiness requirements of FAA and JAR authorities should be met.

III. Structural Description

The Airbus Vertical Tail, with a total height of 8.3 m, consists of leading edge, fin box, nonstructural fairings and rudder (Fig.2).

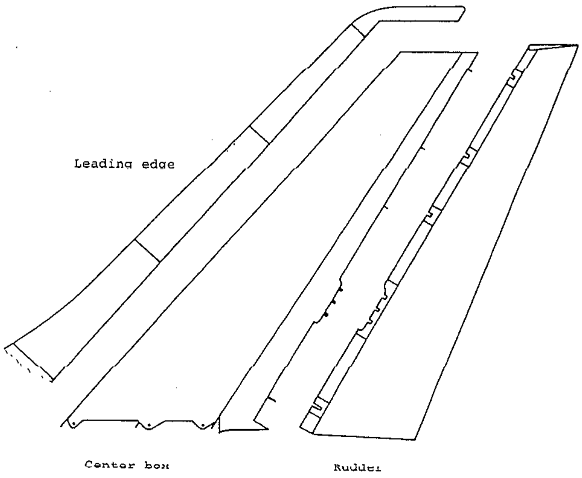


Fig.2 CFRP Fin Main Parts

Leading edge, fairings and rudder are made of honeycomb sandwich with aramid or carbon fibre layers. These parts are certified for unrestricted application on all versions of the Airbus family and are not the subject of this paper. The fin box structure as shown in Fig. 3 consists of lefthand and righthand panels, front and rear spars, a middle spar stump in the root area, 9 web ribs, 9 framework ribs and fittings for the rudder support.

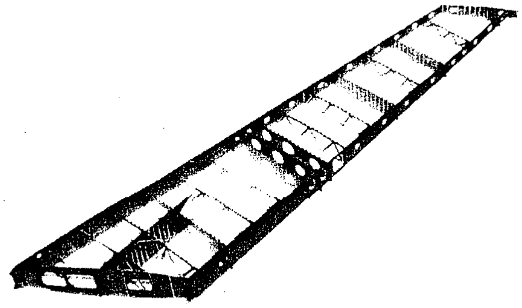


Fig.3 CFRP fin box structural model

The panels are cured containing skin, I-stringers, spar caps, rib cleats and pick up fittings for fuselage attachment (Fig.4).

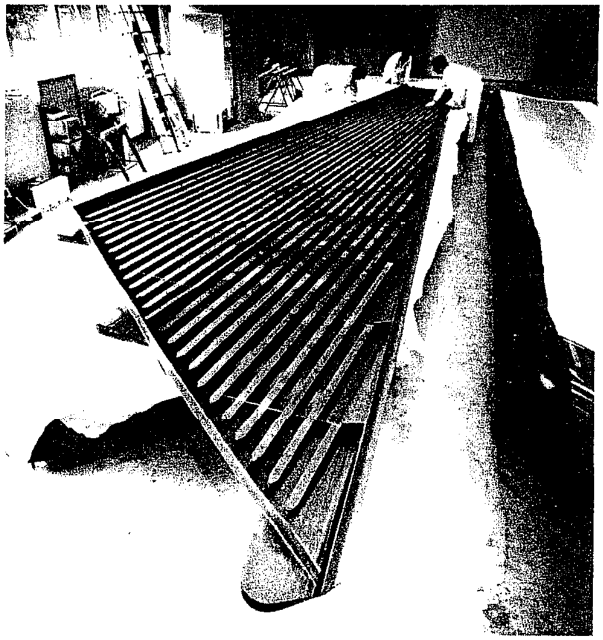


Fig.4 CFRP fin box panel

Fabric is used to a wide extent, tape material is limited mainly to stringer and spar caps.

Fig.5 and 6 show the rear spar and web type rib, both being stiffened laminates fabricated in the modular technique as was applied to the skin panel.

