# A ONE-SHOT AUTOCLAVE MANUFACTURING PROCESS FOR CARBON EPOXY COMPONENTS

M. Kaitatzidis and R. Renz
Dornier GmbH, Friedrichshafen
and D. Wurzel, DFVLR Stuttgart

## Abstract

For the Alpha-Jet aircraft Dornier has developed and fabricated a carbon/epoxy horizontal stabilizer, which has already succesfully completed its qualification tests.

This paper presents the requirements and goals of this development and describes the structural design of the horizontal stabilizer. For its leading and trailing edges a new one-shot manufacturing technique has been developed. The toolings are described, weight and cost savings are reported. This technique is now being applied for series production of ailerons for the Do 228 Commuter Aircraft.

A brief presentation of the results of the qualification tests under various environmental conditions (humidity and temperature) is given.

## 1. INTRODUCTION

The first carbon/epoxy structural components developed and produced by DORNIER were the speed brakes for the Alpha Jet aircraft in differential construction (Fig. 1). To date, approx. 1 000 speed brakes have been manufactured. A long term evaluation program is being conducted by the GERMAN AIR FORCE with 18 speed brakes.

The next CFRP component was the rudder for the Alpha Jet, a sandwich construction (Fig. 1). For a long term evaluation by the GERMAN AIR FORCE, 15 rudders were built.

The horizontal stabilizer of the Alpha Jet is the first advanced composite primary structure component developed by Dornier (Fig. 1).

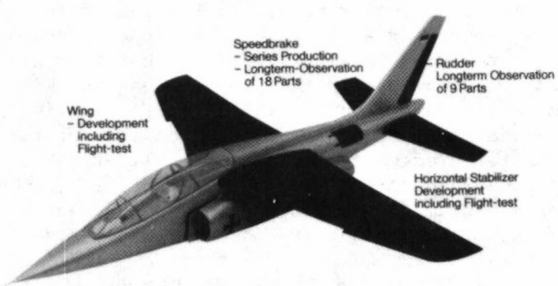


Fig. 1

The qualification tests have been successfully completed and the flight testing will take place this year.

At present carbon epoxy wings are being developed for the Alpha Jet in carbon/epoxy.

At the beginning of the design phase for the horizontal stabilizer, the following requirements and conditions to be fulfilled were set up:

- the structure must be capable of statically supporting 140 % of the limit load.
- The functional capability of the structure must be ensured for an operational life of 5 000 flight hours ( equivalent to approx. 20 years of aircraft life).
- At the end of the operational life, the structure must still be capable of bearing 120 % of the limit load.
- An airworthiness certification for the conduction of a long term evaluation during military operations had to be granted.
- Complete interchangeability with the metal stabilizer.

In addition, the following development goals were to be fulfilled.

- Highest possible weight reduction with lowest possible cost increase as compared to the metal stabilizer.
- Development of technology for future primary aircraft components.

## 2. DESIGN

The horizontal stabilizer of the Alpha Jet is a trimmable stabilizer with a continuous torque box. The stabilizer is moved as a unit about two bearings on the top by an actuator system which is attached to the middle of the lower side. The mounting is statically determinate.

The stabilizer consists of the torque box, the leading and trailing edges and the tips (Fig. 2). The torque box is constructed of two U-shaped continuous shells and 11 ribs. The bearing ribs with the integrated bearing eyes as well as the connecting ribs for the tips are made of metal; all other form ribs are of CFRP.

The shells and the ribs are riveted together. The shells as well as the ribs are made of T 300/ Code 69, unidirectional prepreg.

Leading and trailing edges are of monolithic construction. The manufacturing process for these components will be described in detail in the next chapter. The leading and trailing edges are attached to the torque box with rivet nuts and screws and can be removed for inspection purposes.

The leading edge is made of a hybrid composite of glass and carbon fabric prepreg; the trailing edge of carbon fabric prepreg only (Vicotex 1452/G 803).

