

When looking at aeronautical structures manufactured from carbon fibers, the observer can be misled by the choice of products which has been made :

- Fiber types : high strength, high modulus, very high modulus, twisted or not, coated with finish or not, varying number of filaments which may range from some hundred to several thousands.
- Presentation types : unidirectional tapes, prelaid-up crossed tapes, balanced woven fabrics or with preferred orientation, hybrid fabrics.
- Weight per unit area and thickness of cured ply (0.05 to 0.4 mm).
- Impregnation resins : chemical composition, curing cycle, operating temperature self adhesive on honeycomb.

Before 1974, there were only available on the market tows of 10.000 filaments and such a situation induced the industrial manufacturers to orientate themselves towards tapes. Subsequently, the commercialization of finer tows (incorporating 1000 and 3000 filaments) entailed new possibilities : very thin tapes and, above all, new woven fabrics.

At the same time, weight gain which was initially the major objective of composite material use, proved no more sufficient and the improvement of specific performance and the manufacturing cost decrease compared with metallic materials were much sought after.

At the present time, a wide range of products is available to designer's choice. However, two different trends seem to compete: is it more adequate to select tapes or to privilege woven fabrics ?

A survey of the existing products, of their respective performance and capabilities, practical applications and costs will help to evaluate them globally and to present some applications made in France in the field of carbon composite materials.

Presentation of the various products

It is well known that the carbon basic fibers called filaments are assembled into tows of 1000, 3000, 6000, 10.000, 12.000 filaments or even more designated more simply by the symbols 1K - 3K -6K - 10K - 12 K.

These tows are subsequently:

- placed side by side into tapes,
- or woven into fabrics.

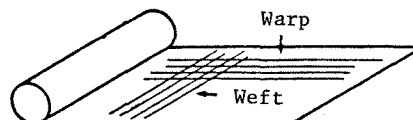
Tapes

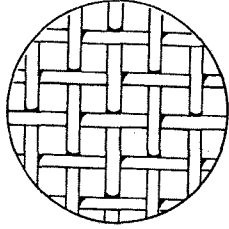
By definition all these filaments are basically arranged so as to be parallel and to form very wide tapes or tapes with varying widths (25,50,75,150,300 mm). The production of intermediate widths or higher dimensions does not entail any particular technical problems. However tapes 300 mm wide tend to be very widely used.

As for as the third basic parameter is concerned, that is to say, the product thickness, it may range from 0.050mm to 0.250mm (which is the cured ply thickness); but it is preferred sometimes to quote the fiber volume per unit area or the prepreg quantity per unit area or even the grade. Standardization is not completed yet in this field and it is most unfortunate as such a situation is complicating the task of the manufacturers, procurement and production departments. Nevertheless for the major part of the manufactured products a cured ply thickness of approximately 0.125mm is used which corresponds to carbon weights of 140 to 150 g/m².

Woven Fabrics

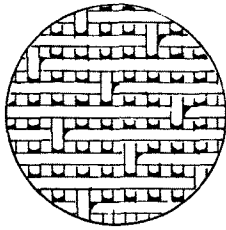
Fabrics are formed by the warp (longitudinal unwinding direction) and weft (transverse direction). The way the warp and weft yarns are interlacing is called "weave" and produces different fabric patterns.





Plain weave

It is the simplest and most commonly used - Warp and weft yarns interlace alternately. It has the best flatness and stability capabilities but it lacks flexibility.



Satin weave

With patterns of this type, a warp yarn runs over several weft yarns. In a 8H satin one warp yarn runs over 7 weft yarns. It is the most flexible weave. This type of construction allows to limit interlacing points and yarn distortion at these points - 4H, 5H and 8H satins are preferably used.

As far as dimensions are concerned, woven fabrics are available (as tapes) in long rolls, the width of which is on request but maximum dimensions exceeding 1 meter can be obtained (1.20, 1.30 m. are standard dimensions in France).