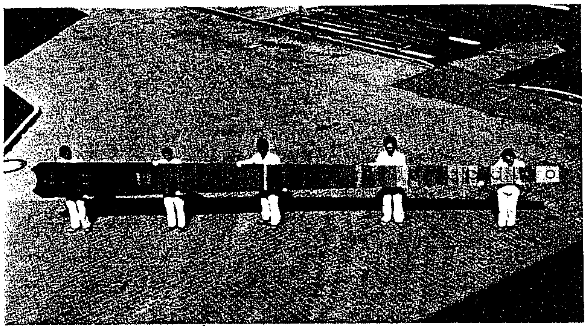


Fig.5 CFRP rear spar

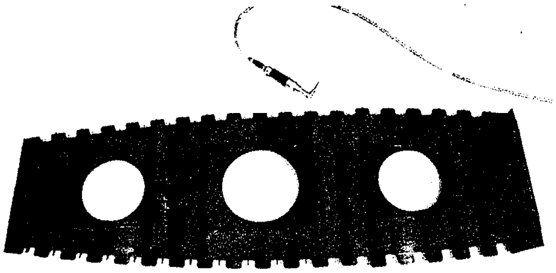


Fig.6 CFRP web type rib

Modular technique was developed for the use of automation and is explained in (2).

Supporting ribs represent framework structure (Fig.7) and are fabricated using moulding technique. The laminates are built up in combined fabric and tape.

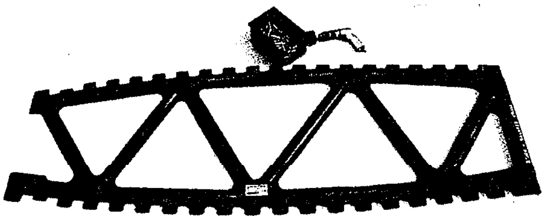


Fig.7 CFRP framework rib

The fittings for rudder support (Fig.8) represent thick CFRP laminates and are cured mainly of fabric material. The connection to the rear spar is carried out by bolting with titanium bolts and rivets.

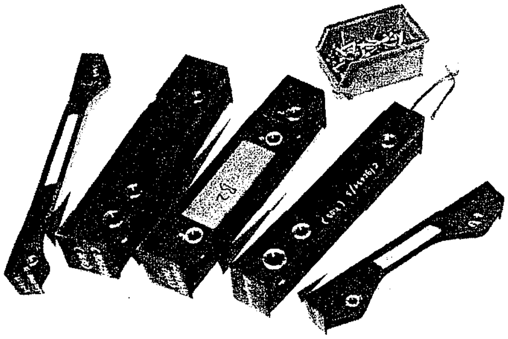


Fig.8 CFRP rudder support fittings

Fig.9 shows the lightning protection system which is performed by aluminium strips at the upper, front and rear edges of the fin box in good connection with the rudder lightning protection system and the metallic fuselage. The concept includes the assumption, that a part of the lightning current will enter the carbon fibre material too. However, the one-shot cured structure is able to carry safely the resulting pulse. This protection results in an additional mass of 11kg.

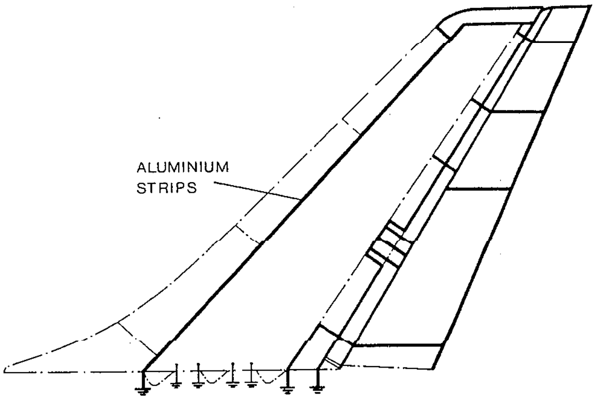


Fig.9 CFRP-Fin lightning protection system

IV. Certification requirements

Basic certification requirements applicable to the Airbus Fin Box are defined in FAR Part 25 Amendment 45 and JAR Part 25, published by the American and European Authorities, respectively. In addition, the authorities have published interpreting papers referring particularly to composites:

- o Advisory Circular 20 - 107
  published by American FAA, 12.8.83

  agreed to by European JAR Airworthiness Authorities
- o Certification des Materiaux Composites
  Note Technique N. 81/04
  published by French STPA, 12.2.81

  agreed to by German LBA.