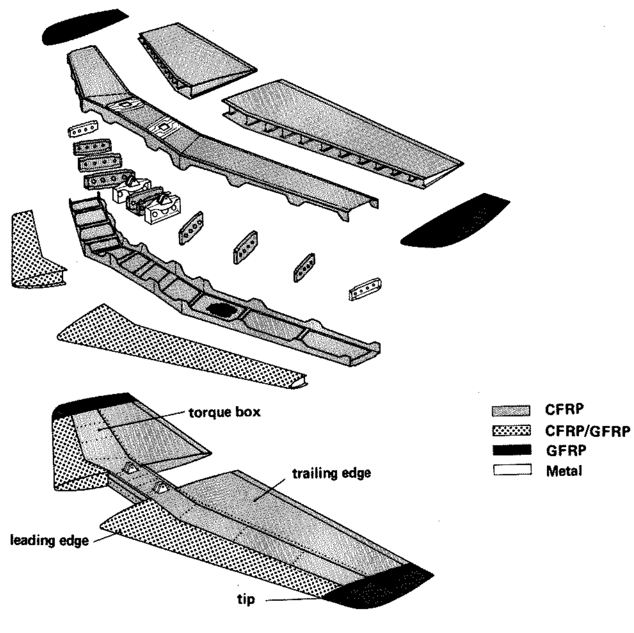


Fig. 2

## 3. MANUFACTURING DEVELOPMENT

The development of the construction method for the leading and trailing edges, including the necessary qualification tests, was performed by the DFVLR (German Aerospace Research Establishment) in Stuttgart.

The development objectives were as follows:

- Lighter than the metal version
- Equally expensive, cheaper if possible
- Adequate strength for the leading edge to resist stone and hail impacts

### 3.1 Preliminary experiments

For the leading edge, a skinrib construction method was selected from three alternatives.

An important mechanical requirement was adequate strength to withstand stone and hail impact. After numerous investigations (Chapt. 4.1) a CFRP/GFRP combination was chosen for the skin.

In the early stages, separate manufacturing of skin and ribs and final assembly by bonding was planned. Tolerance problems however, were encountered with the installation of the ribs. Thickness variations in the skin laminate had to be coped with. In addition, the profile thickness decreases towards the tips. This requires the ribs to be accurately positioned which results in extensive manufacturing efforts. For this reason an attempt was made to develop a cost efficient manufacturing method which does not require the pre-manufacturing of individual parts. This method must provide for the curing of both skin and ribs in one step.

The first investigations quickly indicated that for high-bleed,high pressure prepreg systems the following aspects strongly influenced the feasibility and economy of this plan:

- Materials withhigh resin flow are unsuitable because of the resulting large thickness variations in the laminate
- In areas with small curvature radii, good laminate quality can be achieved only by the application of mechanical pressure.

Therefore, a low-bleed, low pressure fabric prepreg (T 300), Vicotex 1452, which cures at 120°C was selected for the first attempt to manufacture the skin and ribs in one step. The pressure was to be applied by the use of thermal enpansion rubber (TER).

The feasibility of an integral construction by this method was verified to be sure. Especially the leading edge front area showed a satisfactory quality. However, it became apparent that specific problems exist in the TER fabrication process. Yielding of the mold and thickness variations in the laminate resulted in an uncontrollable pressure distribution for different areas. The reproducibility of the manufacturing method was not ensured. Thus, for the planned application, this method appeared unsuitable for production manufacturing.

For this reason, a second process was developed which, with the aid of a reusable pressure bag and also reusable rib supports - first of TER, later simple metal plates - could produce the complete leading edge in a conventional autoclave in a single, reproducible process. The skin laminate including local reinforcements was laid over a male mold and then inserted into a female mold (Fig. 3). The previously laminated ribs are then inserted and positioned.

