# A SURVEY OF COMPOSITE STRUCTURE TECHNOLOGY AT THE AEROSPATIALE HELICOPTER DIVISION

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## 1. SUMMARY

The prevailing factors guiding the engineering choices made by helicopter manufacturers today are primarily the ongoing improvements in the operational capabilities of both military and commercial helicopters and the lower production and utilization costs.

One of the main ways of meeting these objectives is to use composite materials. Their application is becoming one of the essential high technical prerequisites for all aeronautical manufacturers in a competitive market where technological innovation plays a vital role in competiveness.

These technologies have been introduced progressively and slowly on secondary structures, on main and tail rotor blades and in some cases on hubs.

With the experience so gained and the support of specific research programs, these technologies can now be extended to primary structures such as fuselages, at least for a certain category of military or civil aircraft.

This paper summarizes and analyzes the work carried out by Aerospatiale in this field over the past few years; emphasis is placed on certain design, production and quality assurance aspects and on performance/cost effectiveness.

## 2. INTRODUCTION

Aerospatiale's Helicopter Division was quick off the mark in the development of parts constructed from composite materials: typical examples are the Gazelle rotor blade in 1971, the Starflex hub in 1975 and the fenestron/fin assembly in 1981.

First produced in 1981, the Dauphin 366 G1 (Figure 1) today ranks as one of the most advanced Aerospatiale helicopters in terms of composites which account for 25% of its empty weight (without engines, ancillary systems, etc.).

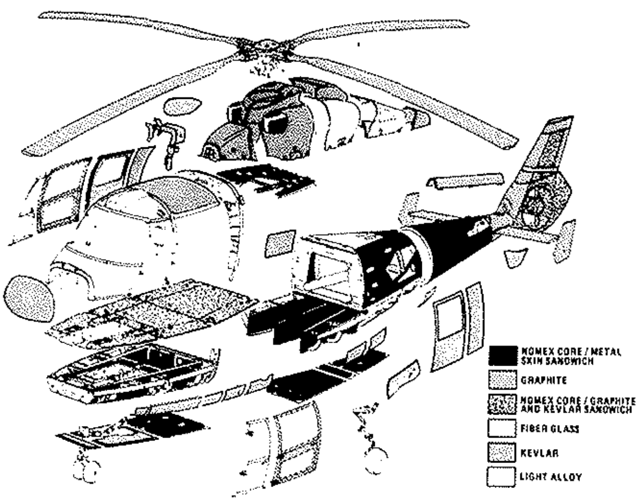



*Figure 1 - Dauphin SA366 G1: Exploded view*

The experience gained up to 1981 confirmed the overall interest of these technologies and presaged further improvements with the development of novel higher performance materials having more extensive fields of application, in particular to the entire fuselage.

In the last few years Aerospatiale has been preparing for this development by undertaking a large-scale research effort (Figure 2) with the backing of the French Authorities. The objective is to assess the value of these technologies in applications on civil and military helicopters.

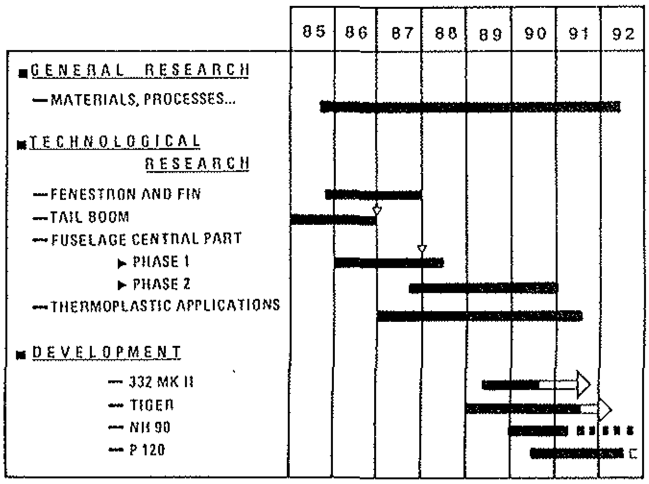



*Figure 2 - Research and Development on Primary Composite Structures*

The above activities cover most helicopter components and can be divided into two categories:

- applications not much dependent of the part and involving certain behavior patterns specific to composites in fields in which they do not perform as well as metals (crash, lightning, nuclear electromagnetic pulse, acoustics, fire resistance, etc.) that can be evaluated by means of tests on specimens.

- applications closely associated with the part considered and integrating concepts, and production and quality assurance methods. The primary objective of these applications is to reduce weight and production costs.

In this paper we will discuss in detail some of the above topics and also talk about current development programs, such as the 332 MKII and Franco-German Tiger, which will be the first to benefit from this research effort.

## 3. GENERAL RESEARCH

This research focuses on the behavior of composites in fields where they appear less successful than metal-based materials.

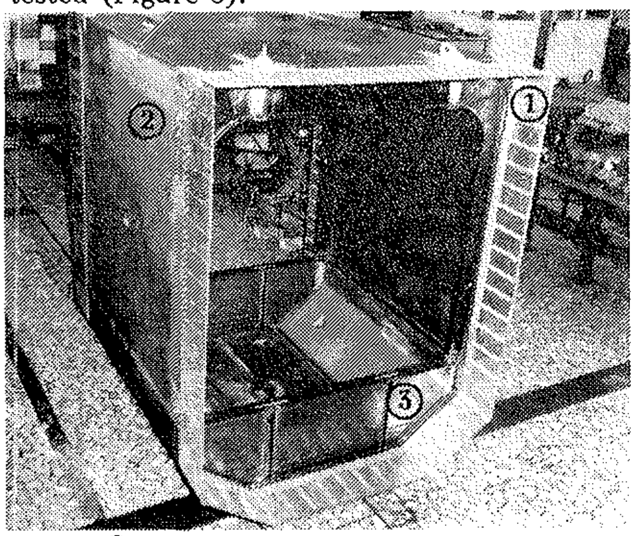
### 3.1 Lightning Protection

When struck by lightning, metal fuselages act like a Faraday cage; the induced currents flow along the surface without causing damage and the electromagnetic waves do not propagate inside. The static charge conducts easily along the fuselage surface and forms a good reference for the aircraft ground.

This no longer holds true for composite fuselages because composites are vulnerable to direct lightning strikes. Moreover the poor (carbon) or zero (glass, aramide) electric conductivity of composites means that on-board systems run a serious risk of interference. Unless additional protection is fitted, composite fuselages will inhibit static charge flow and ground returns.

