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# AUTOMATED FABRICATION OF COMPOSITE STRUCTURES FOR HELICOPTERS

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# AUTOMATED FABRICATION OF COMPOSITE STRUCTURES FOR HELICOPTERS

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## ABSTRACT

The purpose of this paper is to review the achievements of the AEROSPATIALE Helicopter Division in the field of automated fabrication of structures made of composite materials and to point out in this field the ways which seem the most promising for the future.

On helicopters, the imperative necessity to obtain a minimum empty weight for a given gross weight has brought forth the development of challenging solutions among which the application of composite materials has been and still will be determinant.

The commercial success obtained with these aircraft in the military demand and on the civil market is as much associated with the appreciable diminution of production and operation costs, as it is in the improvement of their reliability.

This emphasizes the importance of the contribution brought to the research for improving the manufacturing processes so as to reach these objectives and in particular to a well-studied adaptation of the automation which should be part of a global study of the production tool, the production rate being taken into account firstly to select the industrial options.

Having investigated the processes used in the automated fabrication of composite structure for helicopters, and considering the present production rates and the investments involved to fully automate the manufacturing processes, it is brought out that only some sequences of the production line are automated presently.

However, the constant improvement of technologies, the development of appropriate concepts, the search for constant quality of fabrication as well as the bringing in of new materials are all factors which should promote the rational development of automated production.

N.B. : A few minutes movie will illustrate the production processes presently used at AEROSPATIALE.

## INTRODUCTION

The development of automation of composite material production processes must be analyzed with regard to criteria depending on :

- the type of materials to be used, and the associated technology,
- the complexity of components to be manufactured and the suitability of their design for automation,
- the degree of sophistication of assistance systems likely to be applied at the various phases of production,
- the ability to amortize the investment required for industrialization, i.e. the production rates.

The final analysis, therefore, the suitability for mechanization and the extent to which it is applied to the various phases of production, from storage of semi-products to final inspection, are determined to a large extent by the solutions adopted with respect to profitability on the basis of the factors listed above.

However, the quality requirements may make automation essential for certain critical phases, irrespective of cost, (although the notions of profitability and quality assurance are generally not totally incompatible).

Taking into consideration these general observations, the paper describes the automated processes implemented at the present time for the production * of composite materials in the Helicopter Division of Aerospatiale and indicates the possible trends for the future.

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* Although the inspection procedures are closely linked to the production line, this exposé will be limited to production methods.

## 1 – CURRENT AUTOMATION IN THE HELICOPTER DIVISION

### 1.1 – BACKGROUND

Chronologically, glass/epoxy composites were the first to appear in **the sixties,** in secondary structures such as cowlings (Fig. 1), fairings and interior trimmings, bringing an appreciable cost-saving as compared with equivalent metallic structures (moderate cost of glass fibre, spectacular production time-saving). The common feature of these structures is that they are made up of thin layers with added reinforcements, or sandwich-type assemblies with a filler material. The glass reinforcements are generally bi-directional balanced plies.

Then, **around 1965**, the first stressed components using glass/epoxy composites, such as blades, appeared. The composites brought about a decisive improvement in fatigue strength and safety (Fig. 2).