For this process, the pressure is generated exclusively in the autoclave. Local over-or underpressure is no longer possible. Bracing of the ribs was provided at first by TER supports adjacent to the ribs. Resin fillets which formed between the supports and the pressure bag quickly resulted in damage to the TER supports. In view of the development of a construction concept for the trailing edges of the same stabilizer being conducted in parallel with considerably less favorable geometric conditions,an improvement was attempted with the supports located in pockets in the pressure bag. For removal from the mold, the supports are taken out of the pockets and the pressure bag can be easily extracted (Fig.3). Since, for this version, the pressure bag comes in steady contact with the skin and with the ribs, the resin fillet formation is eliminated. A smooth transition from the rib flange to the skin is produced.

For this version, the pressure bag must be carefully constructed in the area of the inserts and the defined position of the ribs must be controlled by fixing devices. With this manufacturing concept for a one-shot, integral construction process, leading and trailing edge sections of satisfactory quality could be produced. For the transfer of the technology to Dornier for series production,

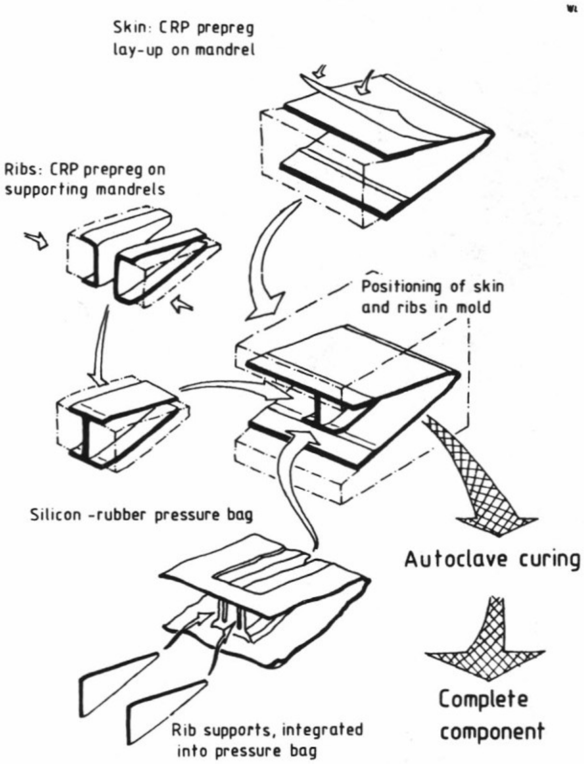


Fig. 3

manufacturing instructions were handed over.

All manufacturing trials were conducted on sections of the leading and trailing edges (Fig. 4).

