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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.

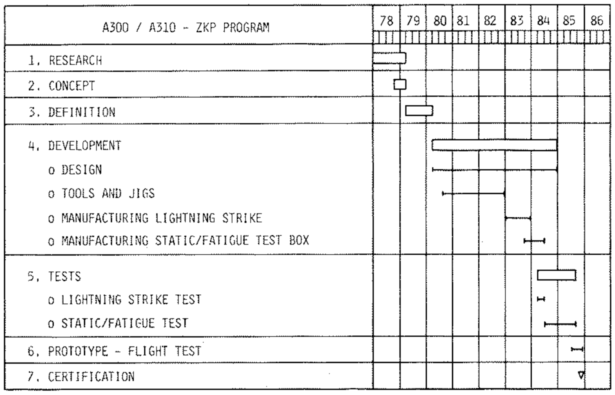


Fig.1 Schedule of Development

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).

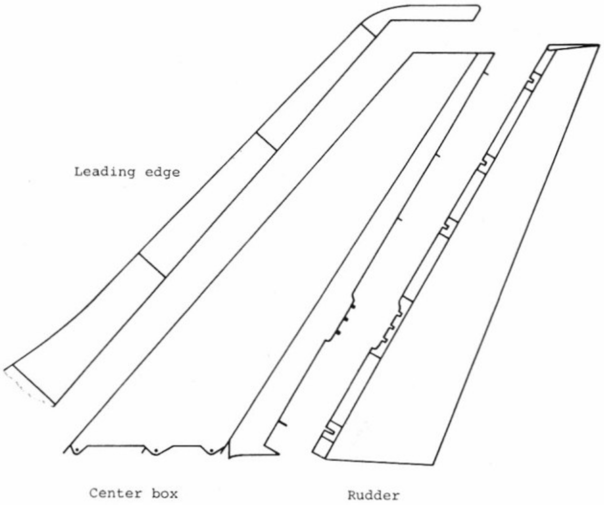


Fig.2 CFRP Fin Main Parts

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.

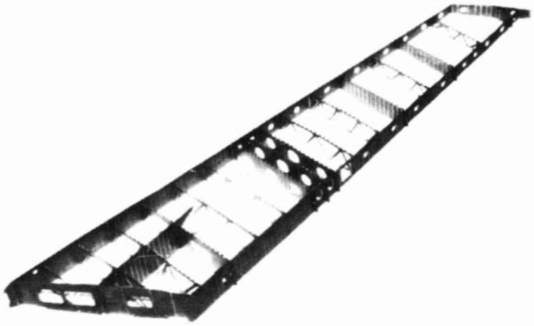


Fig.3 CFRP fin box structural model

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.

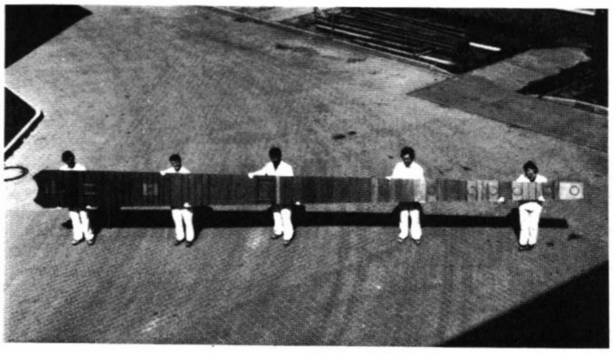


Fig.5 CFRP rear spar

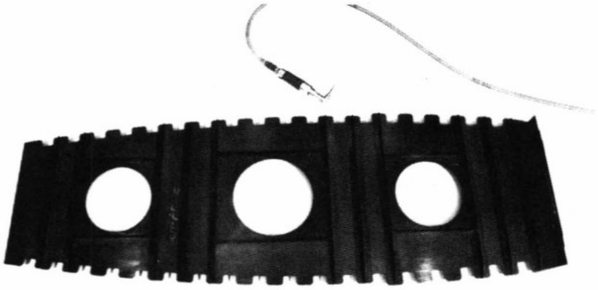


Fig.6 CFRP web type rib

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.

