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OPERATION V10F - DEVELOPMENT OF A COMPOSITE MATERIAL WING

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ABSTRACT

Backing on the experience gained during the last ten years on several airplane parts made of high strenght composite materials, the two french aerospace companies Avions Marcel Dassault - Breguet Aviation and Aerospatiale are now engaged in a major cooperative program on an experimental carbon fiber wing for the Dassault Falcon 10 airplane This program is sponsored by the French government and the objective is to obtain a certificate of airworthiness and put a set of wing in experimental service. The paper describes the design of the structure and the different tests used for development and certification of the wing.

INTRODUCTION

With the advent of high strength composite materials most aerospace companies have seen the advantages offered by the introduction of these new materials. And they have devoted large efforts to develop Airplane parts incorporating this new technology.

Among these companies the two major french companies, Dassault-Breguet Aviation and Aerospatiale (with the financial back up of the french government) have spent a considerable effort in that field, leading to a quasi continuous flow of new composite parts projects and their introduction either as prototype parts or production items in ten different aircraft types - (see figure 1)

As the difficulties of the introduction of these new materials were evident, the progression followed was stepwise :

Development of small prototype elements
Early production run of simple interchangeable elements to get manufacturing and service experience
Development towards larger and more complex elements.

The latest and most advanced project is the experimental carbon fiber wing for the Dassault Falcon 10 shown at the bottom of table 1.

This operation was called V10F program and is the subject of this paper.

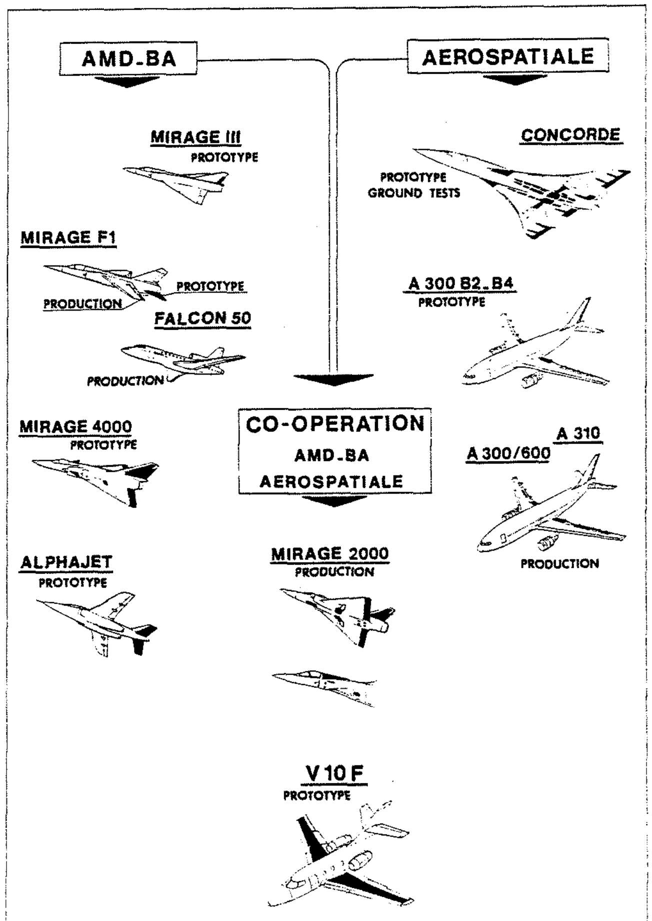

Fig.1 - Composite programs at AMD-BA and Aerospatiale

PROGRAM OBJECTIVES

General

The aim of this program is to obtain the experience necessary to utilize carbon fiber on civil airplane primary structures and combat airplane wings.

The wing of the Dassault Falcon 10 (see photography fig.2) was chosen as being small, but sufficiently complex to represent a good support for such a research program.

The program is a joint effort of Aerospatiale and Dassault (with a 50/50 split) on a French Government Contract, with a financial participation from the manufacturers.