It is thus essential to investigate protection solutions according to where the zone is located on the fuselage and what materials are utilized.

Currently the direct and indirect effects of lightning are mainly simulated experimentally. Consequently the first step was to run numerous tests on elementary specimens (monolithic, sandwich, joints, etc.) in order to compare the various protections with the feasible technologies. Next an experimental section similar to the technology adopted was tested (Figure 3).



(1) FRAME : MONOLITHIC CARBON
(2) SKIN : CARBON/NOMEX SANDWICH
(3) BULKHEAD : KEVLAR-CARBON/NOMEX SANDWICH

*Figure 3 - Experimental Section*

The final solution was based on bronze grid and bronze foil, which provide a protection level equivalent to that of metal structures. Figure 4 illustrates some typical examples of this protection.

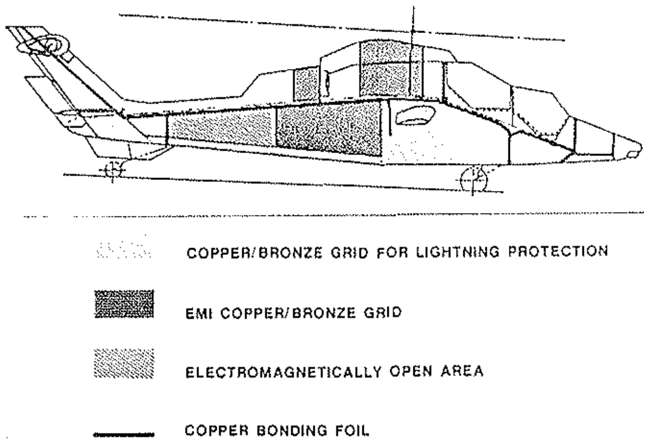



*Figure 4 - Lightning and Electromagnetic Protection*

## 3.2 <u>Crashworthiness</u>

Modern helicopters, notably military models, must integrate crashworthy features as stipulated in MIL-STD-1290 which employs a probabilistic approach to accidents.

This crash capability covers:

- the landing gear,
- the structure (area under floor),
- the crew and passenger seats,
- the fuel tanks and fuel system.

Unlike metal materials, composites have specific structural problems (no plastic range, small rupture elongation, etc.) that can only be solved by special concepts.

These concepts must be developed for each of the components (Figure 5) with a crash absorption capability, i.e. in general for:

- beams (1),
- frame bottoms or ribs (2),
- beam/rib and beam/frame joints (3),
- landing gear load pickup areas (4),
- feedthrough between tanks, beams and tanks (5).

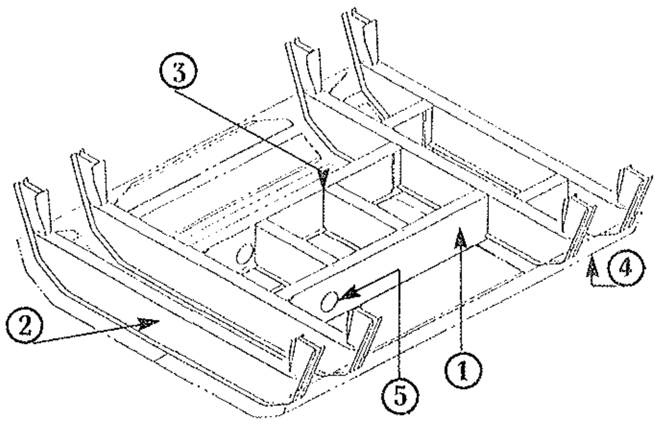



*Figure 5 - Crashworthy Structure Underfloor*

The numerous investigations conducted in this field throughout the world have demonstrated that composites can absorb energy as effectively as metal structures when appropriate solutions such as materials and construction layouts are employed. Material performance was assessed in terms of criteria such as the specific energy absorbed (kJ/kg), the energy per unit length (kJ/m) and the absorption efficiency.

Nevertheless the optimum solution is highly dependent on construction constraints, dimensioning for flight loading, and economic factors. Under these conditions a large and mainly experimental research program was conducted on two classes of aircraft (4-6 T and 8-10 T) of different architecture:

Quasi-static and dynamic ($V_Z$ = 8.5 m/s) crash tests were run on test specimens representative of the critical zones in order to select the basic materials (fibers, resins, orientations) and the technologies (sinewave beam, sandwich, trigger mechanism, etc.). (Figure 6).

The local concepts adopted have been built into a section representative of the center structure of a 8-10 T class helicopter. Crash testing of the section is scheduled for late 1990.