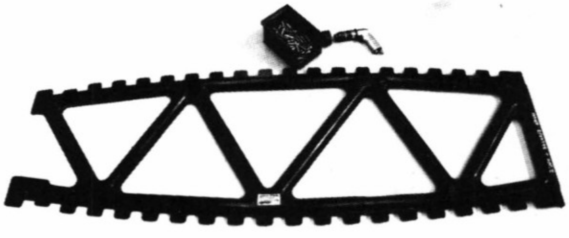


Fig.7 CFRP framework rib

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.

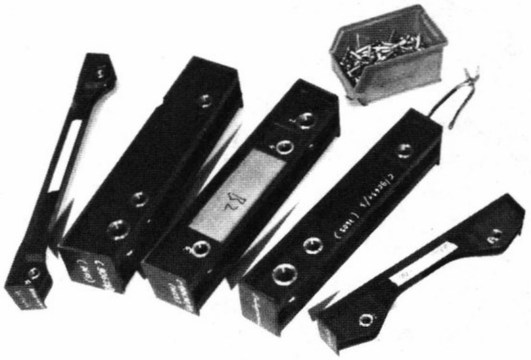


Fig.8 CFRP rudder support fittings

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.

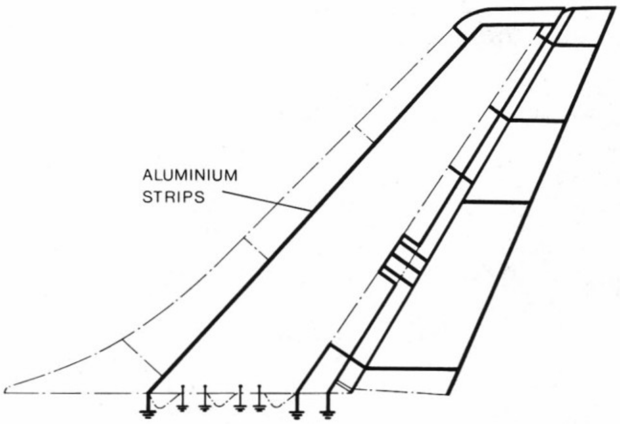


Fig.9 CFRP-Fin lightning protection system

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)

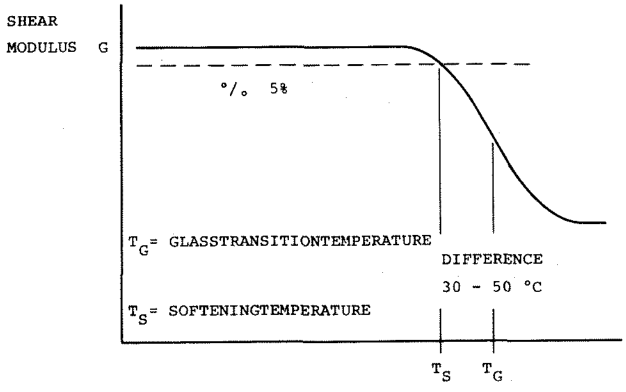


Fig.10 Effect of temperature on laminate stiffness

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.

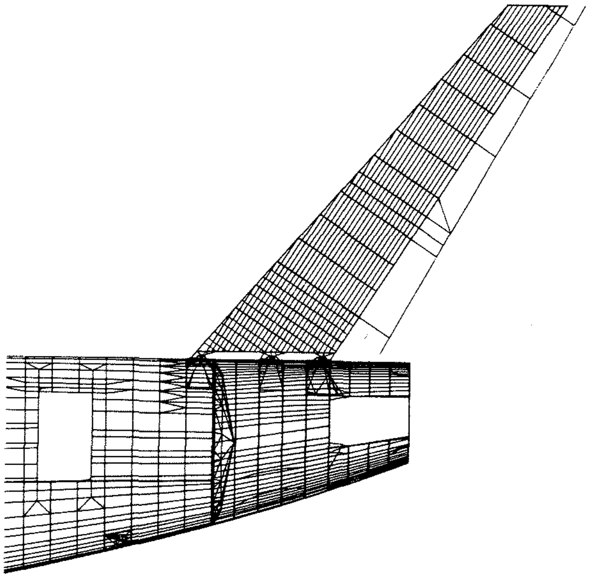


Fig.12 FEM - Model

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.