In both papers special attention is given to the following subjects relevant to the Airbus Fin Box:

Subject	Regulations FAR + JAR
Materials - specifications - allowables - quality assurance	25.603, 613 615
Processing - specifications - quality assurance	25.605
Proof of structure - static strength - fatigue - damage tolerance - flutter - repair	25.303, 305, 307, 571, 1529
Protection of structure - abrasion, ultraviolet radiation, chemicals - lightning strike	25.581, 605 609

Table 1 Regulations concerning composite certification

V. Certification Approach

According to the previously mentioned advisory papers, different approaches are acceptable for showing compliance with structural requirements. It is obvious that the means of compliance depend on the individual structure, the data base available and the experience with comparable structures. Therefore, the fin box crashworthiness and flamability are of less importance than static and fatigue strength under flight conditions. Benefit can be gotten from more than 10 years service experience with the geometrical identical metal fin concerning the confidence in the loading level. Experience is also available on the CFRP rudder of A310 which is fabricated of the same composite materials and designed for identical target life of 40,000 flight hours under identical environmental conditions.

Where possible the same or similar approaches for certification are proposed as for the A310 rudder. This is valid for materials and, in principle, for processing and protection of structure. Proof of structure is handled in a slightly modified manner, which mainly concerns the full scale test procedure (Table 2). The chosen approach relies primarily on full scale testing for the most critical cases under worst environmental conditions as a most reliable procedure with respect to stress distribution, stiffness and strength up to the failure load. Analysis is used as an additional means of substantiation, allowing a broader investigation, especially of load cases and stress distributions.

Having more experience on this subject it is expected that future certification approaches can be simplified.

It should be noted that this certification approach is very expensive especially for more complex aircraft structures because of the full scale testing under environmental conditions. If the understanding of the effects of environmental conditions on the strength of full scale CFRP structures can be improved, simplified simulation approaches will be achieved.

Subject	Rudder	Fin Box
Static strength	Full scale component test under worst environmental conditions without artificial preaging. Complementary analytical substantiation supported by material coupon test data and detail tests.	Full scale component test under worst environmental conditions after artificial aging. Effects of temperature cycling defined by coupon testing. Complementary analytical substantiation supported by material coupon test data and detail tests.
Fatigue	Subcomponent test with wet structure under blocked temperature cycling. Supporting analysis.	Full scale component test on wet structure at room temperature. Thermal stresses applied by mechanical loading. Supporting analysis.
Damage tolerance	Fatigue and residual strength tests with damaged and repaired structure following the fatigue subcomponent tests. Supporting analysis.	Damages of tolerable sizes and repairs are incorporated in the full scale test specimen before test start. Complete run of static and fatigue testing. Special fail safe test with inspectable damages. Supporting analysis.
Flutter	Analysis accompanied by stiffness test.	Analysis accompanied by stiffness and ground vibration test.

Table 2 Principle approach of structural validation for rudder and fin box

VI. Justification / Results

Most of the analysis and partial testing have been completed. The program for full scale component test has been set up and presented to the French and German authorities. Results are reported below.

Materials and processing

For the Airbus Rudder and Fin Box, the same carbon fibre composites were chosen, the fibre material being T300. Woven and unidirectional prepregs are used. The resin systems Ciba 913 and Hexcel F550, both curing at 125°C, fulfilled the requirement for having high softening and glass transition temperatures at wet condition. The softening temperatures, defined in Fig.10, should be 25°C above the max. service temperature of the fin structure which was found to be +70°C.(2)

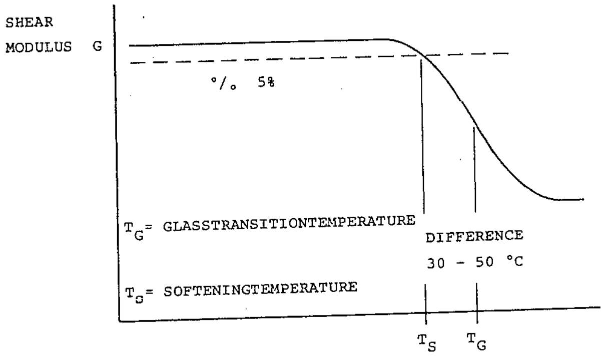


Fig.10. Effect of temperature on laminate stiffness

Environmental related properties of both materials realized by tests are tabulated below.