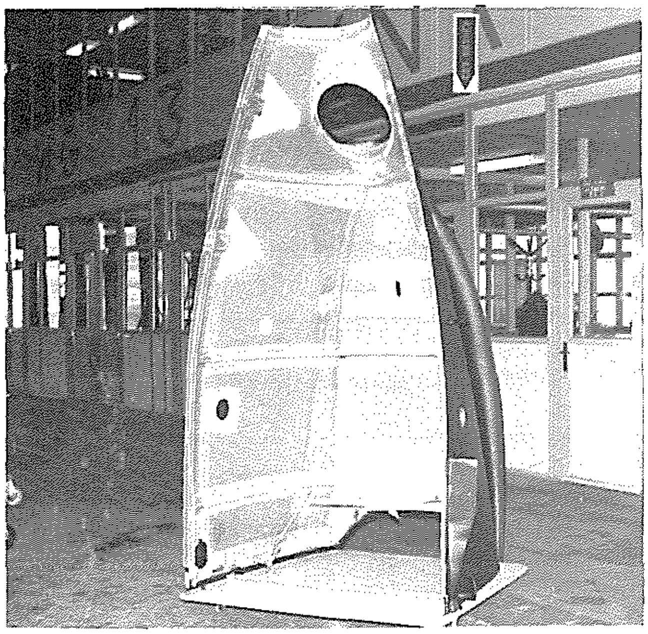


*Fig. 1 PUMA SLIDING COWLING*

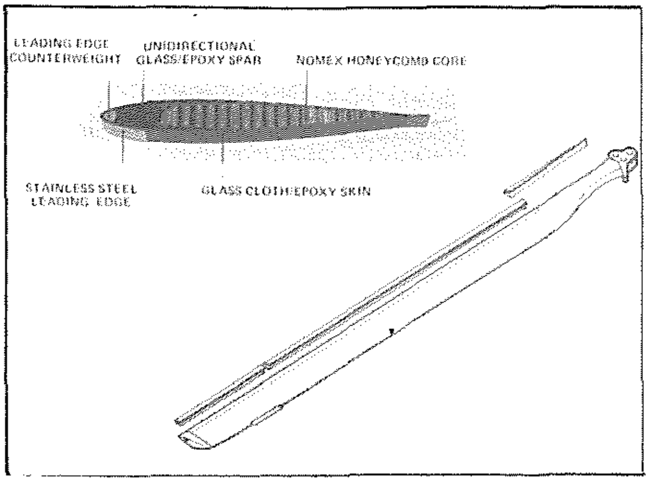


*Fig. 2 GAZELLE MAIN ROTOR BLADE*

**From the seventies,** skin panels with carbon fibre reinforcements began to be used, at first on the DAUPHIN I main rotor blades, later on the PUMA main rotor blades, for which a considerable torsion stiffness was required.

All these structure types called upon manual production techniques (Fig. 3).

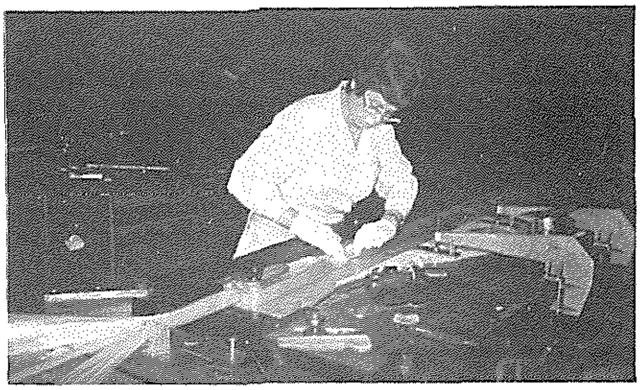


*Fig. 3 MANUAL ROTOR BLADE MANUFACTURE*

**Since 1975,** the field of application of composites has grown considerably for all manufacturers, with the essential aims of cost and weight saving as well as improving reliability, not only for primary but also for secondary components, with the introduction of Kevlar, towards 1980, completing the range of fibres employed in helicopter construction. Let us mention the introduction as from 1977 of the glass-fibre STARFLEX rotor hub (Fig. 4) and more recently, the manufacture of stressed components such as the DAUPHIN 366G1 tail fin, to which we shall later refer, as well as mechanical components (graphite pitch horn, and Kevlar/graphite «Fenestron» tail rotor blade on the DAUPHIN, Fig. 5 to 7).