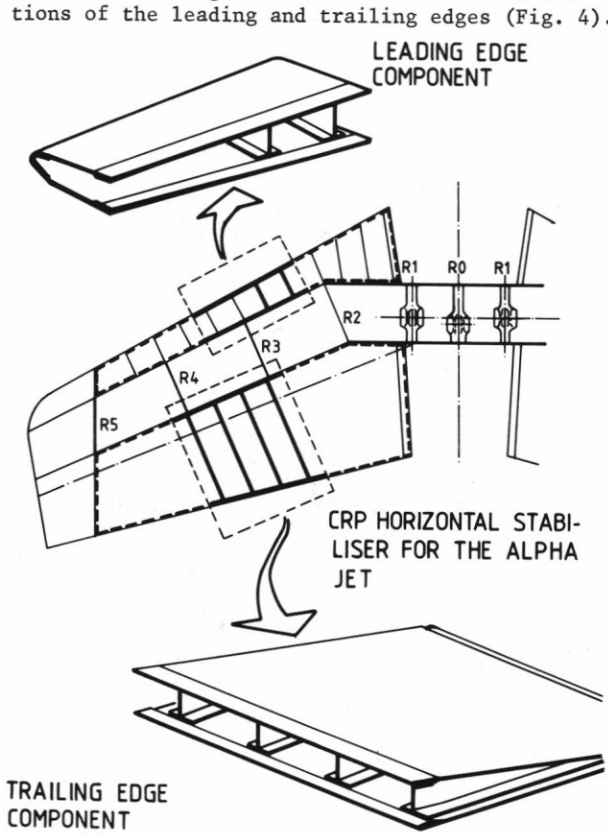


Fig. 4

## 3.2 Fabrication of leading and Trailing edges

Following the development of the manufacturing concept by the DFVLR, tooling was built by Dornier for the fabrication of complete leading and trailing edges for the horizontal stabilizer. The principle for the fabrication of both assemblies is the same, therefore only the fabrication of the leading edge will be described here.

All tooling necessary for the fabrication of the leading edge is shown in Fig. 5.

Fig. 5

They are:

- The Female Mold

  The leading edge is placed in the negative mold for curing. The mold is made of cast iron in two pieces to enable easy removal of the cured assembly.

- The Rib Tooling

  This tooling is made of silicon rubber with a double T-shaped cross section and is strengthened with aluminium sheet metal pieces(Fig. 6).

- The Male Mold

  This mold consists of individual segments (Fig. 5 and 7) which, lined up on a frame, produce the form of the leading edge.

- The Pressure Bag

  The bag is made of thin silicon rubber (Fig. 5). Its function is to transfer the autoclave pressure to the ribs and skin lay-ups.

The fabrication of the leading edge is performed as follows:

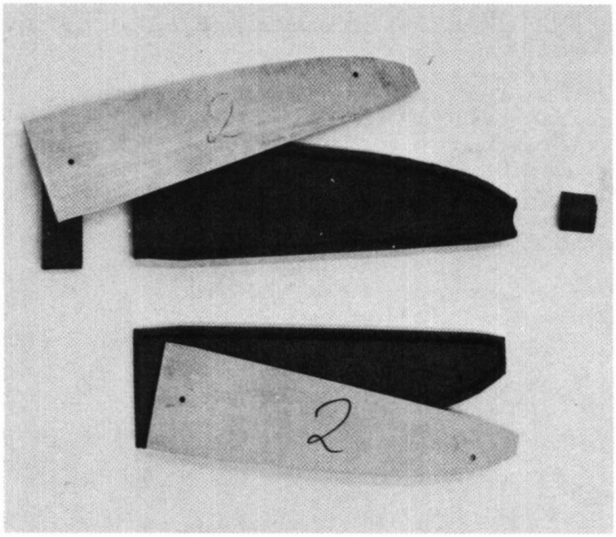

Fig. 6

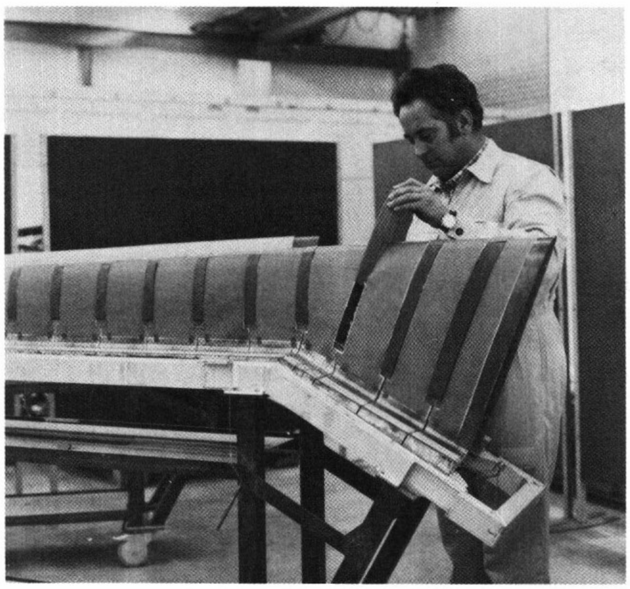

Fig. 7

First, the pressure bag is placed over the positive core. After the deposition of peel ply and separation fabric, all prepared rib lay-ups are inserted one by one in the slots provided in the positive core and the positive core is inserted into the female mold. The correct positioning is ensured by fixing devices.