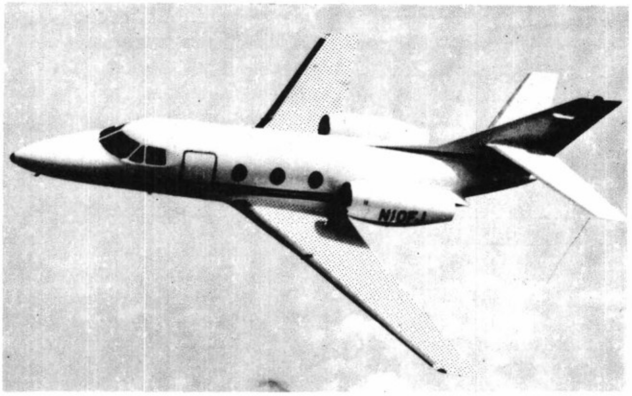

Fig.2 - The Dassault Falcon 10

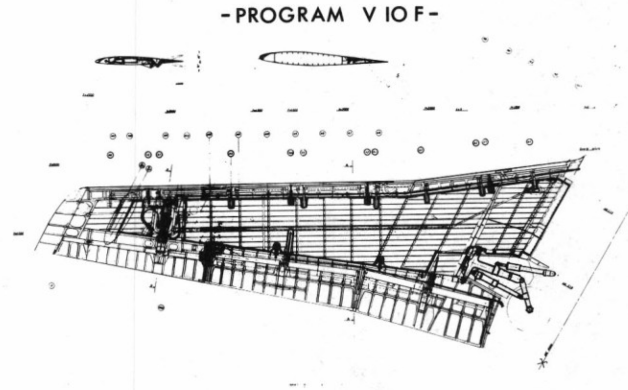

Fig.3 - View of the wing

The design was developped by a common design office. The complete manufacturing of right hand wings is done by Aerospatiale and left hand wings by Dassault. This sharing of work allows each participant to get a maximum of experience.

Objectives and fall out of the program.

The objective of this operation is to allow both manufacturers to develop a primary composite structure up to and including the obtention of a civil certificate of airworthiness, put one set of wing in service and then to acquire service experience on a critical structure, and a high degree of confidence for future large scale applications.

To achieve such an objective, the following technical problems must be adressed :

- to develop the manufacturing and control techniques for integrally stiffened carbon fiber panels and ribs and spars

- to design the details features of such structures -i. e. stringers runouts, reinforcements around holes, rib design ...)

- To develop computing methods leading to a better optimization of composite parts

- To assess on the different elements the influence of different ageing cycles

- To study the effect of lightning strikes on a carbon fiber fuel tank

- To determine rejection criteria for manufacturing or service defects, and repair methods.

DESCRIPTION OF THE WINGS

- A view of the airplane is shown on Fig.2.

The wing is made of (See figure 3) :

- a torsion box (and fuel tank) made of integrally stiffened carbon fiber panels and a substructure of two spars and 16 ribs,

- on that torsion box are attached :

  - at the front leading edge slats in two sections,

  - at the rear two trailing edge flaps, the aileron and two airbrakes,

  - The main landing gear leg is attached on the wing box at the n° 2 rib.

Left and right hand wings are attached to the existing center section by multitension bolts "piano" fitting.

- In the V10F program, for budgeting reasons only the wing box is made in carbon fiber. The other elements (slats, flaps, aileron and airbrakes) remain metal and identical to the metallic wing.

- The wing skins are made of integrally stiffened panels. The undersurface is split in 3 panels (see figure 4), one of them being removable to get access if necessary. The upper surface is just one panel (see figure 5).