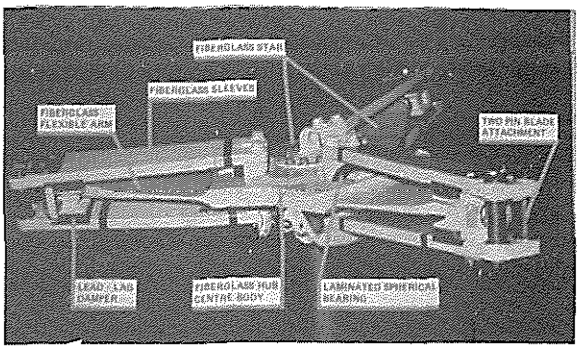


*Fig. 4 STARFLEX COMPOSITE MAIN HUB*

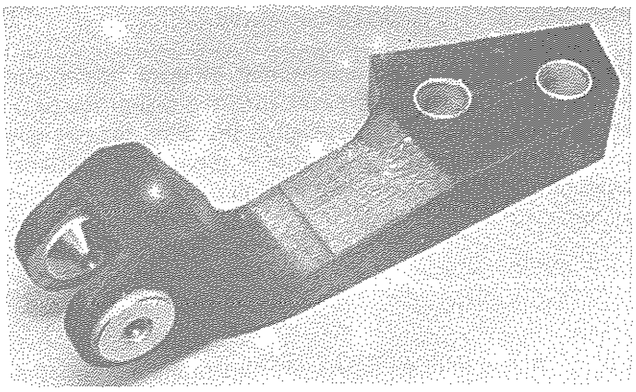


*Fig. 5 STARFLEX GRAPHITE PITCH HORN*

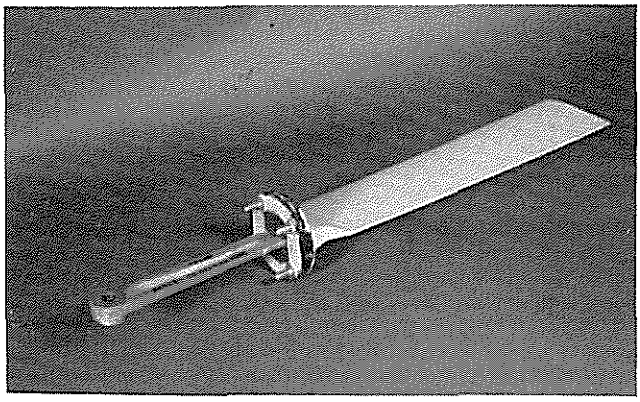


*Fig. 6 «FENESTRON» ROTOR BLADE*

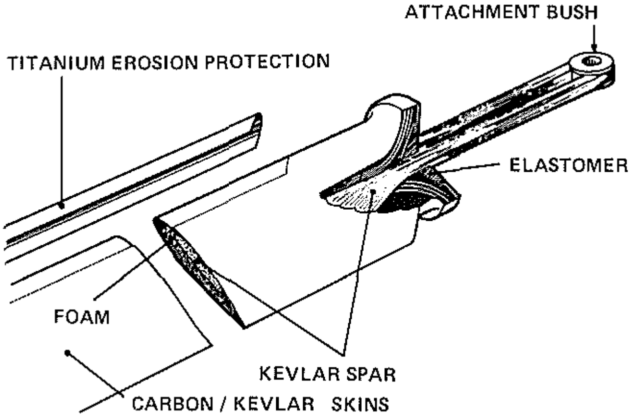


*Fig. 7 «FENESTRON» ROTOR BLADE (DIAGRAM)*

During these last development phases of composites automation of certain production line stages appeared. But before going into the present situation regarding automation in the production of composites in general, it is interesting to describe the part played by composites in the helicopter construction and to examine the relative cost and weight savings, as compared to equivalent metallic components, which they have brought about, for example on the latest aircraft, the SA 366 G1 DAUPHIN whose exploded view is shown in Fig. 8.