The positive mold segments are then removed one after the other. The laminate lay-up which remains in the mold is sealed and placed in the autoclave for curing. The cured assembly (Fig. 8) requires only finishing conture work after removal from the mold.

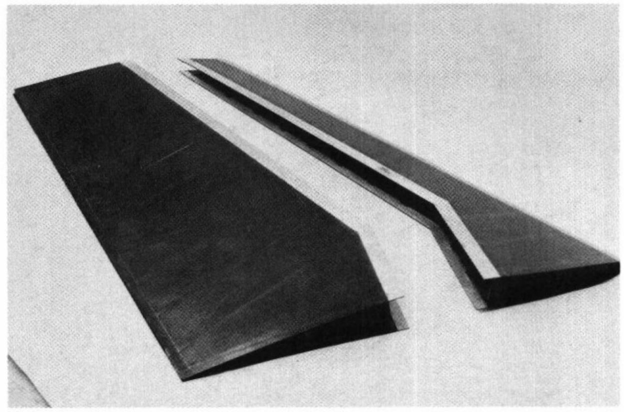

Fig. 8

## 4. QUALIFICATION TESTS

### 4.1 Leading Edge

The front area of the leading edge is exposed to damage by runway debris during take-off and landing rolls as well as hailstones in flight. In order to verify that a composite leading edge is not degraded in its functional capacity to a greater extent than the conventional aluminium leading edge, a testing device was built to simulate stone and hail impacts.

Hail impact simulation consisted of firing ice pellets (15 mm dia., 1,6 g, kinetic energy 47 J) at 250 m/s at the leading edge. This did not cause any damages. To simulate runway debris impact, glass balls (for reproducibility) and real stones were shot at the leading edge tip (6-13 gr, 50 m/s, kinetic energy up to 16 J). None of the test sections made of hybrid laminate with GFRP covering in the forward area suffered permanent deformation, however delaminations of various sizes depending on location and angle of incidence occurred(Fig.9).

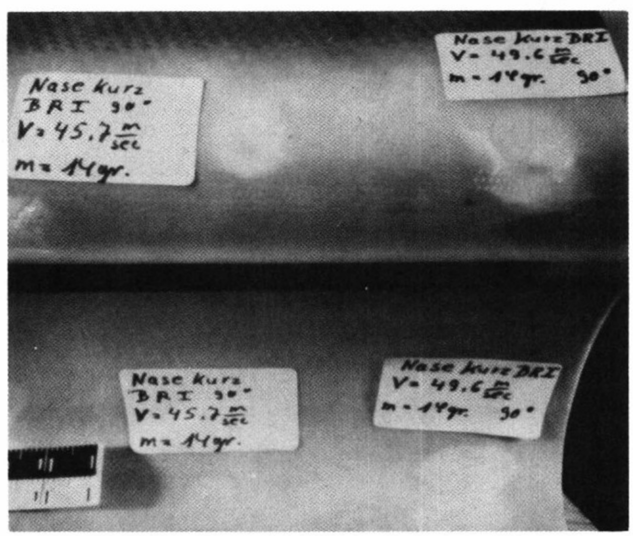


Fig. 9

In order to determine the effects of such delaminations on the functional characteristics of the leading edge, the damaged test sections were subjected to one-step loading tests (air load bending and torsion)which produced approximately the same or larger deformations in the damaged areas as indicated by calculations for the horizontal stabilizer under air loads. The one-step loading tests were performed with at least 40 000 load cycles, in some cases to over 100 000 cycles.

The results of all the tests indicated in no case a significant or unacceptable degradation of the load carrying capacity of the leading edge. The damaged areas neither increased visibly in size nor did the test data clearly indicate any changes after impact damage occurrance. On several leading edge test sections fracture tests were conducted following the load tests.