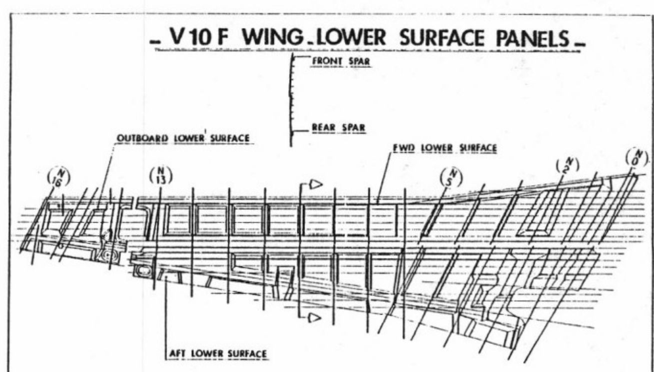

Fig.4

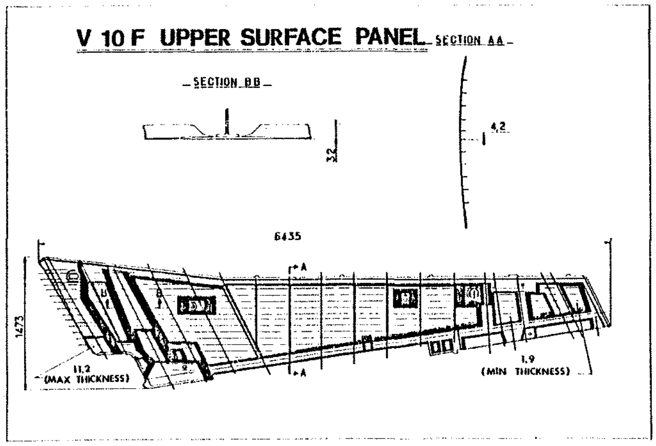

Fig.5 - Upper surface panel

Two types of stiffeners were studied for the Panels

- hat stiffeners,
- blade stiffeners.

A complete study was made for each case, including manufacturing and cost.

The blades stiffeners were chosen as being the most adapted for this type of structure.

Each panel is made of (See figure 6) :

- a base plate of variable thickness, varying from 15 plies at wing tip to 93 plies at the root,
- stiffeners made of "U" of constant thickness (7 plies) and a stiffener core of constant thickness. The pitch of the stiffeners is constant (70 mm) and their height can vary,

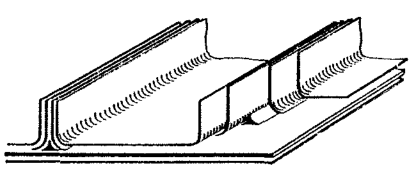

Fig.6 - Section of a panel

- the complete panel, including stiffeners, is cured in one operation,
- the lay up of the panels is optimized to get the best compromise between strength and stiffness. Some zones such as fuel gage holes and the landing gear attach zone have been the subject of a special optimization.

The longerons are made of carbon epoxy tape and are U sections

The front spar is in two parts, spliced at rib 5. The rear spar is one piece from wing tip to landing gear attach. He is bolted on an aluminium inner element which includes landing gear attach points.

The front and rear spar have numerous holes for slat tracks and jacks, and flaps jacks.

These holes were studied by partial tests and detailled computation models.

Ribs. Three types of carbon fiber ribs were studied : Two designs for standard and one for heavy ribs.

All the ribs are made of carbon fiber cloth and cured in one operation.

The standard ribs have webs stiffened either by "Greck" waves or by beads. See fig.7

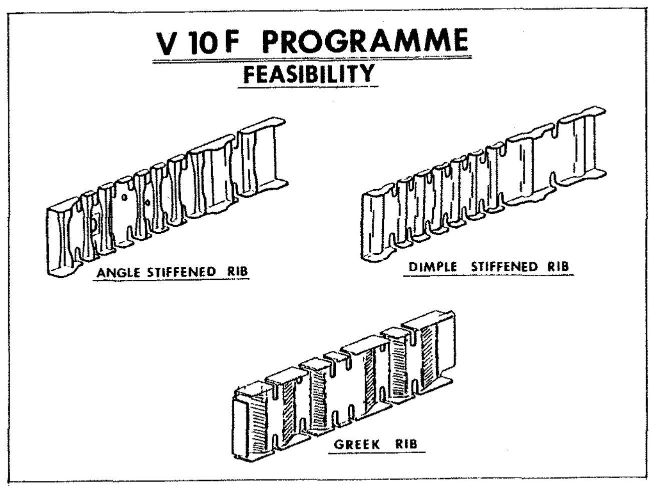

Fig.7 - Rib designs

The heavy rib (rib 5) is of box type box type structure stiffened by angles.

For each type of rib the following tests have been made :

- manufacturing tests (feasability),
- shear strength tests,
- compression and tension tests.

After tests the beaded rib was selected as standard rib.

Some ribs remained metal, including the rib 2 which introduces landing gear loads, where carbon fiber led to a complex and costly design for a very small weight saving.

The torsion box assembly is made using mechanical fasteners. Sealing is done by interposition of a sealant between the faying surfaces.

The liaison with the fuselage is done through an aluminium "piano" fitting bolted to the panels.

Resin systems : to obtain a maximum of experience, two resin systems are used on the different parts of the wing : CIBA 914 and NARMCO 5208, both with the TORAY T300 fibers. When cloth is used, the cloth is a BROCHIER G803 impregnated with the same resin systems.

Conclusion : weight saving.

Because of the constraints of redesigning the wing of an existing airplane, mainly the interchangeability of the carbon fiber wing box with the metallic, it was not always possible to get the maximum advantage of the carbon fibers. The achieved weight saving is not the optimal one which can be obtained when designing a completely new airplane.