If the woven fabrics incorporate as much yarns in the warp direction as in the weft direction, it should be noted that weaving techniques allow to manufacture, so as to optimize structure design, woven fabrics with preferred fiber orientation (for exemple : 90% yarns in the warp direction and 10% in the weft direction) or with a mixture of different fibers (carbon, Kevlar, glass fiber, metallic threads).

It is possible to obtain in some cases very low thicknesses (0.100mm) for extremely light weight woven fabrics in place of two tapes 0.050mm thick which are very delicate to handle. At the opposite side of the range, it is true to say that thick woven fabrics will exhibit wavy surfaces the ampler the waves the bigger the tows; such a situation leads to use 1K, 3K and sometimes 6K fabrics and very seldom higher weave patterns.

Comparison of the mechanical properties of woven fabrics and tapes

The following table makes possible a comparative survey for a same quantity of fibers in volume and same orientation, of the results obtained with test pieces made of woven fabrics (5H satin) and tapes constructed with the same carbon fiber (T 300-3K) and impregnation resin (Narmco 5208).

Two properties are little or not influenced by the nature of the basic product : the interlaminar shear and tensile modulus (except a slight decrease in the fabric weft direction).

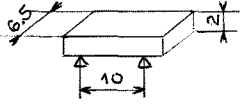
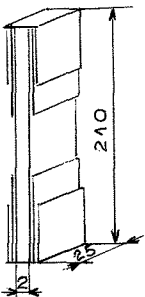
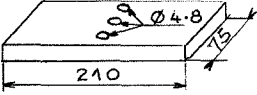
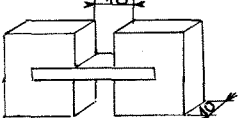
On the contrary, the ultimate tensile loading (normal or notched test pieces) or compression loading entail a decrease in the woven fabric performance of 25 to 30% if compared to the same characteristics of tapes.

However these figures are average values and of course can be modified if the nature of the fibers and of the resins is modified.

However, from experience gained, it seems that woven fabric performance always are lower than tape performance; and this the more difficult the optimization of structures with woven fabric : lay-up of an equivalent material to two 0°-90° crossed tapes per ply of balanced fabric, reluctance to diversify woven fabrics with preferred orientation.

Comparison of the mechanical properties of a 3K T 300 5 H Satin, 5208 impregnated with 3 K T 300 5208 impregnated tapes with same fiber volume

Dry woven fabric 285g/m² - Dry tape 143 g/m²

	3K - T 300 5208 impregnated 5H satin 60% fiber volume	3K T 300 5208 impregnated tape 60% fiber volume	Fabric/tape comparison
Interlaminar shear 	71 MPa	72 MPa	0 %
Tensile test 	Warp direction σ : 560 MPa E : 66 000 MPa	σ : 690 MPa E : 65000 MPa	Warp direction σ : - 18% E : 0%
	Weft direction σ : 470 MPa E : 60 000 MPa		Weft direction σ :- 32% E :- 10%
	σ : 380 MPa	σ : 500 MPa	- 24%
Tensile strength (Notched) 	275 MPa	350 MPa	- 22%
Compression strength 	- 330 MPa	- 460 MPa	- 28%

Specific Technical problems

Ply width

The rectitude of the prepreg tape selvages makes possible an adequate juxtaposition of the latter during the laying up operations (gaps from 1 to 2 mm are admitted) thus permitting to obtain unlimited ply widths. However the situation is quite different with woven fabrics with limited width which sometimes require to maintain load path continuity sliced joints (partial superposition of plies in cut areas) entailing weight increase, local overthicknesses and lay-up complexities.

Lay-up

The ability of woven fabrics to be laid up into complex shapes is one of their major characteristics because tows

can intercross freely without random dispersion and without requiring several complex cuts off which would be necessary with tapes.

A high weave value is recommended for very complex components (8H satin 5H satin 4H satin plain weave).

Automated Lay-Up

The automated techniques contemplated for composite materials may differ depending upon the basic product. If the intend is to lay-up tapes directly (narrow tapes) the use of woven fabrics normally implies a previous cutting of plies - a technics which is likewise applied to tapes -

The choise between woven fabrics and tapes can consequently lead to a different industrialization of certain manufacturing processes.