Test sections which were subjected to fracture tests had endured between 40 000 and 160 000 load cycles. The calculated fracture load (limit design load) was clearly exceeded in all cases.

Thus it could be demonstrated that the toleration of light damages, especially delaminations, in favor of reduced weight leads to impact resistant and therefore useable composite assemblies. Since practically no plastic deformation of the forward area occurs, the aerodynamic performance is degraded far less by impact damages than is the case with the conventional metal version.

### 4.2 Trailing edge

To qualify the trailing edge in integrated construction, various load tests were conducted. Air loads were simulated as well as torque box bending by means of a variable geometry. The loads were applied statically at room temperature at 70°C with j=2,0 as well as in a one-step load cycling test with 40 000 load cycles at 70°C. These loads were tolerated with no damage to the assembly. The buckling characteristics of the 0,9 mm thick paneling (three CFRP Fabric layers ±45°/0°/90°/±45°) between the ribs proved to be non-critical. Maximum strains in the buckling areas at j=2,0 reached 0,12 and 0,19 % at room temperature and 70°C, respectively.

### 4.3 Complete Horizontal Stabilizer

Following the verification of the construction methods for the leading and trailing edges, a complete horizontal stabilizer was fabricated in 1980 for the conduction of qualification tests. For reasons of cost and schedule, the static as well as the dynamic tests were to be conducted on one stabilizer unit.

The following load tests were conducted:

| | j | temp. | humidity |
|---|---|---|---|
| 1. Static load | 1,25 | RT | * |
| 2. Static load | 1,15 | -55°C | * |
| 3. Static load | 1,15 | +70°C | 1 % |
| 4. Fatigue test to 20 000 flight hours | max 0,8 | RT | * |
| 5. Static load | 1,0 | RT | * |
| 6. Static load | 1,0 | -55°C | * |
| 7. Static load | 1,0 | +70°C | 1 % |
| 8. Static fracture test, right side | 1,33 | +70°C | |
| 9. Static fracture test, left side | 1,65 | +50° | 1 % |

*Ambient humidity

On the monolithic constructed leading and trailing edges, no damage was detected after completion of the tests with the exception of some delamination at the fastening holes.

## 5. APPLICATION OF THE CONSTRUCTION METHOD FOR THE DO 228

Encouraged by the successful course of the development of the monolithic construction method for the horizontal stabilizer, it was decided to apply the same method to develop and fabricate ailerons of the Do 228 utility/commuter aircraft.

The one-piece spars are made of aluminium sheet metal in the classical construction method. The three-part leading edge is a CFRP sandwich construction. The trailing edge is of epoxy-aramid fiber-fabric prepreg using the monolithic construction method(Fig. 10).

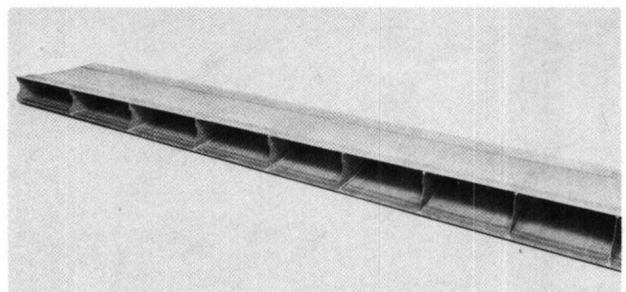

Fig. 10

The fabrication concept for the trailing edge is identical to that described for the leading and trailing edges of the horizontal stabilizer in that the rib and skin lay ups are also inserted in a positive core and cured as a unit. The tooling design could be simplified, however, since all ribs are arranged in parallel.

The simplification is that for the trailing edge of the Do 228, only one fixture is needed for lay-up and curing.