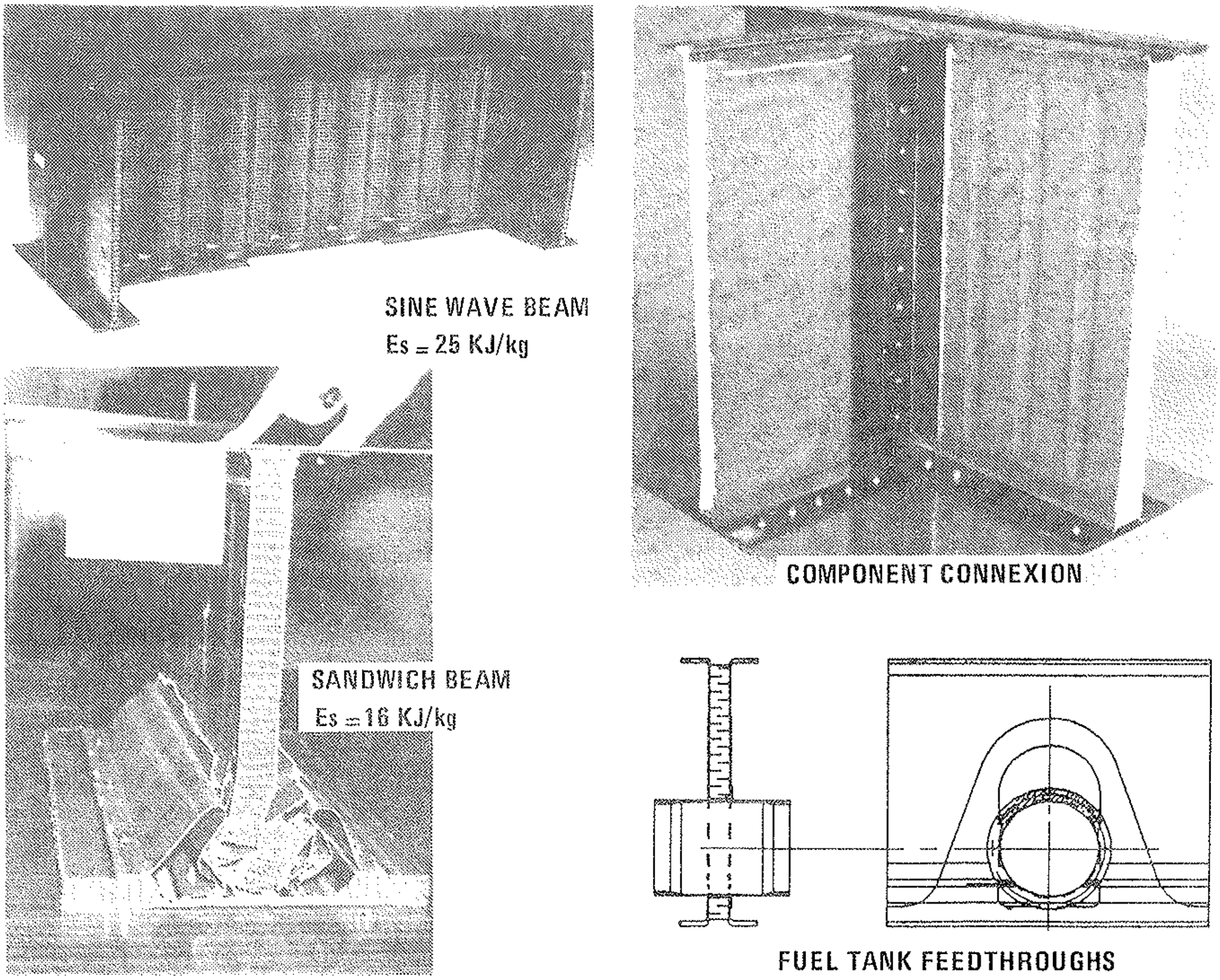



*Figure 6 - Crash Specimen*

### 3.3 Survivability

. Impact Resistance

The effect of composite technology on military impact resistance has been studied by firing perforating 7.62 mm and 12.7 mm caliber shells and 23 mm caliber HEI explosive shells at some typical structural elements. Residual static or fatigue strength was also measured in certain cases.

The following structural elements were tested:

- Dauphin tail boom (23 mm HEI),
- fin/fenestron assembly (7.62 mm) (Figure 7),
- composite main frame for 8-10 T class helicopter (12.7 mm) (Figure 8).

The overall conclusion is that composite technology is virtually equivalent to metal technology in terms of these threats.

. Nuclear, Bacteriological, Chemical (NBC) Threats

Military helicopters must be protected against the effects of tactical NBC weapons which give rise to:

- a 100-200 mbar overpressure,
- a heat flux,
- chemical attack from contaminants, e.g. yperite.

These different effects of the NBC threat on composite technology were investigated mainly experimentally by testing:

- a complete Gazelle type aircraft (Figure 8),
- composite specimens, including residual strength measurements.

The existing results show that composite structures are equivalent to their metal counterparts provided a few "precautions" are taken.