Machining

Apparently, laminates made from woven fabrics are less sensitive than laminates made from tapes :

- . to scaling of the external plies during drilling operations,
- . to delamination during routing.

However provided certain precautions are taken, it is possible to machine both types of laminates without problems.

Surface condition

If the use of tapes does not generate any particular clearly visible surface defects, the same comment does not always apply to woven fabrics which sometimes exhibit unacceptable surface porosity.

Specific processes (toap-coat application, additional protection) are consequently necessary but they are cost consuming and they increase weight.

Economic comparison

Weight saving

The best asset of tapes when compared to woven fabric normally involves the use of a lower quantity of carbon fiber and hence entails a sensible cost saving not only at production level but above all at operation level.

Cost Price

Because of the great number of parameters involved in cost pricing, it proves difficult to produce a comparative survey of these two materials.

However the following list lays the emphasis on some of these major parameters :

- Type of fiber
- Filament number
- Resin system
- Impregnation Ratio
- Impregnation system.

To these technical requirements we must add the commercial data which have an effect on the proposed prices :

- Quantity ordered
- Competitiveness
- Commercial aggressiveness
- ...

And in France thanks to the expertise of weavers such as BROCHIER and GENIN it is possible to obtain practically the same cost prices per kilo for both fabrics and tapes.

Cut trim percentage

As tapes are not very wide and can be arranged side by side as previously said without particular precautions a relatively moderate trim percentage (from 10 to 15%) is prevailing.

Fabric cut trims are directly related to the respective dimensions of the component and of the fabric, to the use or not of optimized cuts-off. Most of the time they are twice the amount recorder for tapes.

Exemples of practical applications

The economic survey on the respective applications of tapes and woven fabrics depends essentially of the type and complexity of the component to be manufactured; each of these materials in effect has privileged fields of application : for instance, for very complicated components woven fabrics allow to save time during the lay-up operations.

Figure 1 shows a wing tip of the Transall aircraft which had been selected for an evaluation and comparative survey of tapes and woven fabrics : in this case eleven T 300, Narmco 5208 impregnated tape plies were necessary (8 in the transverse direction and 3 in the longitudinal direction). Because of the great complexity of the component, it was necessary to cut up 529 different prepreg pieces.

But by using five plies of woven fabric, lay-up was divided by 15.