Even so the weight saving is 20,3 % or 86 kg on a total weight of 425 kg.

DEVELOPMENT PROGRAM

The development program includes :

- feasibility tests
- calculations
- strength tests
  - on coupons
  - on elements
  - on boxes
- damage tolerance tests
- lightning strike tests

At the end of development there are two major tests, a static one on a left wing, a fatigue one on a right wing.

Feasibility tests. (See figure 8).

These tests were an important part of the program, mainly the development of toolings permitting the one shot cure of integrally stiffened panels.

Panels, spars and ribs were manufactured. The development was done with the two resin systems : T300 NARMCO 5208 and T300 CIBA 914, both in prepregs with low resin content (37%) and without the use of bleeders.

Panels of increasing size (1m, 3m, 6m) and increasing complexity were made before going to actual wing panels.

Several tooling types were developed, all using autoclave cure and silicone rubber, and two were successful.

In general, the CIBA 914 proved easier to handle than the NARMCO 5208.

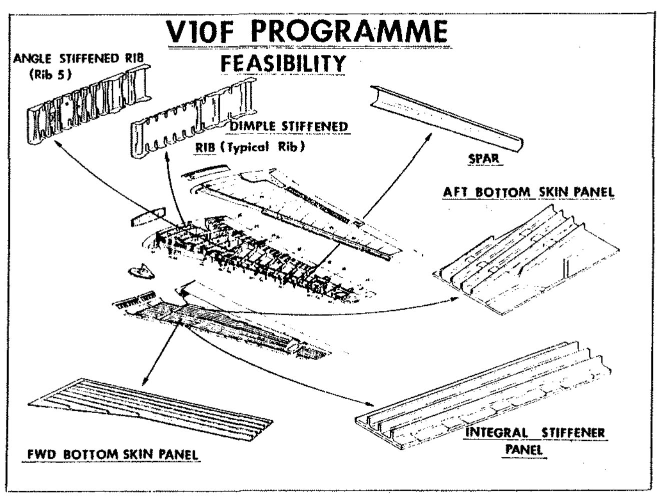

Fig.8 - Feasibility tests

Computations.

A large amount of computation was done on the V10F program.

The general finite element model is shown on figure 9. This model is very detailed and in some critical regions (wing root and landing gear attach points)it goes down to the individual bolt and uses composite bending plate elements.

This leads to a very large model : 36 500 degrees of freedom, utilizing the AMD-BA finite element code.

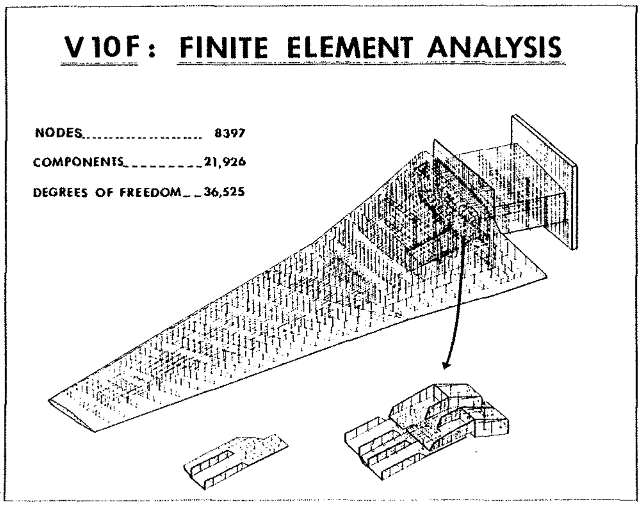

Fig.9 - Finite element model of the wing on the loading jig

This model was also used to compute flutter and divergence.

- Some other parts of the wing containing structural discontinuities have been the subject of separate and very detailed finite element computations including in some cases an optimization of the local reinforcements.

- A large number of local calculations was also made, based on the outputs of the finite element models and on the results of element tests.

Strength tests.

Strength tests were performed to define material properties (coupon tests) and to check design details (element tests and test boxes).

One very important objective of these tests was to assess the effect of ageing and temperature on strength and particularly to check the feasibility of simplifying the ageing cycles applied on large tests.

Two types of combined fatigue and ageing cycles were used :

- one complex (called C2) as close as practical to the actual usage of the wing.

Figure 10 shows the cycle.