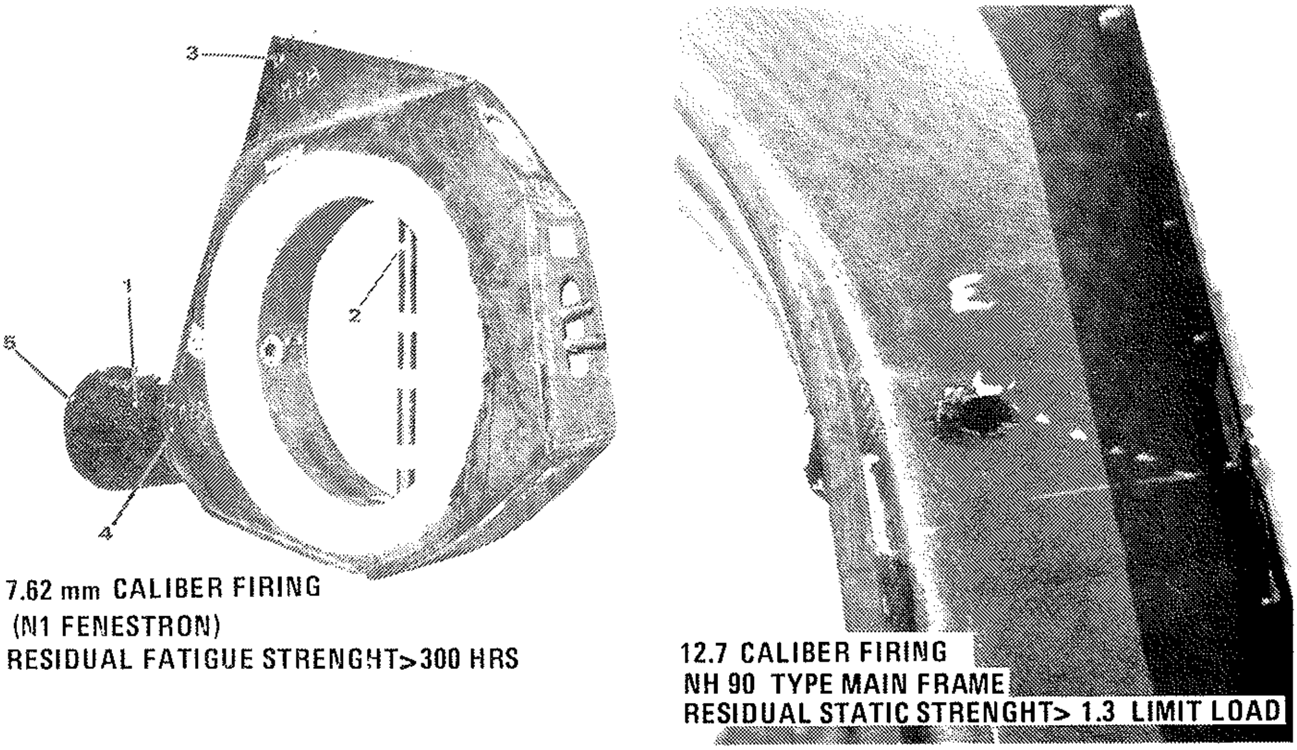



*Figure 7 - Perforating Shell Vulnerability*

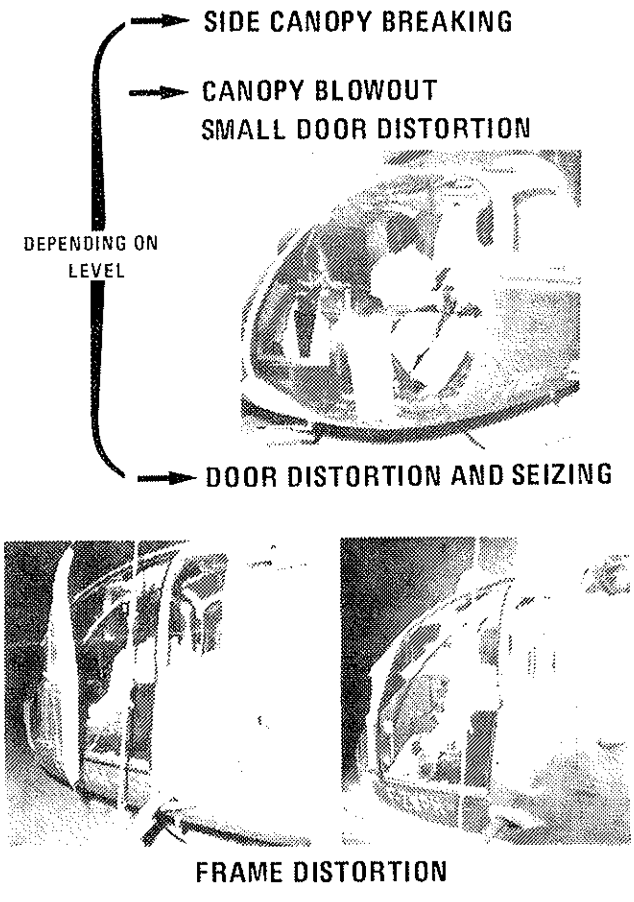



*Figure 8 - NBC Vulnerability*

### 3.4 Stealth

Stealth is primarily characterized by infrared (IR) and radar signatures:

. IR Signature
Regardless of whether metal or composite technology is employed, IR emissions can only be diminished by protecting surfaces.

. Radar Signature
The fuselage shape and materials are the two parameters affecting its radar signature. For a given shape the signature can be reduced by two methods depending on the location on the helicopter:

- application of a special non-structural skin on the fuselage. With metal structures this is the only solution.

- on-site treatment of the basic structure, which is feasible when absorbant composites are utilized.

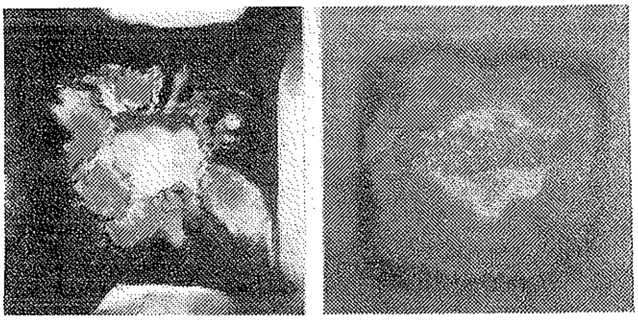
The treatment method is probably the way to go in the future as current research in this field suggests near-term application of these materials.

### 3.5 Fire Resistance

Certain helicopter areas are subject to very stringent fire requirements, i.e. self-extinguishing capability, fire resistance and fire proof. Since thermosetting resins appear less effective than metals in this respect, different research programs have been conducted on:

. resins, in cooperation with the suppliers. The objective was to develop higher performance self-extinguishing resins.

. technological concepts for areas subject to the above requirements. These areas include the cabin sandwich skins and the engine and transmission decks. Composite solutions have better behavior and weight characteristics than metal technology (Figure 9).



ALUMINIUM SANDWICH AFTER 2' | CARBON/KEVLAR SANDWICH AFTER 15'

*Figure 8- Typical Fire Resistant Example (Flame at 1100°C)*

### 3.6 Internal Acoustics

As composites and specific sandwich concept designs were increasingly utilized in structural components (such as the transmission deck), special allowance had to be made starting in 1987 for the specificity of these technologies. Conducted jointly with ONERA (French Aeronautical Research Council), this program focused on elementary and global forecasting respectively for the component parts and helicopter cabin.

The results of this program were as follows:

. compared to ordinary panels, metal sandwich structures have a very low critical frequency and hence a very different attenuation in the problematic frequency range from 500 Hz to 5 KHz.

. good agreement was obtained between the measured and estimated panel behavior when average frequency-dependent laws were introduced in the finite element model for the mechanical properties (E, G, $\eta$).

. the elastic/acoustic response of a composite helicopter section excited between 100Hz and 10KHz was characterized by a dynamic amplification factor of 3 on the sandwich panel close to 2KHz. The amplification was associated with a high acoustic radiation coefficient.

These initial results stressed the importance of continuing these actions in order to integrate the special acoustic features of composite structures in the design phase more effectively; a significant research program was therefore initiated in this field.

### 3.7 Materials

Three factors must be taken into account when selecting composites, i.e.:

- Technical: the design properties varying with time, temperature and environmental conditions.

- Technological: the application characteristics such as draping, drop-out rate, etc.

- Economic the cost of materials, the control of procurement sources, etc.

The contradictory nature of these factors leads to expensive and time-consuming research, usually conducted jointly with the suppliers.

In this paper we will restrict the discussion to the Aerospatiale policy governing the selection of resins, which of course conditions many of the important properties.

The growing presence of composites in primary structures means that allowance must be made for certain specific features such as:

- the need for a self-extinguishing capability, which could profitably be integrated in the resin, in compliance with the expected toxicity legislation.

- the high operating temperatures (from 90 to 120°C according to the area) combined with a conventional wet aging environment, conditions which favor 180°C class resins.

- the widespread use of sandwich structures, requiring the development of self-adhesive resins to avoid costly and heavy films of adhesive.

- the introduction of damage tolerance substantiation regulations together with the difficult trade-off between a high $T_g$, residual compression after impact and wet aging, and resin toughness ($G_{1c}$) (Figure 10).

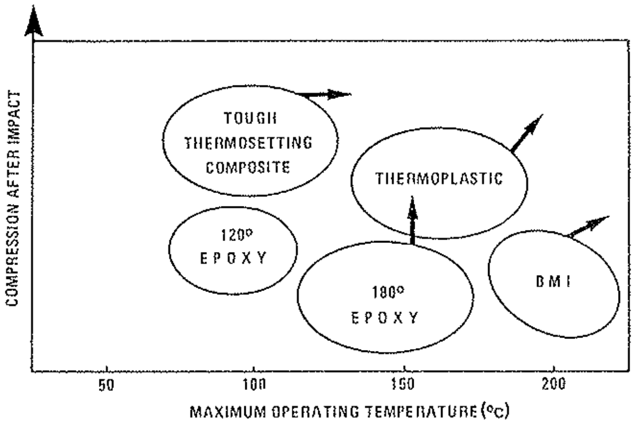



*Figure 10- Thermosetting and Thermoplastic Composite Performances*

In addition, the number of different products must be reduced for economic reasons and, whenever possible, harmonized with the fixed wing aircraft manufacturers' products in order to benefit from the effect of larger quantities on cost.