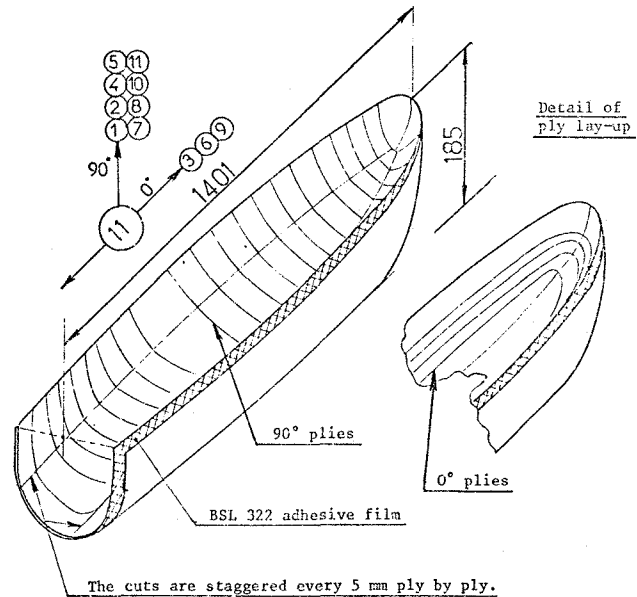


FIGURE 1 - TRANSALL OUTER WING TIP

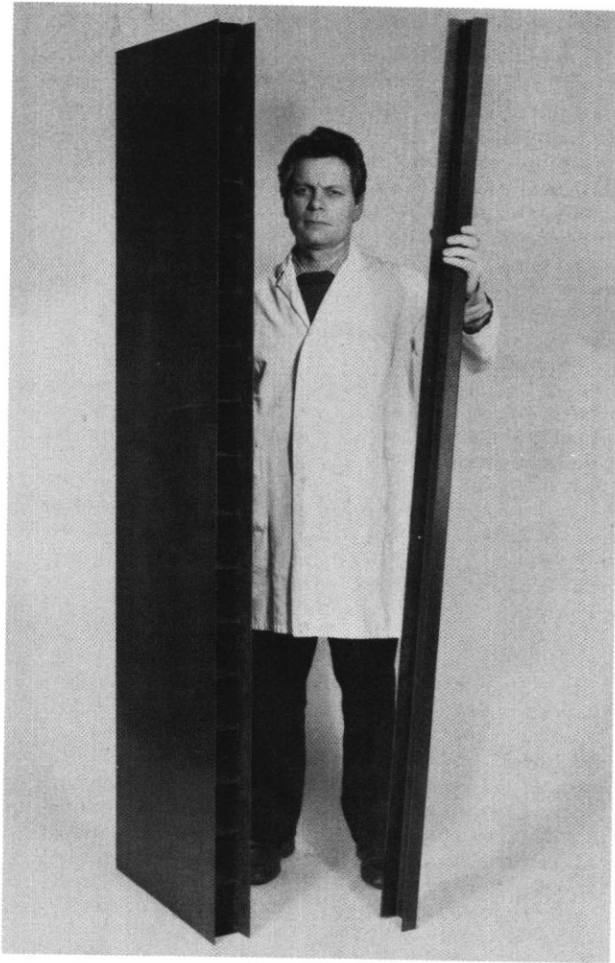


FIGURE 2 - AIRBUS LIFT DUMPER

Figure 2 shows a moving component of AIRBUS 300 wing (lift dumper).

For this component which was manufactured in one stage operation on a thermo expandable tool and which has a relatively simple shape, the application of woven fabric was not justified.

If the time saving is 5 to 10%, with the woven fabrics, more than 10% is lost on weight and the cut trims are more important.

As a whole, Figure 3, shows the various applications of carbon fibers to the Airbus A 310 Aircraft.