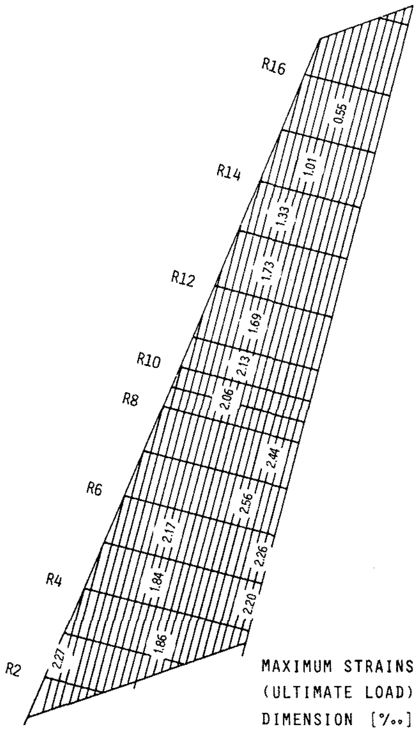


Fig.13 Strain in stringer direction induced by ultimate gust loading

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°/oo
at the tip : 2,0°/oo

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

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

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.

<u>Element and detail tests.</u> 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.

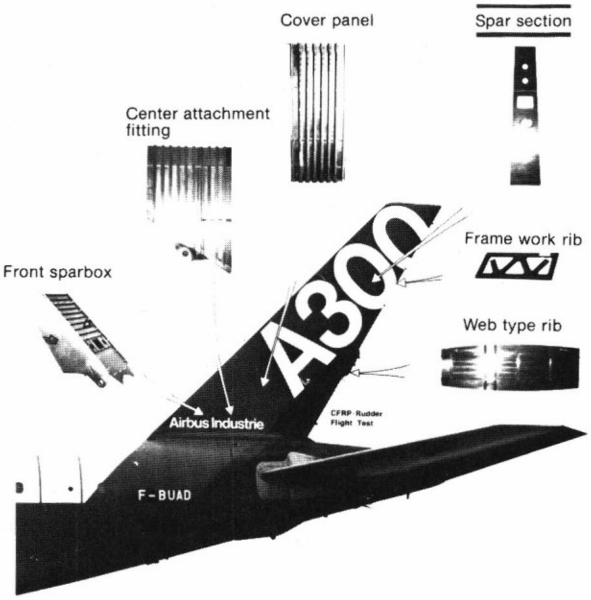


Fig.14 Detail test specimen

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.