These considerations have prompted us to give progressive and long-term priority to the following solutions for the primary structure assembly:

. a 180°C class, self-adhesive and self-extinguishing resin with a humid $T_g \geq 90°C$.

. a 180°C class, self-extinguishing resin with a humid $T_g > 135°C$..

Both the above resins feature higher damage tolerance ($G_{1c}$) than existing systems.

The systems currently in use or being evaluated are depicted in Figure 11.

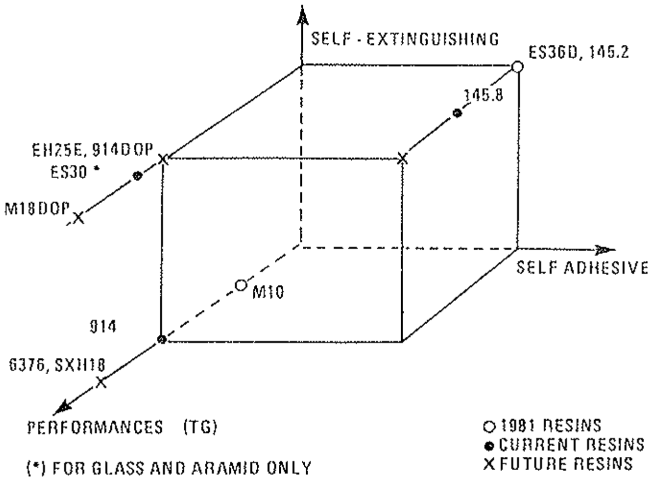



*Figure 11- Resins for Use in Primary Structures*

## 4. TECHNOLOGICAL RESEARCH

This research has been based on experimental full scale structures and on tests with components from existing or future aircraft. Its goal has been to gather realistic technical, economic and industrial data.

This research concentrated on 4-6T and 8-10T class helicopters not only because of their important market potential (Tiger, 332 MKII, NH90) and high commonality but also because of their exchange rate (cost admitted per kilogram saved) more advantageous for introducing composites, particularly on military versions.

### 4.1 Existing Items

#### 4.1.1 Dauphin Tail Boom

The initial work on integrating composites in tail booms started in 1980 with the experimental fabrication of a wound tail boom for the Dauphin C [1].

This item was not industrialized due to the very small weight savings achieved and the resulting extra costs incurred relative to modern metal technology as incorporated on the Dauphin $N_1$ or $G_1$.

The tail boom of the aircraft is fabricated in a three 1/3 metal sandwich/Nomex shell sections bonded together and to the end frames.

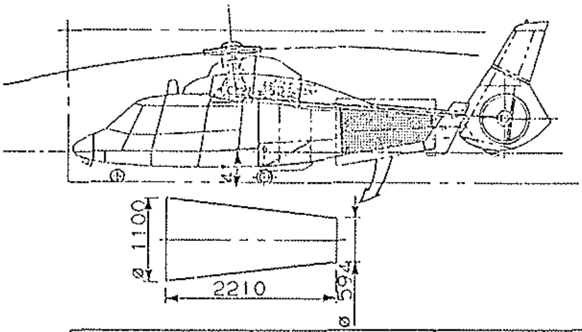
A new program was started in early 1985 in cooperation with our Aerospatiale Research Center. Its purpose was to compare the performance (weight, stiffness, strength) and cost of the following three structures:

. Nomex/aluminium sandwich,
. Nomex/carbon fabric sandwich,
. Nomex/carbon tape sandwich.

Composite solutions are applied with one shot molding operation. This takes place after the various materials (Kevlar fabrics, preformed Nomex, end reinforcements, carbon skins) have been draped on a vacuum mandrel and after an external shroud and inflatable bags have been installed for applying the required differential pressures.

Once the mold is closed, the part is oven-cured according to a precise cycle of temperature, and under- and over-pressures and time.

On this simply shaped part, composite technology only produced direct weight savings of about 10%, but was 20-30% more expensive and reduced the bending/torsional strength by roughly 25% - acceptable in this application (see Figure 12).




| | CURRENT METAL VERSION | FABRIC VERSION | TAPE VERSION |
|---|---|---|---|
| | ADHESIVE, e=0,5 AU4G1, 3,2, e 0,1, NOMEX | GLASS, COPPER MESH, CARBON/145.7, KEVLAR 145.7 | GLASS, COPPER MESH, CARBON/914, ADHESIVE, KEVLAR 145.7 |
| WEIGHT M/MO | 1 | 0,89 | 0,91 |
| COST C/CO | 1 | 1,2 | 1,3 |

*Figure 12- Tail Boom Technology*

### 4.1.2 Dauphin Thermoplastic Fin

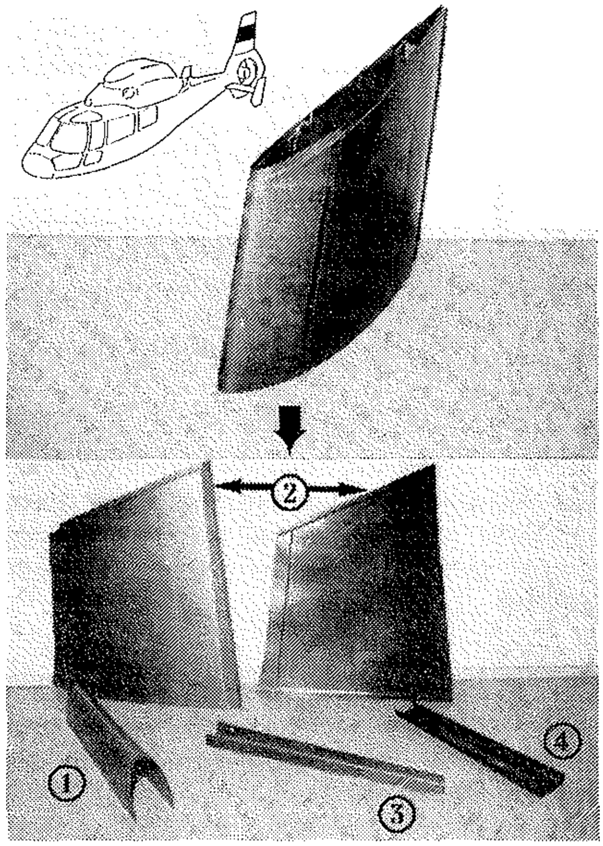
The specific properties of thermoplastic matrix composites can provide a real solution for the relatively poor performance of thermosetting composites with respect to cost, environmental resistance (temperature and relative humidity) and damage tolerance.