CARBON FIBER APPLICATIONS TO A.310 AND A.300/600 AIRCRAFT

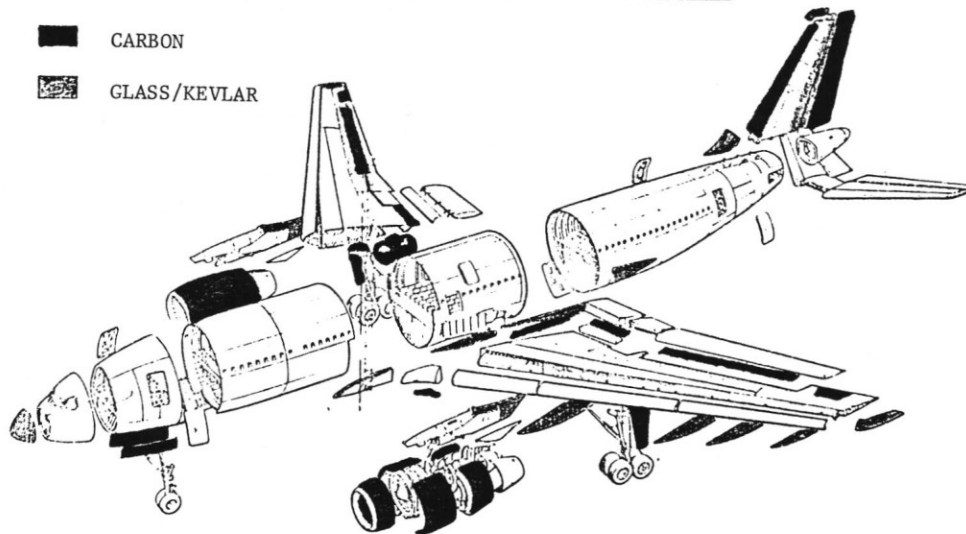


FIGURE 3 - CARBON FIBER APPLICATIONS TO A 310 AND A 300/600 AIRCRAFT

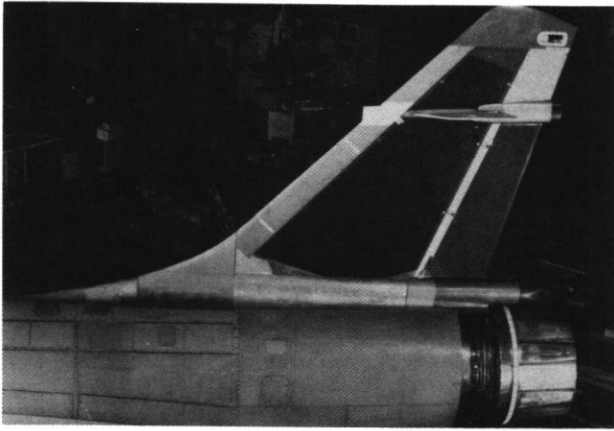


FIGURE 4 - MIRAGE 2000 FIN

For the MIRAGE 2000 fin, a component manufactured for DASSAULT by AEROSPATIALE the woven fabrics do not allow to optimize the performance/weight/cost parameters.

Tapes were consequently retained to manufacture the two skins which have been subsequently bonded to a nomex honeycomb core. (Figure 4)

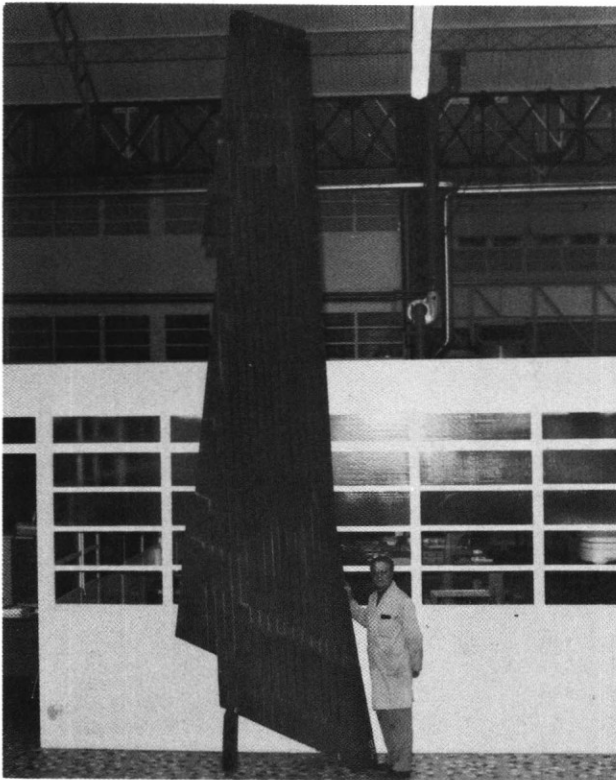


FIGURE 5 - FALCON 10 - SELF-STIFFENED CARBON WING SKIN

For the FALCON 10 carbon wing, AEROSPATIALE produced in cooperation with DASSAULT the tapes allow to optimize the cured self stiffened skin in one stage operation whereas woven fabrics are much more adapted to the production of ribs with complex profiles. (Figure 5)