	Ciba 913	Hexcel F550
Equilibrium moisture pick up after extreme climatic long time service (wet condition)	1.2 %	0.9 %
Softening temperature at wet condition	97°C	110°C

Table 3 Environmental related material behaviour

Design values were already established for the rudder taking into account the effects of extreme environmental conditions that can be expected in service. B-values are published in (1) for Hexcel F550 which can be used also in case of Ciba 913 application since they are the lower ones. Specifications have been set up for incoming material. Continous statistical interpretation is under way.
In order to get reproducable quality for all parts, process specifications are set up with special attention to layer orientation, sequence and autoclave curing parameters. The production flaw is accompanied by inspection steps. Type of inspection and tolerable production flaws are defined but will be reviewed on the basis of the full scale test results. In Fig.11 the applied NDT-methods are listed.

NDT - METHODS

ULTRA SONIC TECHNIQUE

- KIND OF DETECTIBLE DEFECTS: DELAMINATIONS, PORES, CRACKS, LACK OF RESIN, RESIN SURPLUS

1. SQUIRTER TECHNIQUE
   - APPLICATIONS: SKIN (THROUGH-TRANSMISSION)
     MODUL FLANGE (IMPULS/ECHO)
2. IMMERSION TECHNIQUE
   - APPLICATION: RUDDER HINGE FITTINGS
3. CONTACT TECHNIQUE
   - APPLICATION: MODUL WEB

X - RAY TECHNIQUE

- KIND OF DETECTIBLE DEFECTS: PORES, CRACKS, INCLUSIONS, LACK OF RESIN
- APPLICATION: TRUSSWORK RIBS, FITTINGS

Fig.11 Application of NDT-technique

Proof of structure

Analysis and tests are carried out to show compliance with the requirements referring to static strength, fatigue and damage tolerance.

Analysis. In order to obtain internal strain distribution, finite element calculations were carried out. The finite element model (Fig.12) consists of all main structural elements of the fin box, while the rudder is represented by a beam having equivalent bending stiffness. The fin box is fixed to the fuselage by 6 fittings for transfer of the side panel loads and 3 fittings for transfer of the spar web loadings. To get a precise distribution of the interaction forces for this hyperstatic structure, the idealization of the rear fuselage was also very detailed and incorporated in the NASTRAN calculation. Strain analysis was carried out for all relevant maneuvre and gust cases including the effects of different thermal expansion potential between the metal fuselage and the CFRP fin box.

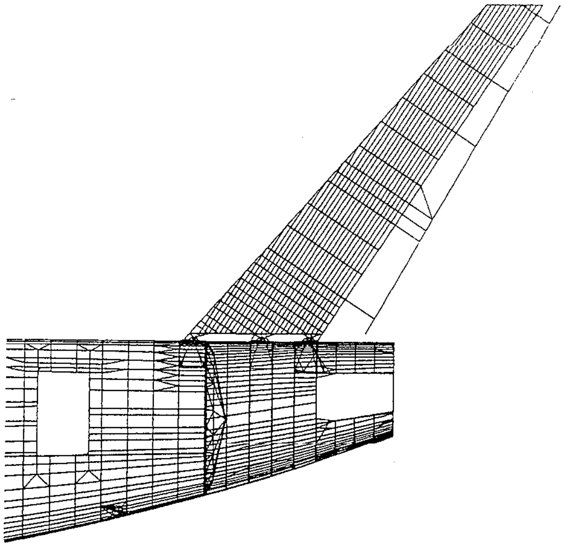


Fig.12 FEM - Model

Typical results are presented in Fig.13 for gust loading. The allowable strains were derived from element and detail tests and depend on stringer stiffness, rib pitch and onset of skin buckling.