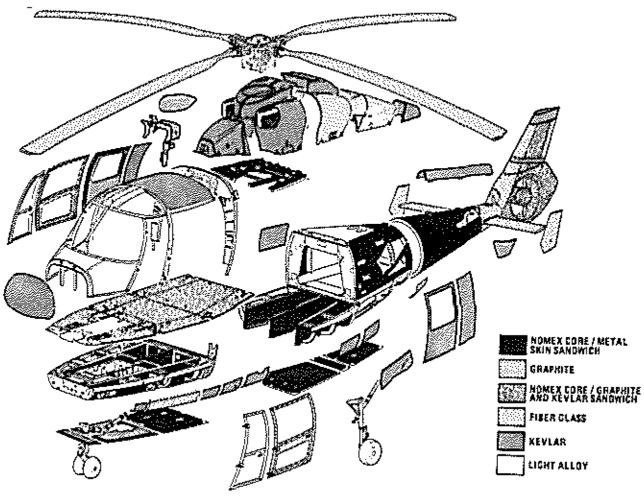


*Fig. 8 DAUPHIN SA 366 G1 : EXPLODED VIEW*

| Summary of Works achieved on the DAUPHIN | | Reference : equivalent metal part | |
|---|---|---|---|
| | | Weight saving in % | Relative cost in % |
| Main rotor | Starflex hub | 40 | 40 |
| | Rotor blades | 0 | 70 - 80 |
| Secondary structures | Cowlings * (Kevlar) | 55 | 15 |
| | Doors (Kevlar) | 31 | 30 |
| | Canopies (Kevlar + Graphite) | 15 | 50 |
| | Floor (Graphite + Kevlar) | 20 | 170 |
| Primary structures | Tail boom (Graphite) | 15 | 40 |
| | Horizontal stabilizer (Graphite) | 44 | 45 |
| | Stabilizer fins (Graphite) | 18 | 110 |
| Accessories - Equipment | Hoist arm (Graphite) | 40 | 120 |
| | Emergency flotation gear container (Graphite) | ≃ 25 | ≈ 50 |
| | Rescue basket (fiber glass) | 30 | 90 |
| | Pilot seat (Kevlar) | 20 | 20 |
| | Hoist cable (Kevlar) | 50 | |
| Control system | Pitch horn (Graphite) | 45 | 80 |
| SA 366 G1 Dauphin Fenestron/tail fin assembly | Rotor | 24 | 45 |
| | Tail fin (Graphite + Kevlar) | 22 | 66 |

* As compared to fiber glass cowlings, the weight saving brought in by Kevlar would be 13 % and relative cost 130 %.

*Table 1*

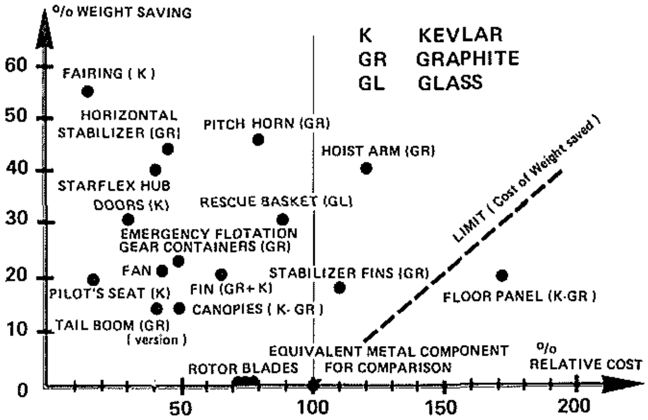


*Fig. 9 WORK BREAKDOWN*

Table 1 and Figure 9 show that, except for blades, weight savings range from 15 to 50 % as compared to metallic components. When graphite is employed, the cost of a composite component is frequently greater than that of the metallic component. However, in those cases where the use of composites sufficiently simplifies the concept, a cost reduction may be realized.

Kevlar, used either alone or together with High Strength Graphite widens the field of application for composites thanks to its density and cost lower than those of graphite, and there is an increasing trend to use it.

On an aircraft like the SA 366 G1 DAUPHIN, the percentage of empty weight consisting of composites relative to the empty weight (structure and mechanics) is approximately 26 %.

## 1.2 – CURRENT AUTOMATION

### 1.2.1 – Secondary structures

The pre-impregnation technique was the essential condition for their development on account of the decisive advantages brought about as compared with the former manual impregnation techniques (even weights per unit area, possibility of prolonged storage, etc .).

For this type of thin-walled structure, often of non-developable form, the saving in weight and cost with respect to the metal structures replaced is considerable, although the additional advantages of extensive mechanization would be apparent only for **large-scale production.**

The most significant example in this respect is illustrated by the development of MGB and engine cowling technology for which the adoption of composites has made it possible to divide production costs per m2 by a factor of up to 20 (Table 2).

| Cowlings | Engine cowling 330 | MGB cowling 350 | Engine cowling 365 N | MGB cowling 366 G1 |
|---|---|---|---|---|
| Designed in (year) | 1965 | 1974 | 1978 | 1980 |
| Type of structure | Metallic (light alloy) | Glass fabric and foam | Glass fabric and honeycomb | Kevlar fabric and honeycomb |
| Weight / m2 (Kgs) | 2,8 | 2,3 | 1,5 | 1,3 |
| Relation to prod. cost | 100 | 2,5 | 3,8 | 5 |
| Relation to material cost | 100 | 200 | 600 | 800 |
| Relation to total cost | 100 | 5 | 11,3 | 15 |