The mold is assembled as follows:

On a CFRP base plate, a core consisting of several parts is assembled (Fig. 11). The spacing of the parts is identical to the spacing of the ribs in the trailing edge. A one-piece bag molded of silicon rubber is placed over the core (Fig. 12). It is removeable and shaped so that the prefabricated rib lay-ups with the associated tooling parts (sheet metal supports) can be inserted . Over this, the rib doublers are laid.The skin lay-ups are individually placed in the pressure shells (two-piece mold) and manually pre-densified. The pressure shells are then applied to both sides of the positive core and joined together. The complete assembly is then sealed and placed in the autoclave for curing. Since the base plate as well as the positive core are provided with suitable holes the autoclave pressure can act on the lay-up from the outside via the shells and from inside via the rubber bag.

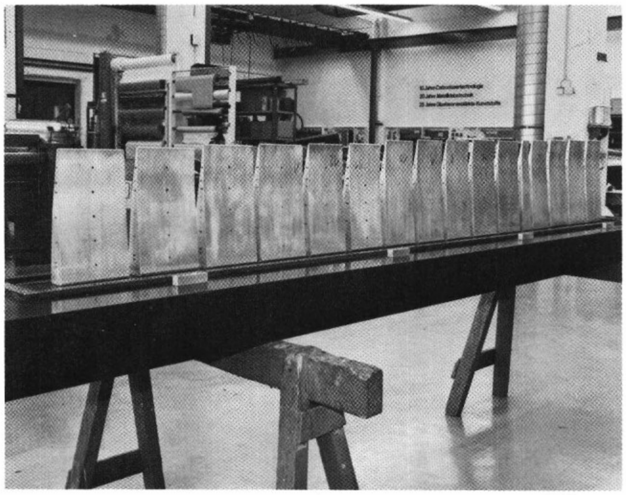

Fig. 11

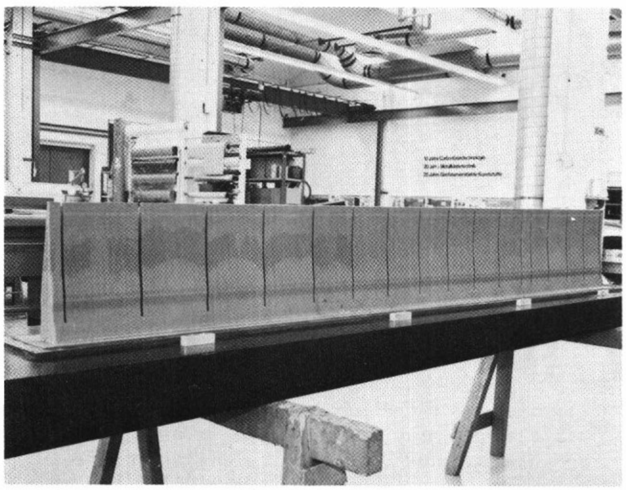

Fig. 12

The curing in the autoclave is performed with a pressure of 3,5 bar and a vacuum of 0,27 bar (pa) with a temperature of +125°C.

The removal of the assembly from the mold is without problem. No mechanical processing is necessary with the exception of cutting to length.

## 6. RESULTS

The objectives of the horizontal stabilizer development were achieved as follows:

Weight In Fig. 13 the weights of the metal and the CFRP horizontal stabilizers are compared. The CFRP stabilizer is 14 % lighter than the metal stabilizer. The weight savings can be increased by an additional 2 % by making the tips of Kevlar instead of GFRP. In the comparison of unit weights, it should be noted that, for the CFRP stabilizer, the outline surface of the torque box is smaller and that of the trailing edge larger than for the metal stabilizer. Related to the same surface sizes, the weight reduction for the torque box would be approx. 12 % and for the leading and trailing edges 25 % and 16 %.