During the past few years Aerospatiale has been conducting preparatory research in this field [2], notably with the Dauphin upper fin, in order to:

- characterize the basic materials (APC2, etc.),
- assess the different molding and assembly methods,
- fabricate experimental components for ground testing (static, damage tolerance) and flight testing,
- carry out an economic and technical assessment in comparison with the production version constructed from thermosetting composites.

It should be stressed that this research topic was selected because of the complex nature of the part built from 5 monolithic or sandwich components. In addition the part has an evolved shape with decreasing spanwise thickness and multiple draping.

Figure 13 illustrates the components and their application processes.




(1) MALEMOLD+AUTOCLAVE
(2) VACUUM BAG MOLDING IN OVEN IN TWO OPERATIONS
(3) PRESS MOLDING WITH BLOCK AND DIE BLOCK, AND SILICON INSERT
(4) PREFORMING IN OVEN AND MOLDING IN AUTOCLAVE

*Figure 13- Thermoplastic Fin*

Electric resistance welding with 11 beads was adopted for assembly of the fin components.

The program is now in the ground test phase. An initial economic and technical assessment shows weight savings of 10% but costs are up by 23% compared to the actual production baseline. This is due not only to the high cost of materials and associated products but also to the complexity of the part and to the interfaces present.

Improvements must therefore still be made at suppliers and manufacturers.

We are nevertheless convinced that these objectives can be achieved in a mid-range timeframe and we are currently studying an "optimized" version of this technology.

Thanks to the knowhow already accumulated, we are developing several experimental parts for helicopter structures including:

. thermal protection for the Super Puma,
. an engine deck for the Tiger.

## 4.2 New Parts

### 4.2.1 Ecureuil Fenestron/Fin Assembly

The experimental development of a composite tail fenestron/fin assembly for a 2-3 T class helicopter followed the 4-6 T class Dauphin $N_1$ development. The latter started production in 1981 and at the time was one of the first attempts to integrate composites in primary structures [3], an experience that was to prove successful.

Compared to the Dauphin, the main differences are:

- enhanced rotor aerodynamic optimization,
- simplified fabrication processes (molding and bonding of two half shells integral with the tunnel),
- preferential utilization of Kevlar and glass instead of carbon (Figure 14).

The net effect is to cut costs (fewer parts, lower material and assembly costs, etc.) which are a critical factor for this type of helicopter. Other significant advantages include reliability, safety as well as performance characteristics which are close to those of conventional tail rotors.

With the success of the ground and flight tests in 1987, this concept represented a significant advance over the Dauphin $N_1$ and it can now be applied to the next generation of light helicopters.

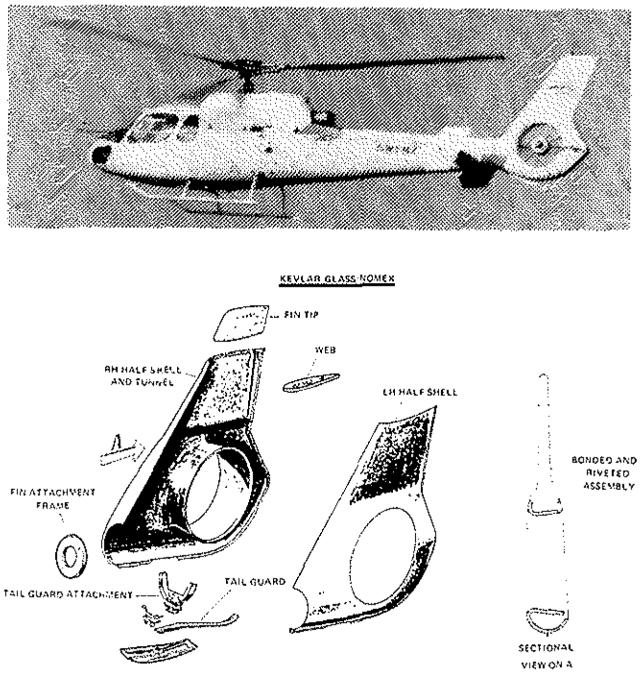



*Figure 14- 350Z Composite Fenestron and Fin*

### 4.2.2 Experimental development of a a Center Fuselage Section

Backed by the Official French Authorities, this development was designed to evaluate composite technologies on the center fuselage of a 8-10T class tactical transport helicopter.

This section integrates a large number of problems relating to concepts, dimensioning, fabrication and quality control.
The program has two phases:

#### 4.2.2.1 Phase 1

In this phase simplified 2.15 x 1.68 x 1.60 m sections (Figure 15) were fabricated and subjected to static, dynamic, lightning, acoustic and other tests in order to:

- gather initial data on this technology and to define the future orientations of the program,
- make structures quickly available for use in longer term research programs on acoustics or electromagnetic effects.

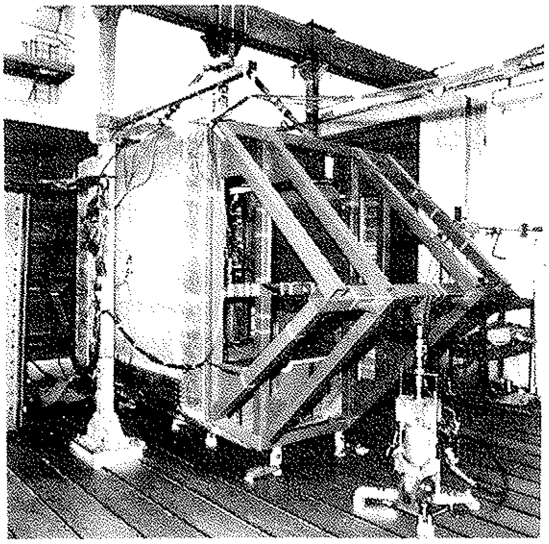


*Figure 15- Section Static Test (area under MGB)*

#### 4.2.2.2 Phase 2

Realistic data on the applicability of composites in fuselages can only be obtained through the development of a representative assembly, based on the general aircraft specifications and compared with an identified baseline metal technology.