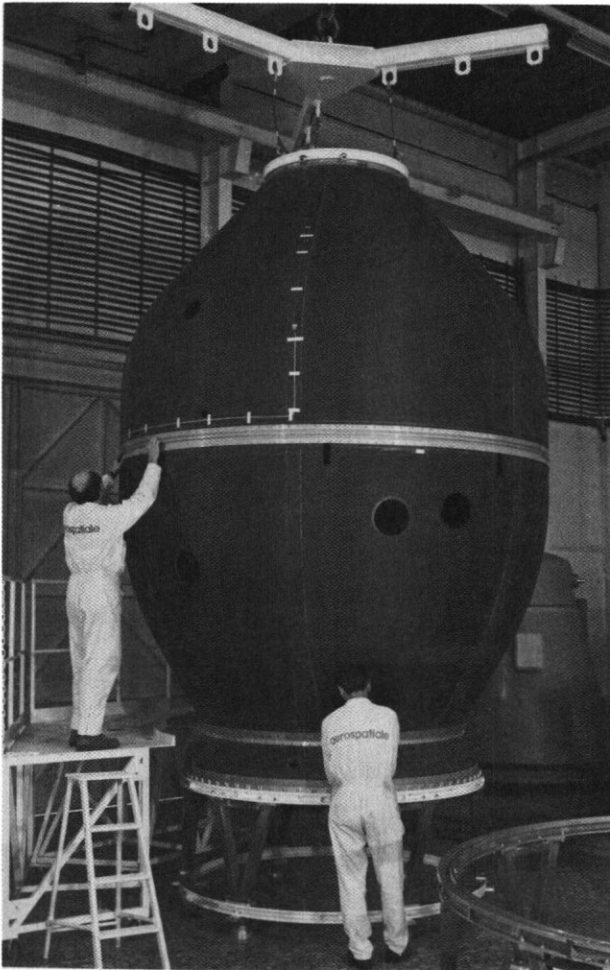


FIGURE 6 - SYLDA SYSTEM FOR SIMULTANEOUS LAUNCHING OF TWO SATELLITES BY ARIANE LAUNCHER

In space applications, the basic objective is a maximum weight saving. Thus, for the SYLDA system intended for a simultaneous launching of two satellites with the european launcher ARIANE, the skins 0.4 mm thick are made up of only four isotropic plies (woven fabrics would have increase the weight of the component 3.9 m high and 2.8 m diameter). (Figure 6)

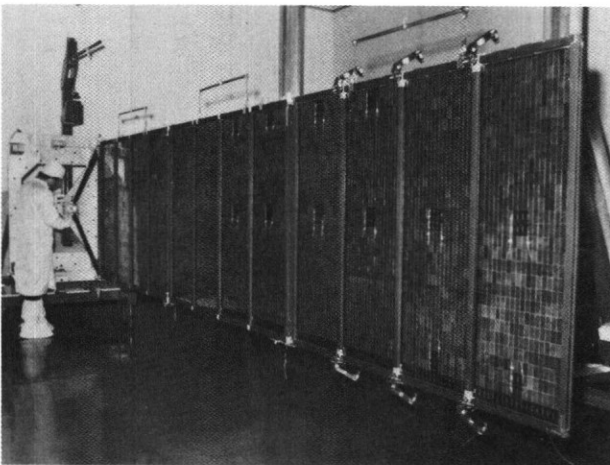


FIGURE 7 - SOLAR PANELS FOR SATELLITES

On the contrary, to facilitate the lay up and to decrease costs, woven fabrics equivalent to 2 tapes 0.050 mm thick were selected to sustain the photovoltaic cells of solar panels (Figure 7)

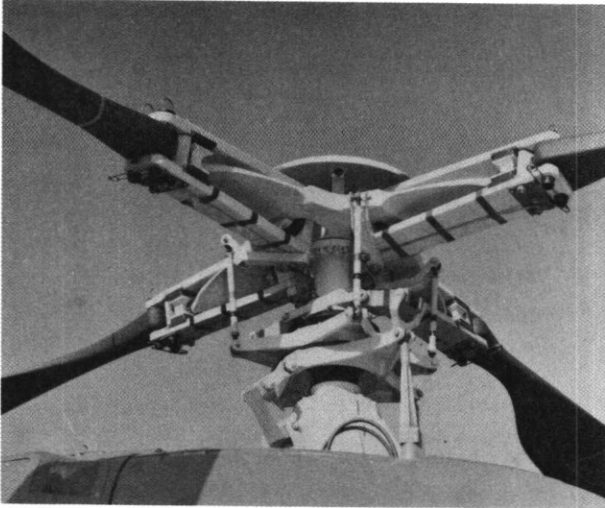


FIGURE 8 - HELICOPTER BLADES

For the carbon fiber blades developed since 1967 on the various helicopters produced by AEROSPATIALE, tapes maintained or not in the transverse direction by synthetic threads are used with great success. (Figure 8)