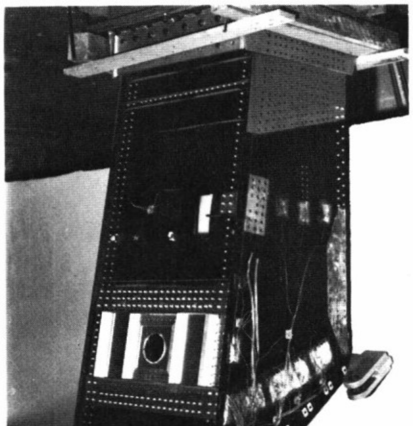


Fig.15 Subcomponent front spar box

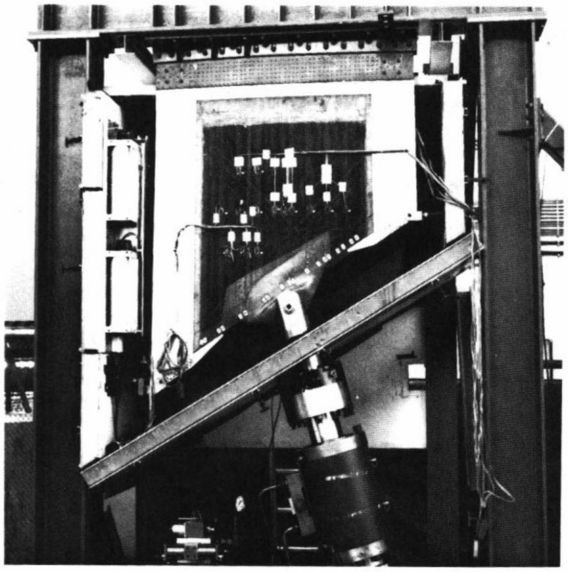


Fig.16 Subcomponent middle main pick up fitting

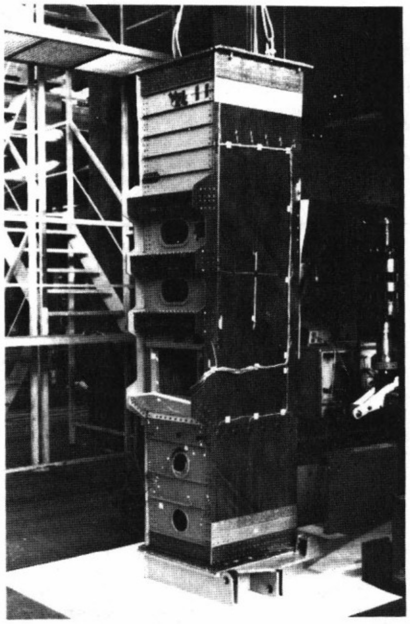
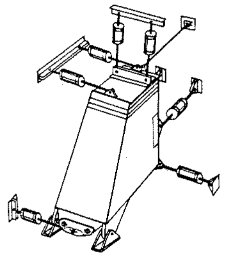


Fig.17 Subcomponent rear spar box

	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.

<u>Full scale component test.</u> 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.

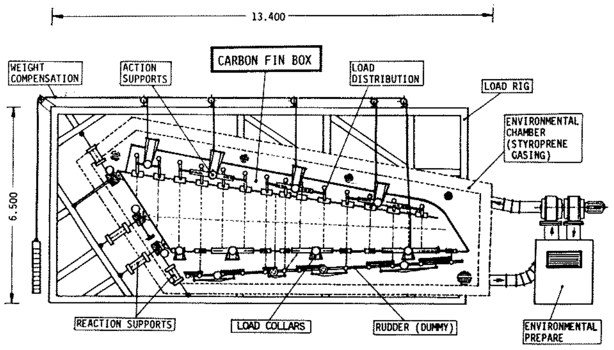
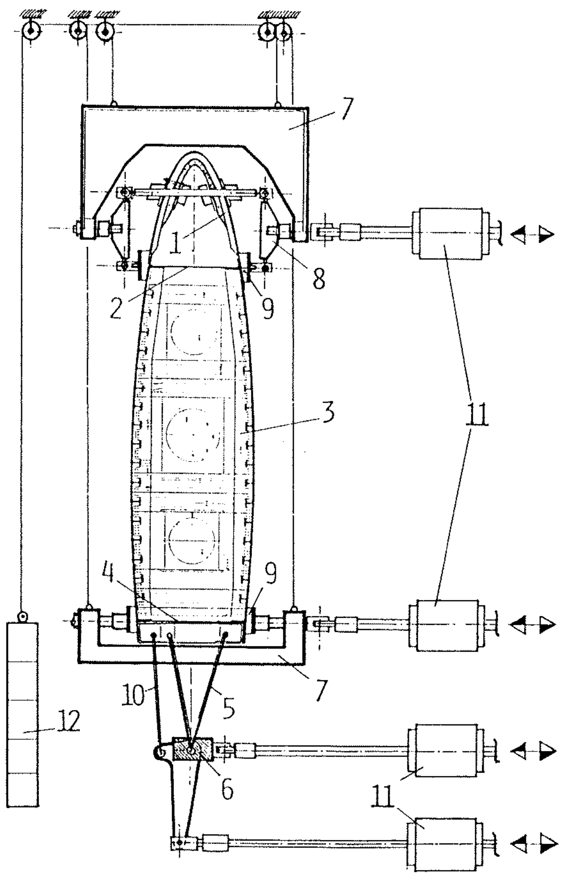


Fig.19 Full scale component test arrangement



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

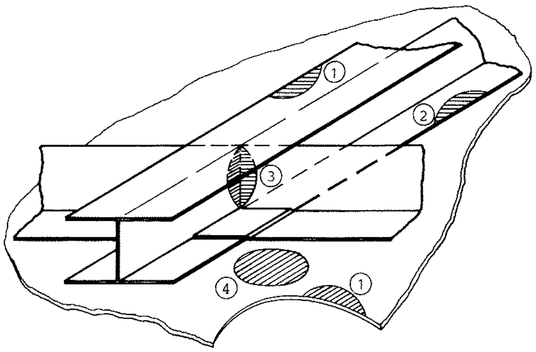
Special features of the CFRP Test Fin Box

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

Component \ Material	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

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

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