*Table 2 COWLING TECHNOLOGY EVOLUTION*

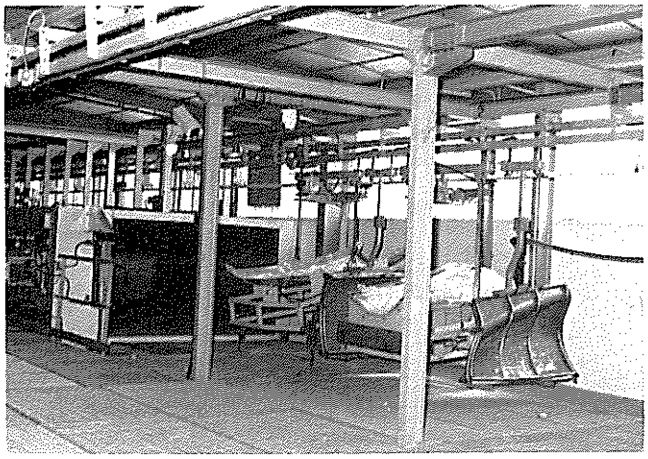


*Fig. 10 ECUREUIL COWLING PRODUCTION LINE*

In these circumstances, only the ASTAR/TWINSTAR cowling production line (Fig. 10) has benefited from mechanization, covering the following aspects in particular :

- Cutting of cloths by laser
- Interphase transfer functions
- Application of the water jet technique to the final cutting out phase.

### 1.2.2 - Stressed primary structures

With respect to the more recent manufacture of primary structures from relatively thin, but more complex shells or skins, automation is at the present time limited to certain phases (in view of the criteria listed at the start of this paper).

In the case of the horizontal stabilizer of the DAUPHIN, for example, curing and extraction of mould cores become automatic (Fig. 11 and 12).

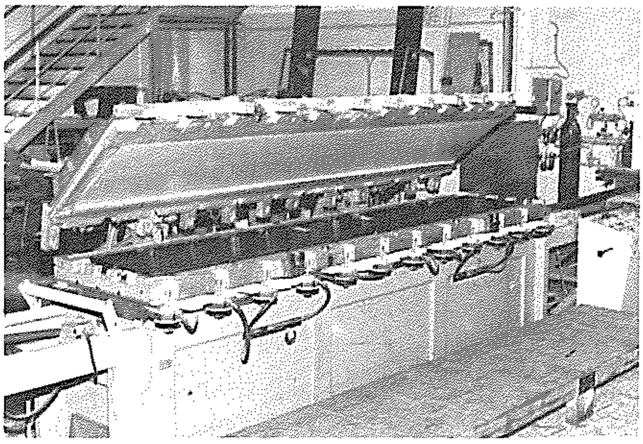


*Fig. 11 MOULDING TOOL FOR DAUPHIN STABILIZER*

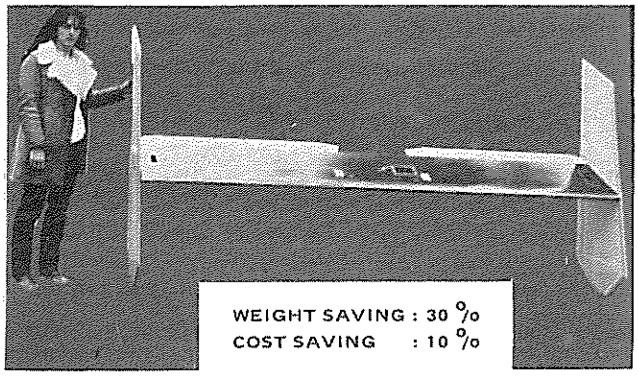


*Fig. 12 DAUPHIN STABILIZER*

However, manufacture of the entire tail structure of the DAUPHIN N1 and G1 versions comprising (Fig. 13 and 14)

- End of tail boom
- Airduct and fairing
- Rotor support and vertical fin.

does not at present justify detailed development of automation in view of the complexity of forms and the moderate production rate (less than 10 assemblies per month).