The test sample is subjected first to a preliminary ageing of 750 h at 70°C, 95% RH without load, then to 800 cycles with mechanical loads.

- One simplified cycle called C1 :

As it is very difficult to apply C2 to large structures like a wing, the use of C2 is restricted to coupons and to some element tests.

For the other cases a simplified loading C1 is used. This cycle includes :

250 hours at 70°C, 95 RH without load, followed by 33 000 flights mechanical loads.
This being repeated three times.

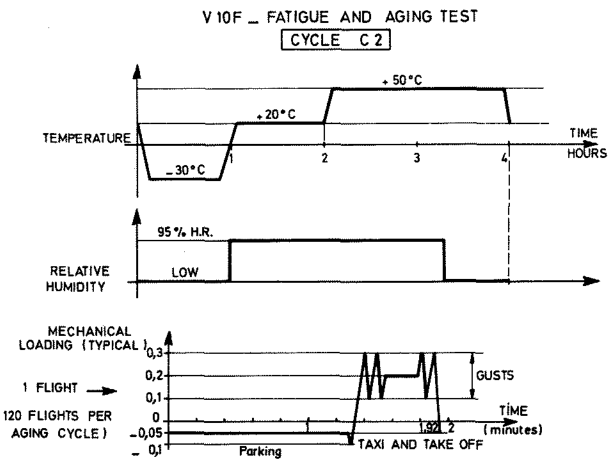

Fig.10 - Exemple of a C2 cycle

- In both cases the specimen is tested up to residual static strength,

- The differences between C1 and C2 cycles are assessed by comparative tests on coupons and elements and will be covered by a factor on the loads of the major tests.

V 10 F PROGRAM

TESTING OF BASIC MATERIAL PROPERTIES

TYPE OF TEST	PARAMETERS TESTED: STATIC AS NEW	RESIDUAL STATIC AFTER AGING C1	STATIC AFTER AGING C2	DAMAGE TOL TESTS: POROSITY	DELAM.	IMPACT
THREE POINT BENDING	X	X	X	X		
INTERLAMINAR SHEAR	X	X	X	X		
TENSION COMPRESSION	X	X		X	X	X
FASTENER HOLE	X	X	X		X	
LARGE HOLE	X	X				
REINFORCED HOLE					X	
LAP JOINT	X	X	X	X	X	

Fig.11 - Coupon tests

V 10F PROGRAM

ELEMENT TESTS

ELEMENT TESTED	TYPE OF LOADING	PARAMETERS TESTED: STATIC AS NEW	RESIDUAL AFTER AGING C1	STATIC AFTER AGING C2	DAMAGE TOL.
PANEL – STIFFENER	TRANSVERSE LOADING	X	X		X
PANEL = STIFFENER RUN OUT	TENSION + COMPRESSION	X	X	X	X
PANEL = SPLICE	TRANSVERSE LOADING	X	X		
PANEL = ACCESS HOLES	COMPRESSION	X	X		
"PIANO" Wing to fuselage FITTING	TENSION		X		
REAR SPAR	THERMAL + MECHANICAL FATIGUE		RESIDUAL AFTER THERMAL + MECHANICAL FATIGUE OF THE SPAR		
SPARS = AT HOLES	SHEAR + BENDING	X	X		
SPAR SPLICES	SHEAR + BENDING				
RIBS	SHEAR	X			
RIBS	FUEL PRESSURE	X	X		X
SMALL TORSION BOXES	COMBINED SHEAR + COMPRESSION	X	X	X	

Fig.13 - Element tests

- Figure 11 shows the coupon test used to assess basic material properties. All these tests have been performed on the two resin systems.

Figure 12 is showing the element tests performed.

These tests are made to check different design features of the wing and to help in getting the certification of the wing.

Tests are done either at ambient temperature on new structures, or after fatigue and ageing residual strength test at the most critical temperature.

Tests and testing conditions are given in the table, figure 13.

They include a test to assess the cyclic thermal stresses between the aluminium rear spar and the wing skins, and their effect on the fatigue of the aluminium.