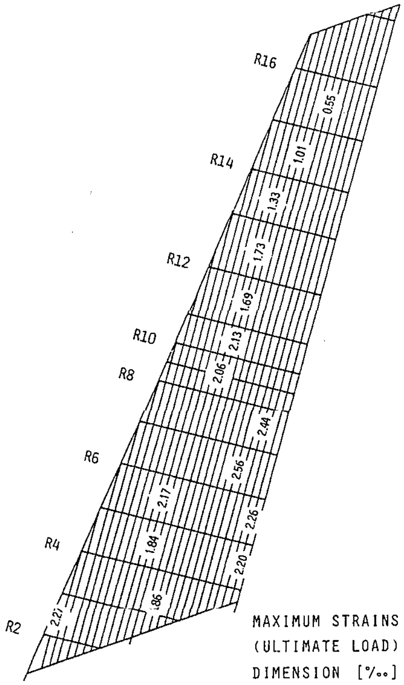


Fig.13 Strain in stringer direction induced by ultimate gust loading

The failure criteria for the panels was found to follow the formula

$$\left(\frac{\varepsilon_{x,c}}{\bar{\varepsilon}_{x,c}}\right)^2 + \left(\frac{\varepsilon_{xy}}{\bar{\varepsilon}_{xy}}\right)^2 \leq 1$$

$\varepsilon_{x,c}$: shear strain in stringer direction

$\bar{\varepsilon}_{x,c}$: failure compression strain
at the root : 3,2‰
at the tip : 2,0‰

ε_{xy} : shear strain in stringer/rib direction

$\bar{\varepsilon}_{xy}$: failure shear strain
at the root : 3,9‰
at the tip : 3,0‰

The given limits cover the strength of the existing panels at +70°C and max. service moisture. Similar failure criteria are set up for the other structural components also.

Element and detail tests. More than 100 element and detail tests were carried out to provide a data base for set up of process specifications and allowables for critical areas, as there are

- spar and rib webs with holes
- spar and rib webs without holes
- rib struts
- lugs, bearings and rivetings

In Fig.14 the most important test specimen are shown.

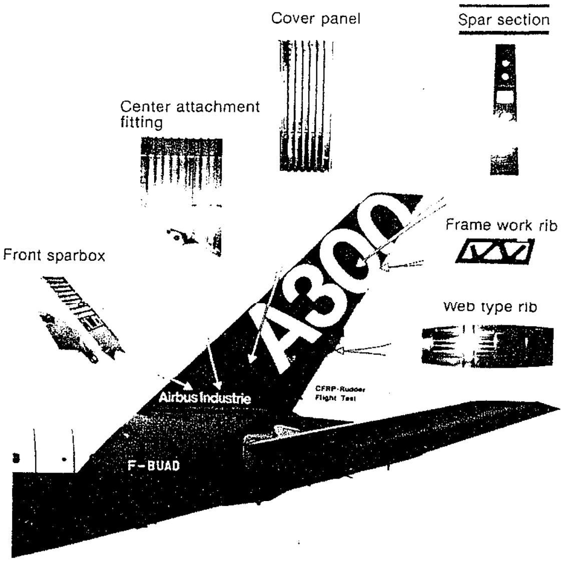


Fig.14 Detail test specimen

As indicated in table 4 not all element and detail tests were run at extreme hot/wet conditions.

Specimen	Loading	Test cond.
panels	tension compression shear combination	RT / dry hot / wet
spar webs	shear	RT / dry
truss ribs	compression bending shear	RT / dry
web ribs	shear	RT / dry
fuselage attachment fittings	tension compression fatigue	RT / dry hot / wet
rudder attachment fittings	tension	RT / dry hot / wet

Table 4 Element and detail tests

Test results obtained under RT/dry conditions had to be reconsidered for the effects of moisture and elevated temperature. For resin relevant loading conditions, such as compression and shear, a conservative strength reduction factor of 0.7 was applied before establishing the design values. Considering the element and detail test results it can be stated, that the strength variation of complex CFRP structures is not higher than for metals.

Subcomponent tests were run to check the strength at more integrated structures (Fig.15, 16, 17) under ambient and extreme service conditions. They also can be considered as preparational tests for the full scale certification test with respect to test procedure.
Table 5 gives brief information about the subcomponent tests.