A center fuselage section of an NH90 type helicopter was therefore developed using the specifications defined in the preliminary phase of the NH90 program. The Super Puma was employed as the baseline technology , i.e. skin stiffened with stringers, two-part machined main frames, etc.

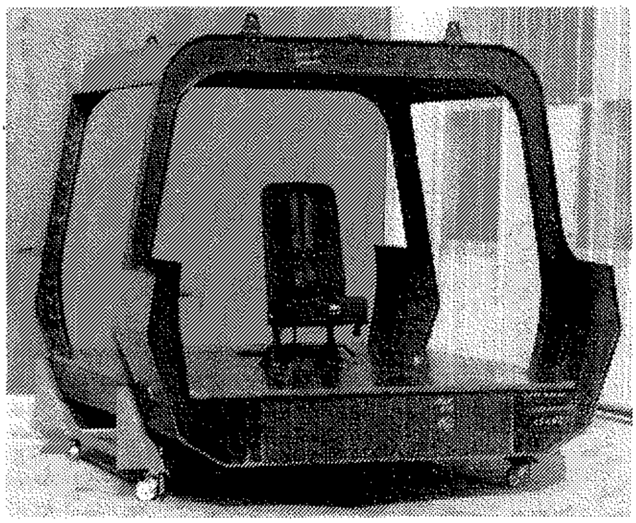


*Figure 16- Cabin Section*

This section is 3 x 2.50 x 2 m in size and weighs 145 kg. It is composed of the following main components:

- main frames with attachments for the gearbox and main landing gear,
- simplified transmission decks and conventional cabin floor,
- crashworthy understructure with fuel tanks (570 kg),
- lower sandwich skins.

These items have been fabricated and are being assembled. The elementary tests on specimens (materials, crashworthiness, lightning, etc.) and the static tests on both frames subjected or not to 12.7 mm caliber firing have all been completed.

Crash tests are scheduled in the next phase on an individual frame and then on a complete section at $V_Z$ = 8.5 m/s.

The ensuing discussion will be restricted to the following aspects:

- general design and materials,
- stress analysis,
- quality assurance,
- provisional weight/cost evaluation.

a) General Design and Materials

This type of aircraft was designed with a modular shell type structure consisting of main frames in load pickup areas (MGB, landing gear) supported by a series of longitudinal beams covered with large sandwich panels.

Although this architecture closely resembles a metal fuselage structure whose components (frames, skins, beams, etc.) are all included, it integrates the functions more effectively and has significantly fewer parts and attachments.

The lower skin (Figure 17) is built up from asymmetric sandwich [4] with Nomex core, external carbon skin (0.7 mm) and internal Kevlar skin (0.5 mm)

This large 3m x 2m panel is fabricated on an Invar die and then polymerized in vacuum bag and in an autoclave.

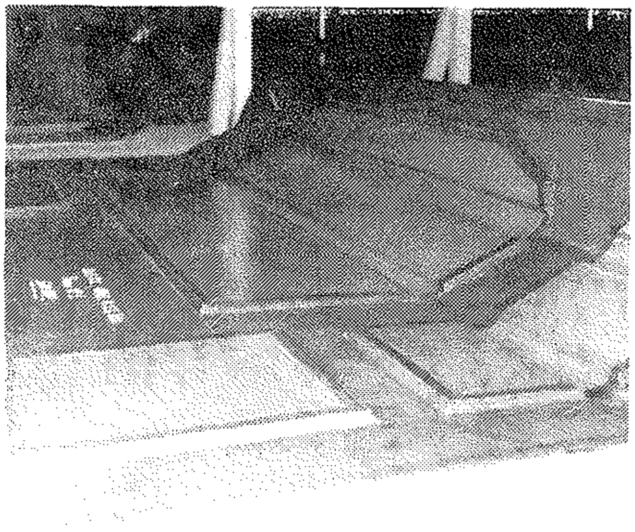


*Figure 17- Sandwich Skin (Carbon/Nomex/Kevlar)*

The main frames (Figure 18) are molded in a single operation in an Invar fixture and consist of:

- a monolithic part made up from fabrics and carbon tapes,
- a sandwich part with a Nomex core and Kevlar/carbon fabric skins providing crash resistance.

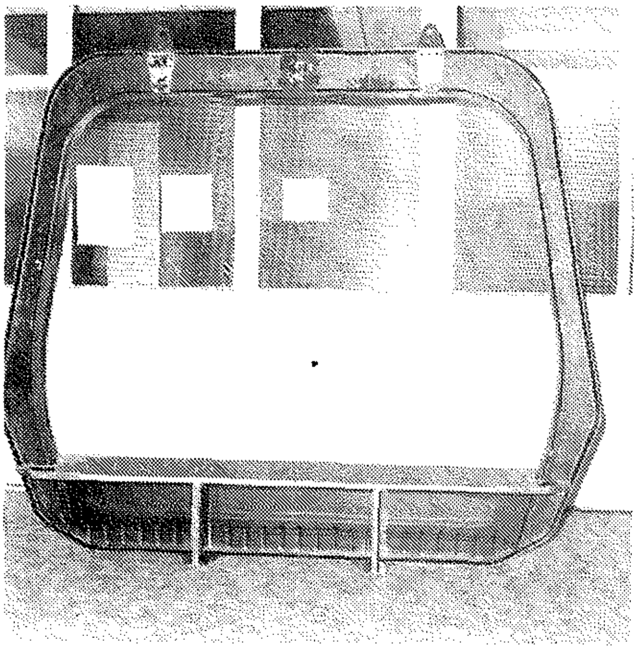


*Figure 18- Monobloc Main frame*

The crashworthy subfloor (Figure 19) is composed of beams and sandwich bulkheads (Nomex, Kevlar and carbon) technologically similar to the frame bottoms and designed for the tank pressures and crash absorption.