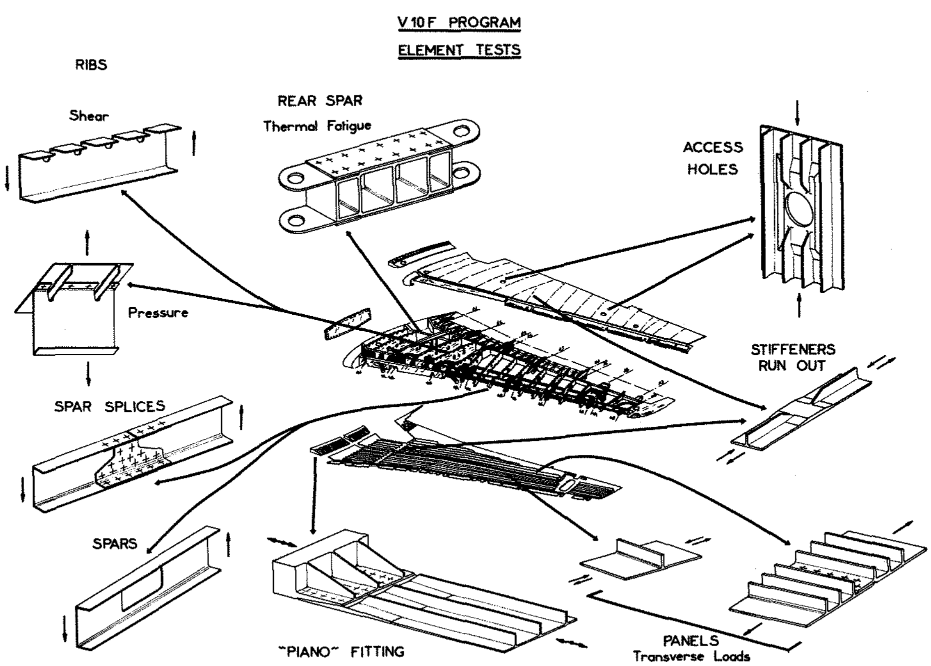

Fig.12 - Element tests

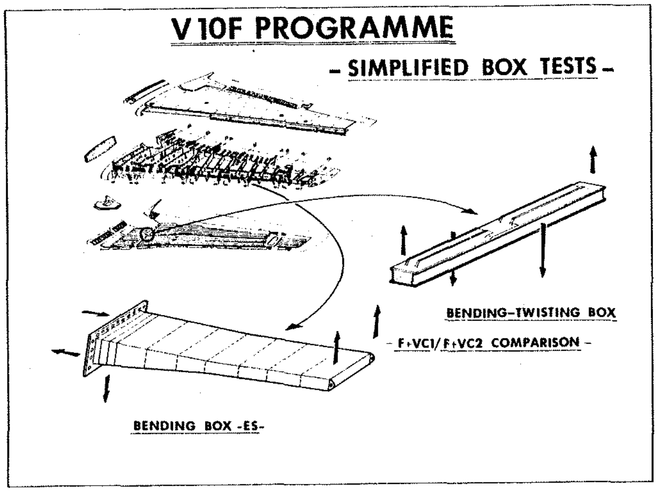

Fig.14 - Tests on boxes

Tests on boxes. (See figure 14).

Bending test : a bending test was done on a box of 3 m length attached at one end. The box is made of two integrally stiffened carbon skins (upper surface T300 N 5208, lower surface T300 CIBA 914) bolted on two aluminium spars. It represents the upper surface of the wing in the most critical region. It includes a fuel gage access hole and its reinforcement.

The test was done at ambient temperature, and did fail at the upper surface exactly as predicted.

This test, done very early in the program, was an important milestone in checking both the feasibility of integrally stiffened panels and the validity of computing methods.

Bending and torsion boxes.

These tests are aimed at checking the effects of fatigue and ageing in a complex loading case representing compression and shear loads on the joint between the upper skin and the front spar.

Bending and torsion boxes are tested in these conditions :

- new at ambiant temperature
- residual strength at 40°C after ageing VC1
- residual strength at 40°C after ageing VC2

Damage tolerance tests.

A large test program was launched to determine the influence of damages, either manufacturing defects or in service damage, on the strength of the structure.

Test are done in two phases.

1rst phase.

Test on artificial defects on small coupons and simple loading tension, compression, bending.

These artificial defects are representing (see figures 15 and 16) :

- manufacturing defects :voids, delaminations
- ground damage due to impacts (tools or stones) or scratches
- flight damage : hail impact on the upper panel loaded in compression.