1 BLANKING PANEL (GRAPHITE/NOMEX/KEVLAR SANDWICH)

2 FIN CAP (KEVLAR/NOMEX/KEVLAR SANDWICH)

3 LEADING EDGE BOX (GRAPHITE)

4 REAR FAIRING (FOAM/KEVLAR SANDWICH)

5 RIBS (GRAPHITE)

6 SKINS (GRAPHITE/NOMEX/KEVLAR SANDWICH)

7 TAIL CONE (GRAPHITE)

8 TAIL GUARD FAIRING (FOAM/KEVLAR SANDWICH)

9 TUNNEL (GRAPHITE/NOMEX/KEVLAR SANDWICH)

10 UPPER FIN (GRAPHITE AND SANDWICH)

*Fig. 13 EXPLODED VIEW OF DAUPHIN TAIL STRUCTURE*

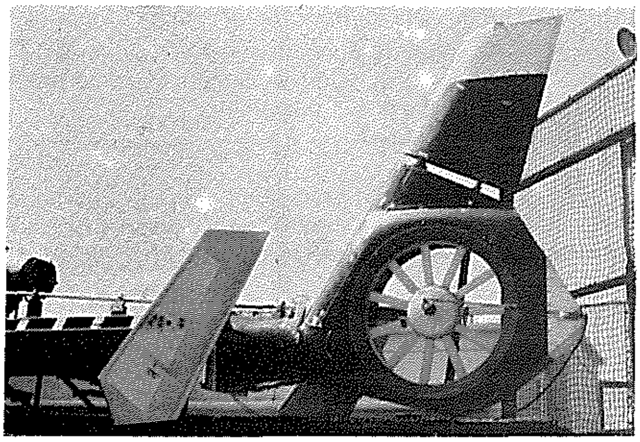


*Fig. 14 SA 365 N1 / SA 366 G1 FIN*

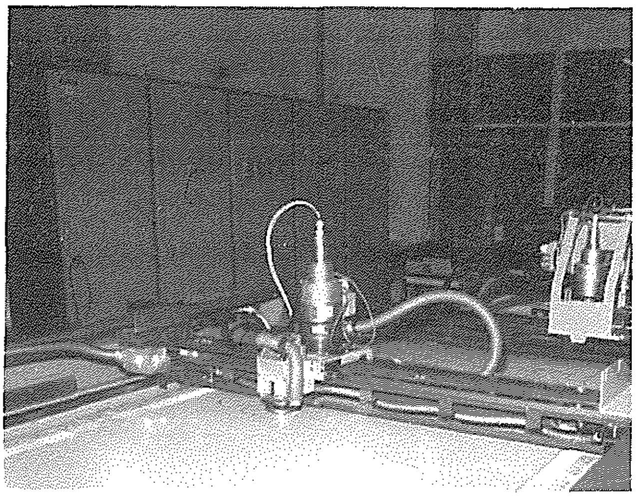


*Fig. 15 STARFLEX (LASER CUT-OUT)*

### 1.2.3 – Single-piece components

The multi-layer single-piece components, such as the STARFLEX hub, were designed from the outset with a view to mechanizing the main phases (cut-out, automatic transfer of the cut-outs, automated mould closing, automated curing) to meet quality requirements whilst at the same time considerably reducing costs as compared with manual techniques (Fig. 15 and 16).

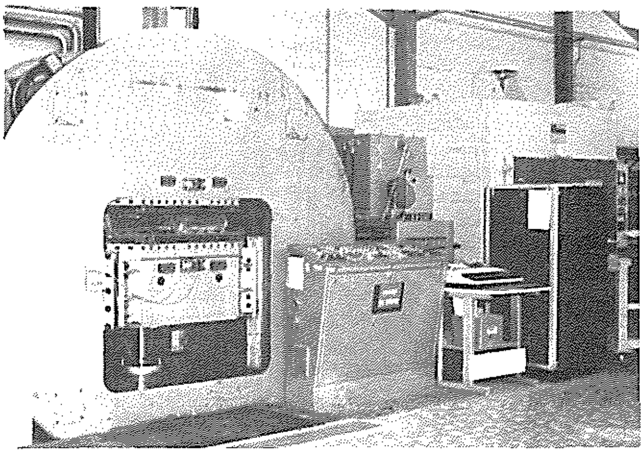


*Fig. 16 STARFLEX (CURING PRESS)*

The blade spars have also been the subject of considerable work with respect to automation, with significant results in the fields of productivity and quality. For the ASTAR/TWINSTAR, the impregnated rovings are assembled in bunches, thus ensuring their equi-tension before the installation operation (Fig. 17), while the ± 45° winding over the foam core is carried out automatically (Fig. 18).