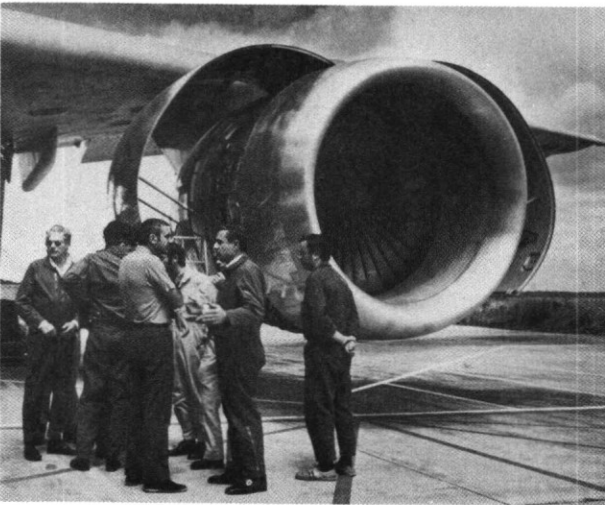


FIGURE 9 - ACOUSTICAL LININGS FOR ENGINE NACELLE

The production of acoustic linings for engines requires the achievement of an evenly perforated panel subsequently bonded on to a cellular material. At the present time, this lining is made by drilling, stamping and swaging :

- Light alloy sheets (a solution used all over the world).
- Composite materials : fabrics punched over the protruding nails of a tool during the lay-up operations. (Figure 9)

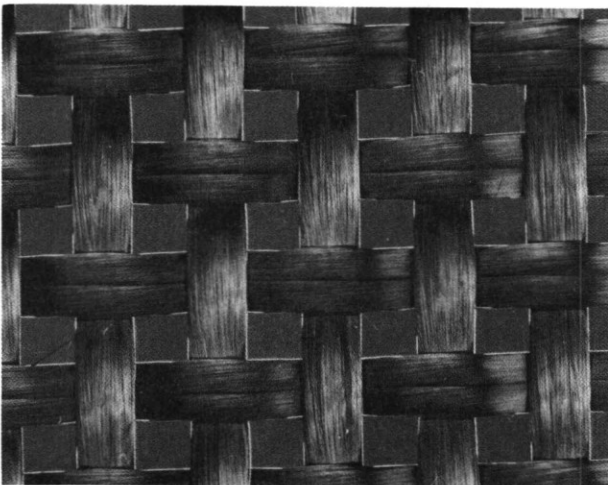


FIGURE 10 - CARBON LARGE MESH FABRIC REINFORCED WITH BRONZE THREADS FOR ACOUSTICAL LINING PANELS

The wide range of technical solutions offered by the weavers encouraged us to develop in cooperation with BROCHIER Company a large mesh carbon fiber fabric reinforced with bronze threads able to replace advantageously the inner linings of engines. (Figure 10)

Conclusions

In spite of the complexity of the parameters which have an effect on material cost prices, it seems that in France the prices of tapes and woven fabrics under the form of a prepreg are very close. This is the reason why we must try to find elsewhere the motives justifying the selection of either one or the other product for aeronautical structures.

In the field of performances, tapes are without any doubt superior to woven fabrics and consequently they will be selected in those cases where a weight optimization is sought.

However, it is undeniable that for some applications generating very complex shapes, woven fabrics will be retained in place of tapes which have no cohesion in the transverse direction.

Specific applications likewise enhanced woven fabric capabilities : very light fabrics competing with success with two crosses tapes which are difficult to handle; large mesh fabrics for acoustical linings.

It only remains for me to add that the current position of the various aircraft manufacturers is liable to change in line with the future improvements which can be achieved in the fields of fibers and resin system properties as well as with the automation of the lay up technics.