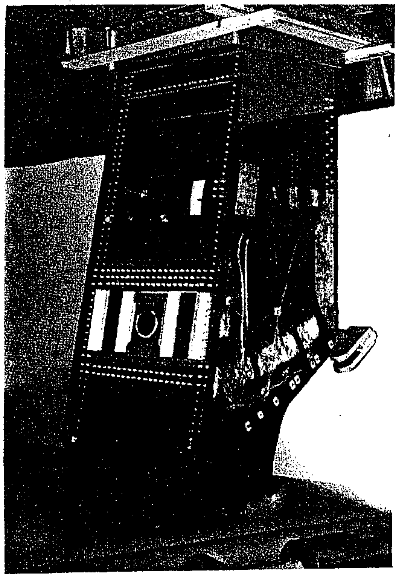


Fig.15 Subcomponent front spar box

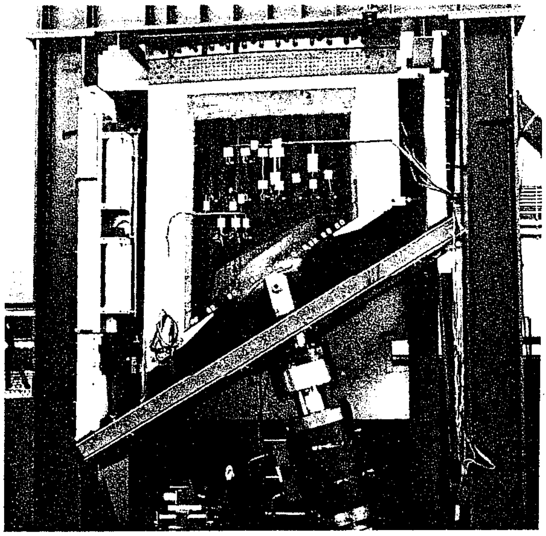


Fig.16 Subcomponent middle main pick up fitting

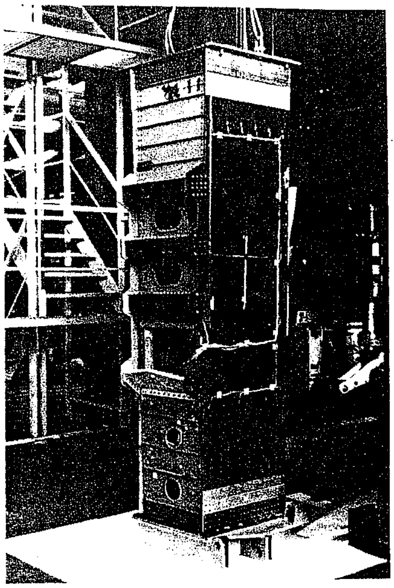
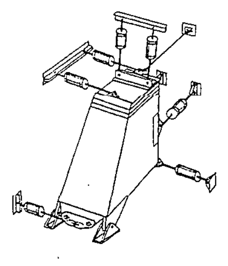


Fig.17 Subcomponent rear spar box

	Special features of selected areas	testing	outcome
Lower front spar box 1.8m x 0.7m x 0.7m Fig.15	High load transfer from main front pick up fitting to the side panels. Stringer not parallel to the front spar	Fatigue, static, repair, damage tolerance, temperature and moisture application by hot water spraying	Failure and modification of front spar cut out.
Lower side panel with middle main pick up fitting 1.5m x 1.8m Fig.16	Pick up fitting with highest loading	Fatigue, static, aging within a climate chamber by controlled humidity	Failure and modification in the transition area fitting/ side panel
Rear spar box 2.5m x 0.6m x 0.6m Fig.17	Complex structure with rudder actuator pick up fittings	Static, ambient condition	Failure and modification of rear spar box cut outs

Table 5 Subcomponent tests

Based on the experience of the front spar box testing the full scale test program was drawn up. Both programs are identical in principle. In Fig.18 the main steps of the subcomponent test program are shown.