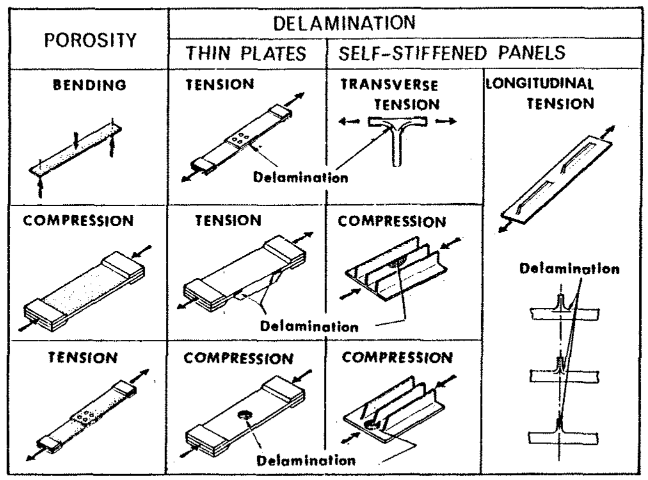

Fig.15 - Damage tol. tests on manufacturing defects

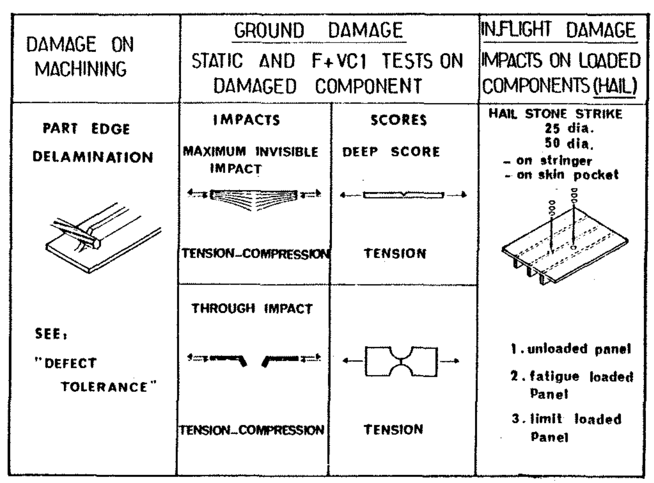

Fig.16 - Damage tol. tests on manufacturing defects and service damages

For each type of defect test were done on :

- virgin samples as references
- defect sample at ambient temperature
- defect sample after fatigue and ageing VC1.

2nd phase.

On the static test wing and the fatigue test wing, some manufacturing defects were left unrepaired. They have been identified and will be followed during the test.

Lightning strike tests (See figure 17).

Three kinds of problems are to be covered for the wing certification :

- direct strike on the wing itself (mostly on the leading edge, the wing tip and the aileron)

- transfer of lightning strike currents (on all the wing box)

- problems with the fuel in the tank : absence of electric flashes inside the tank.

A complete study was made and is continuing on a serie of test specimens representing the critical zones.

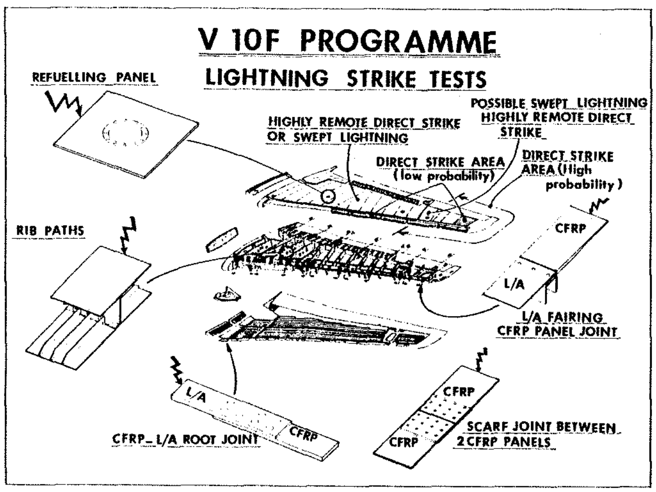

Fig.17 - Lightning strike tests

Finally, lightning strike test will be made on a wing box, with an analysis of the currents in the pipes and wires running inside the tank.

The first test results are showing that the metallic leading edge, wing tip and trailing edge are giving the wing box a good protection against direct hit.

- For the transfer currents, special precautions have been taken to carry as much current as possible through the metallic parts. Element tests have shown that transfer was also possible through the carbon epoxy wing box.

- A particular attention was also given to the metallisation of pipes and the shielding of electric wires to avoid induction currents caused by the presence of high intensity currents on the wing outer skins.