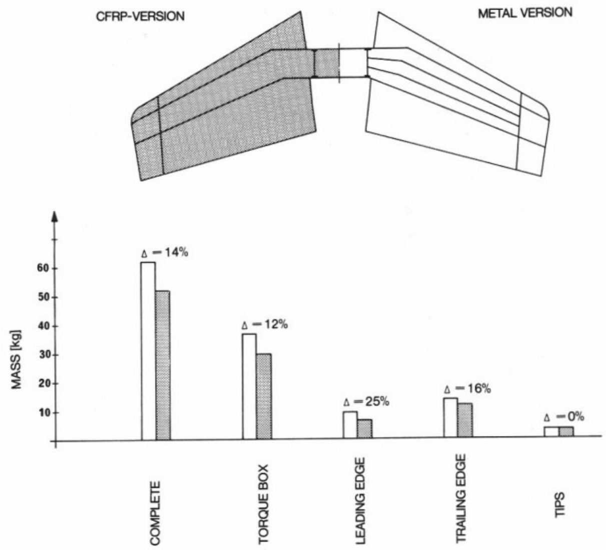


Fig. 13

Number of Parts and Fasteners The number of individual parts is significantly lower for the CFRP version as for the metal production version (Fig. 14). The number of fastener elements is even more drastically reduced especially for the leading and trailing edges.

For the trailing edge of the Do 228 aileron similar results were achieved (Fig. 15).

| | | METAL-VERSION | COMPOSITE-VERSION |
|---|---|---|---|
| HORIZONTAL STABILIZER COMPLETE | Number of structural elements | 215 | 80 |
| | Number of fasteners | ca.5000 | ca.1200 |
| LEADING EDGE | Number of structural elements | 36 | 4 |
| | Number of fasteners | 300 | 6 |
| TRAILING EDGE | Number of structural elements | 54 | 6 |
| | Number of fasteners | 720 | 12 |

Fig. 14

With the use of kevlar, the weight savings is even larger than for the horizontal stabilizer, however. The savings was approx. 45 % for the trailing edge alone and 35 % related to the weight of the complete aileron.

The cost calculations for the trailing edge which is to go into series production resulted in a reduction of 7 % compared to the metal version.

| | | METAL-VERSION | COMPOSITE-VERSION |
|---|---|---|---|
| Do 228-AILERON | Number of structural elements | 21 | 6 |
| TRAILING EDGE | Number of fasteners | 537 | 36 |

Fig. 15

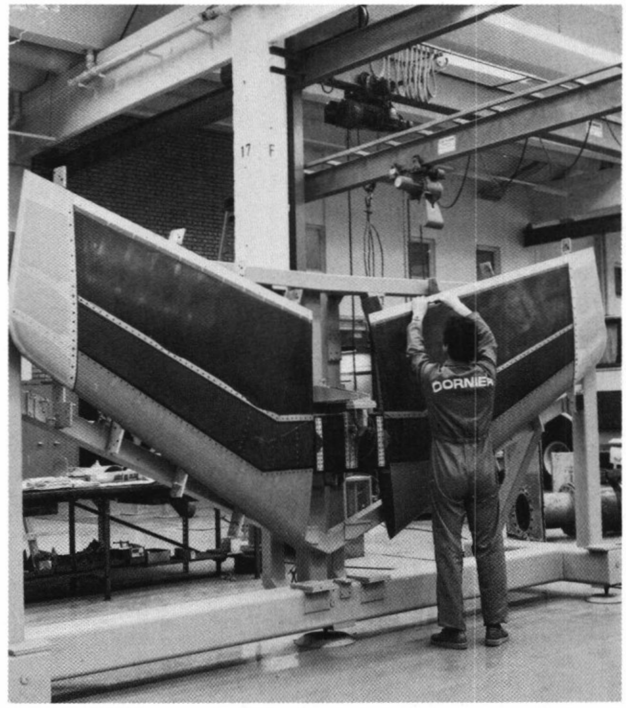


Fig. 16 : Horizontal stabilizer for flighttest in assembly rig