1. Limit load (j=1.0) with a basic strain measurement at RT and +70°C in steps of 10%
2. Fatigue load proof in single flight program ($\bar{R}= -1$) at RT with laminate moisture of 0.7±0.2 weight % (2 lives)
3. Ultimate load proof (j=1.5) with strain and deformation measurements at +70°C and 0.85÷0.9 weight % laminate moisture
4. Introduction of artificial damages and representative repair solutions
5. Fatigue load proof (1x life) at RT with 0.7±0.2 weight % laminate moisture (investigation of damage propagation rate)
6. Fail safe proof after 144,000 flights at RT and limit load (j=1.0)
7. Repair of fail safe cuts
8. Residual strength test under worst environmental conditions

Fig.18 Subcomponent front spar box test program

Proof of static strength was carried through with a fatigued test specimen under extreme environmental conditions (1.0% moisture, 70°C). The check of damage propagation was part of the program. Damages resulted from impacts, artificial saw cuts, delaminations and production flaws. Final residual strength test was run with the repaired structure and ended with compression failure of the side panel with a reserve factor RF = 1.13. It was learned from this test, that at fin relevant strain level no dramatic fatigue coursed damage will occur. Propagation of the artificial damages were not observed. The decrease of stiffness of the aged, damaged and repaired structure at 70°C related to the virgin structure at RT was below 10%.

As already mentioned, heating and moisturizing was performed by waterspraying inside the test box. Thereby the use of a climate chamber became redundant, allowing good observation of the test run and external inspection of the specimen. On the other hand the variation of moisture content in the structure was larger than would be realized in a climate chamber.

Full scale component test. The test article consists of a leading edge reinforced for load application, the CFRP Fin Box to be certified and the rudder dummy representing realistic bending stiffness. The specimen is loaded by non bonded pads acting in compression only. The loading rig can easily be removed for inspection or repair reasons. In Fig.19 and 20 the general arrangement is illustrated. Fuselage attachment loads including thermal effects are controlled by hydraulic actuators. To obtain close tolerances of moisture and temperatures, the test will be performed in a climate chamber.

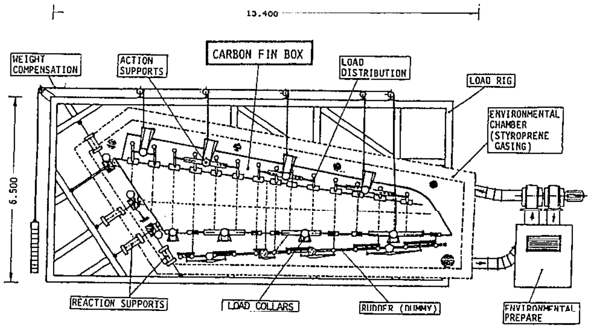
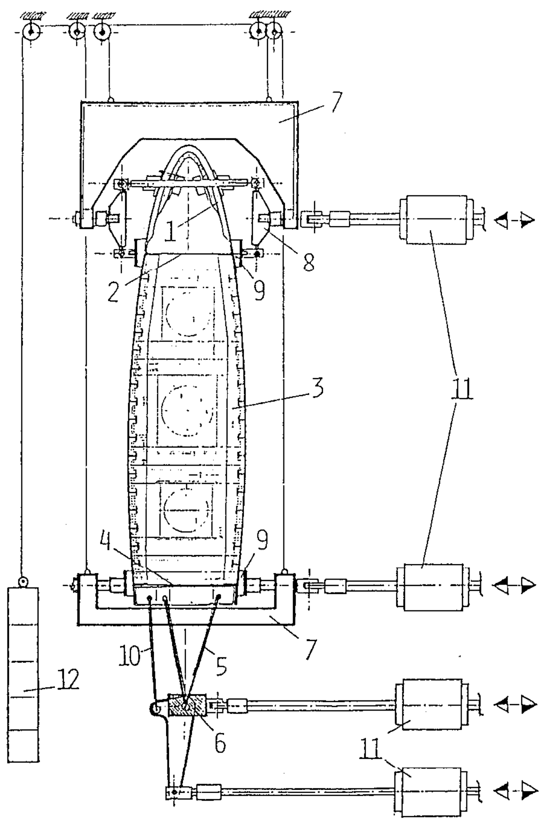