Major static and fatigue tests.

Two major tests are planned :

- a static test on one left hand half wing
- a fatigue test on one right hand half wing.

- These two half wings are attached on dummy center sections designed to reproduce accurately the loads at the wing root of the real fuselage.

- The program of the static test is the following :
    - limit and ultimate loading cases in the critical cases, on a new structure at ambient temperature
    - then humid ageing of the wing to reach the moisture content expected in service
    - then ultimate load cases at temperature.

- The program of the fatigue test is to do :
    - a preliminary humid ageing
    - the mechanical loads of 100 000 simulated flights at ambient temperature
    - residual static strength test
    - eventually damage tolerance tests.

The static and fatigue test wings have been fabricated (see photographies figures 18,19 and 20) and tests have been started.

The static test was halted by a premature failure at 1.35 limit load (failure of the lower surface of the wing in the region of the landing gear attach point).

Modifications are under study to continue the program.

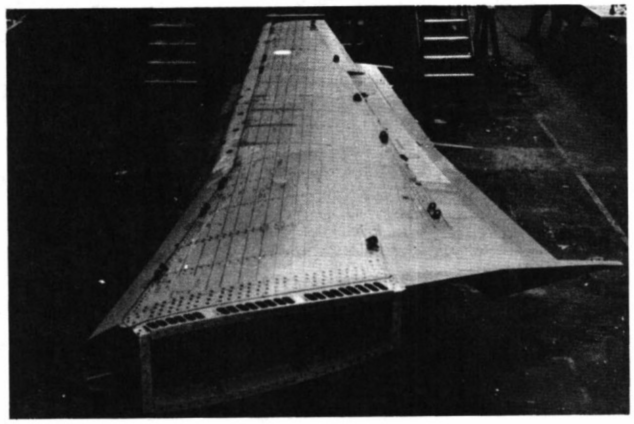

Fig.19 - Fatigue test wing

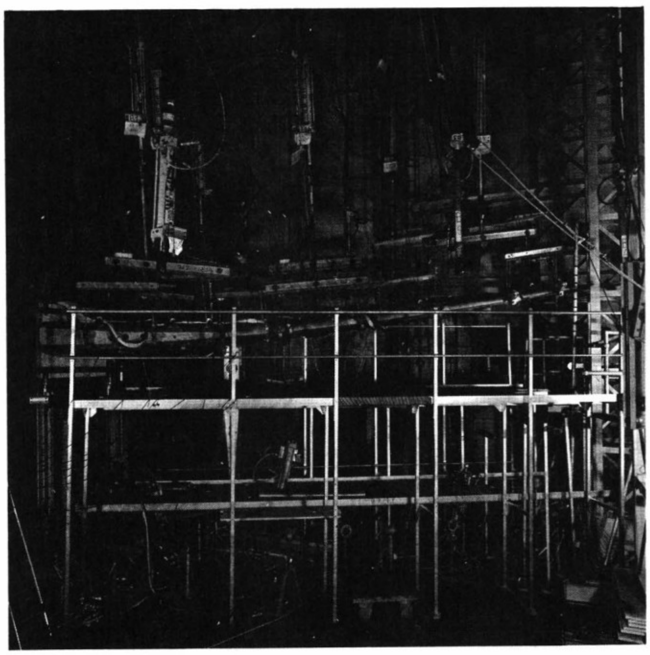

Fig.20 - Static test wing under load

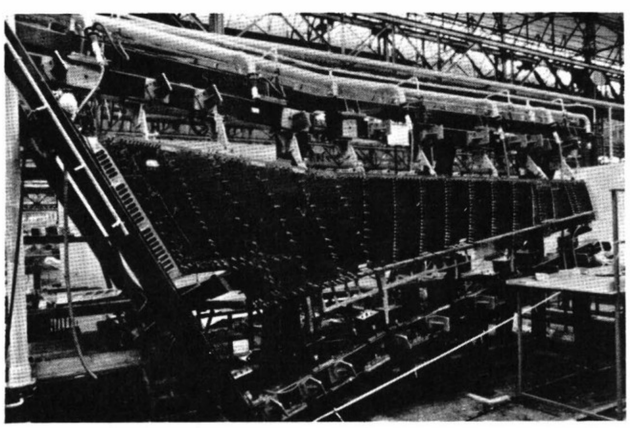

Fig.18 - Fatigue test wing on its assembly jig