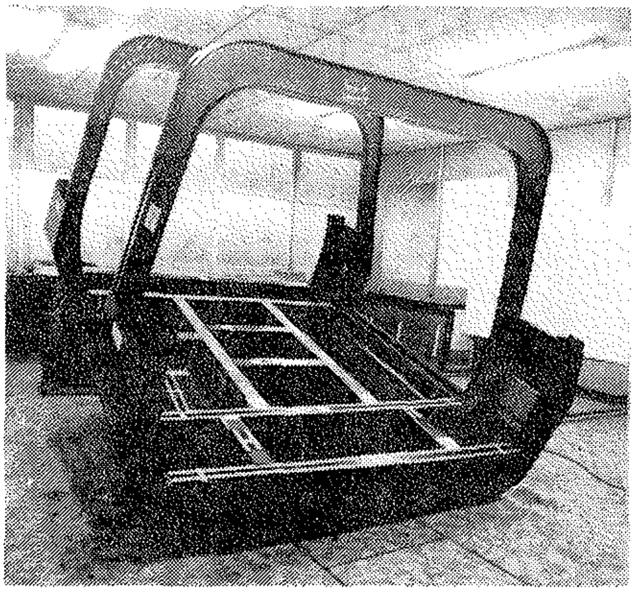


*Figure 19- Crashworthy Subfloor*

The various components are riveted together (average pitch 80 mm) and bonded at 110°C on a special fixture. The rivets position and squeeze the prebonded items together.

As described above the two 180°C class impregnation resins are:

- a self-adhesive and self-extinguishing resin for areas at temperatures less than 90°C,
- a second resin for hotter areas.

b) Stress Analysis

Composite structures require considerably more computing time than metal structures; they are mainly analyzed with finite element models, the only method capable of representing their complex stress distributions.

The approach was to first use a general finite element model to identify the critical areas as a function of the loads and then to use detailed submodels to analyze these areas in greater depth.

A few examples are given below:

- <u>General Finite Element Model</u> (Figure 20)
  - SAMCEF code
  - preprocessing and postprocessing by SUPERTAB and CAEDS
  - model characteristics:
    - 3175 composite shell type elements
    - 137 beam type elements

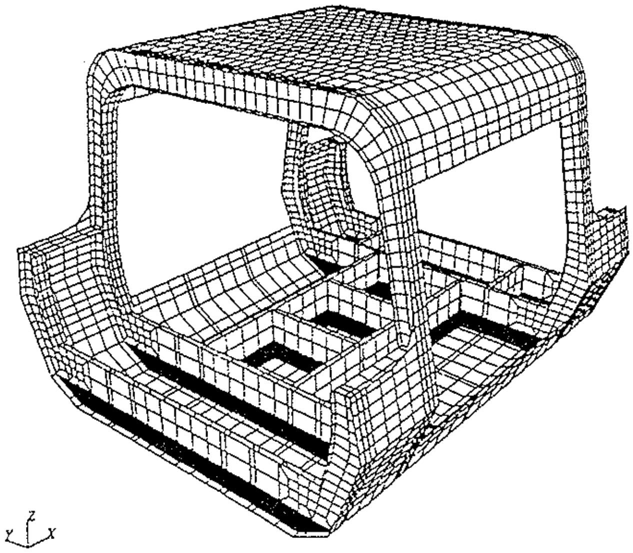


*Figure 20- Finite Element Model*

- <u>Specific Models for Main Frame Stressing</u>

  Three areas on main frames require special analysis:

  - the structural elbow (Figure 21) the stability of which was analyzed in detail in crash conditions,

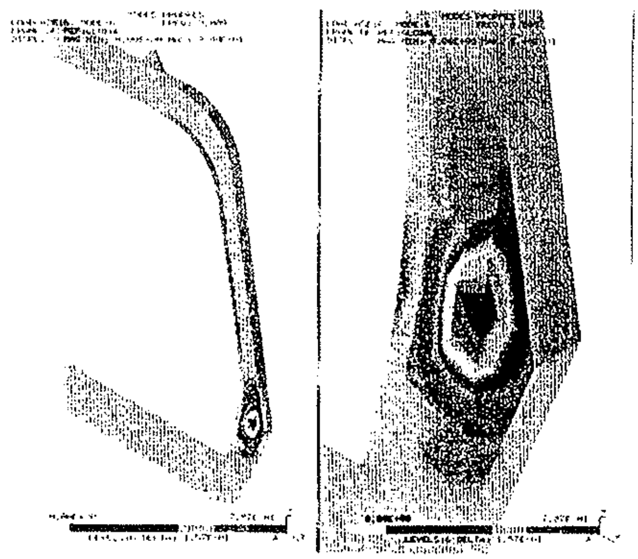


*Figure 21- Main frame-local stability studies*

<u>Model Characteristics</u>:

- 1251 shell type elements
- 4099 nodes.

- the upper part of the frame because of the dominating transverse stresses, difficult for composites (Figure 22).

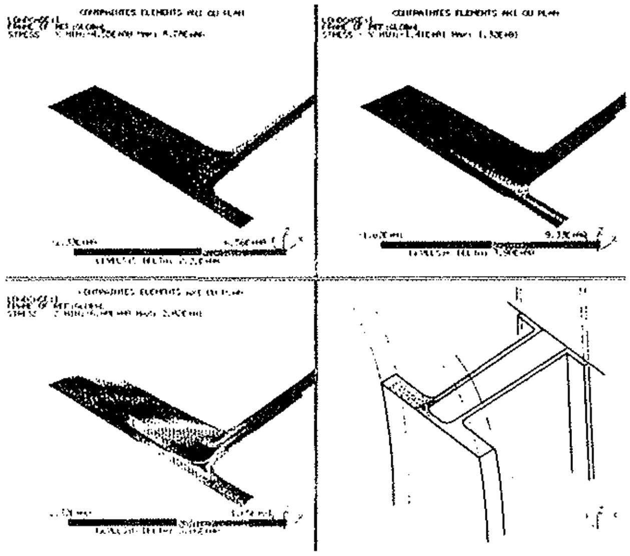


*Figure 22- Main frame - Top section : stress distribution (3D)*

<u>Model Characteristics</u>

- 257 volume elements
- 301 nodes

- the bottom sandwich part of the frame (Figure 23) to identify the stress pattern as a function of the damage occurring in the zone during a crash (7 computing increments).

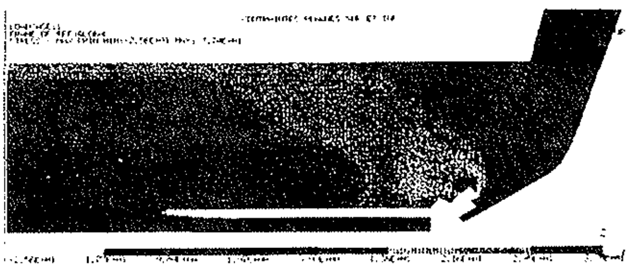


*Figure 23- Frame bottoms - Rupture mechanisms*

c) <u>Quality Assurance</u>

Quality assurance was given priority as it directly influences the reliability of composite parts insofar as their strength is very dependent on the materials used and on their implementation.