Fig.19 Full scale component test arrangement



1. Reinforced leading edge
2. Front spar
3. CFRP fin box
4. Rear spar
5. Hinge arm
6. Rudder dummy
7. Loading collar
8. Loading rig
9. Loading pads
10. Actuator
11. Action support
12. Weight compensation

Fig.20 Full scale component test Load application

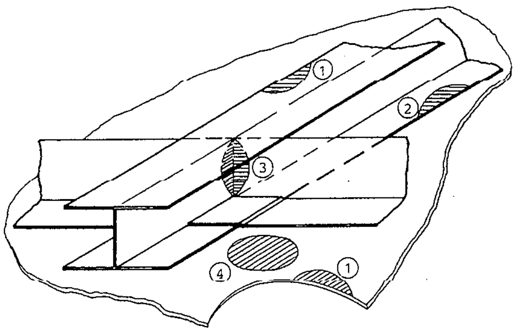
Special features of the CFRP Test Fin Box

The fin box itself is fabricated of the two prepreg materials Hexcel F550 and Ciba 913c as shown in table 6.

Material / Component	Ciba 913c	Hexcel F550
lh panel	1	---
rh panel	---	1
Front spar	---	1
Mean spar	---	1
Rear spar	1	---
Ribs	9	9
Fittings	3	4

Table 6 Material application in full scale test component

The application of Hexcel and Ciba materials to panels, spars and ribs is well mixed to get comprehensive substantiation of the strength for both materials. As a consequence of the dual material application, static loads have to be applied to lefthand and righthand side as well. As shown in Fig.21 artificial damages are built into the fin box during the production for damage tolerance demonstration.



1 Edge delamination (Teflon shim)
2 Teflon shim between skin and stringer
3 Teflon shim in stringer rib intersection
4 Teflon shim in laminate

Fig.21 Typical artificial damages applied to test structure

The test results will influence the production checks, service inspection methods and intervals. Repairs will be carried through at the virgin fin box and tested through the complete run. Strain gauges are applied to all major parts.

Test program in sequence

1. Demonstration of strain distribution and stiffness for dry virgin structure at RT and +70°C up to limit load.
2. Demonstration of fatigue and damage tolerance (part I) for a structure with mean service moisture (approximately 0.7%).
   The flight by flight test will run for 2 lifetimes at RT including thermal loads due to different thermal expansion of metal fuselage and CFRP fin box.
3. Demonstration of static strength and stiffness for a fatigue cycled structure under worst environmental conditions (max. laminate moisture, +70°C) up to ultimate gust and maneuver loads with additional load factor for missing thermal cycles in fatigue test. This factor is determined by coupon testing.
4. Continuation of fatigue and damage tolerance demonstration (part II) at RT with wet structure. Additional inspectable damages (saw cuts and delaminations) are applied.
5. Fail safe tests up to limit load at max. laminate moisture and +70°C. (Loosen main connecting bolt, strong mechanical damages)
6. Residual strength test (max. laminate moisture, +70°C).

Lightning protection. The effects of lightning strike were checked at the upper fin (Fig.22). Lightnings of extreme intensity (200 kA) attaching at the diverter did not damage the structure at all. Lightnings of swept stroke type (100 kA) attaching at the CFRP skin only caused limited failures within one stringer bay which easily can be repaired. The applied conductivity system works satisfactory.

Fig.22 Lightning strike test specimen

VII. Conclusions

The Airbus CFRP Fin Box certification is scheduled to be achieved by the end of 1985. The chosen strength justification approach relies mainly on testing, especially of the full scale component covering static strength, fatigue and damage tolerance. This test will start end of 1984 and be finished mid of 1985. The test program was prepared based on the experience of the former certification for Airbus CFRP rudder and fin subcomponent tests. Analysis and partial tests support the strength evaluation.
The certification program was presented to the French and German authorities.

Acknowledgement

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References

1. D. Schulz
   Airbus-Seitenruder in Faserverbund-werkstoff
2. D. Schulz
   Development of the A300 Fin in Modern Composite Fibre Construction