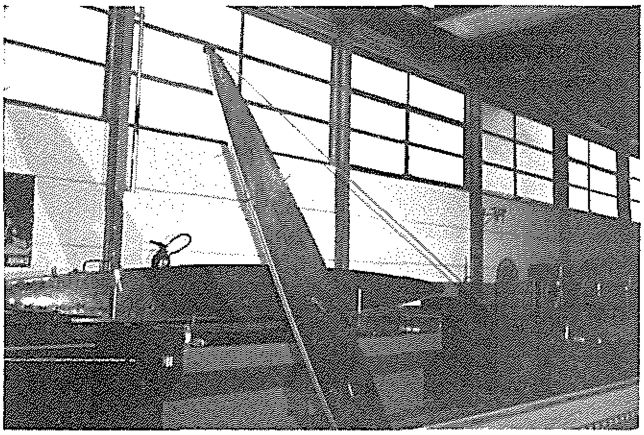


*Fig. 17 WINDING (BUNCHES)*

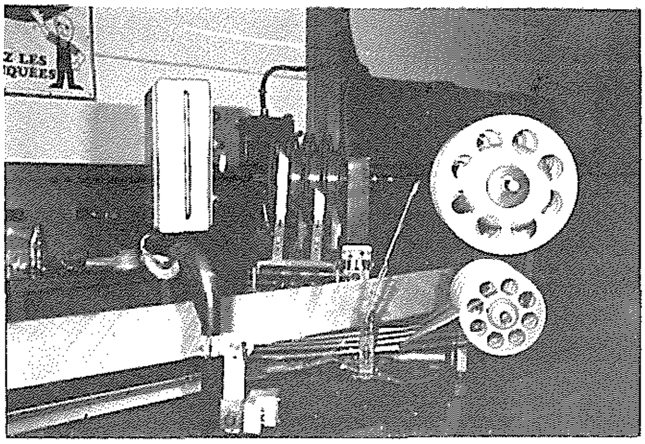


*Fig. 18 ±45° BLADE SPAR WINDING*

### 1.2.4 – Thermoplastics

Automation has, however, found a much more favorable application in the manufacture of the ASTAR/TWINSTAR cockpit structure, basically because the material used (reinforced polycarbonate) is a **thermoplastic** which is particularly suited to forming and hot welding techniques (Fig. 19).

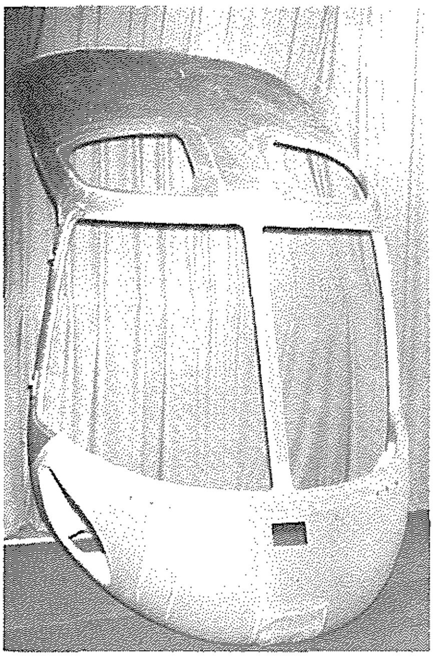


*Fig. 19 ASTAR / TWINSTAR CANOPY*

## 2 – FUTURE TRENDS

The mechanization of manufacturing processes, given the prevent state of composite materials technology for helicopters, is determined by industrial choices based on production cost, quality and reproductibility criteria for the components to be produced.

Bearing in mind the modest production rates, it will be understood that in most cases automation is limited to a few sequences of a production process where it offers definite advantages.

However, constant technological developments suggest that automation applications will be extended by a more complete and more rational adaptation of robots to the industrialization of composite materials.

An analysis of current data reveals two stages in this development, **one being short term,** based on optimization of existing or potential methods, and **the other relating more to future prospects** since it concerns the use of composites still in the research stage or about to be developed.

### 2.1 – OPTIMIZATION OF PRODUCTION METHODS FOR PRESENT MATERIALS

### 2.1.1 – Use of prepregs

The actual techniques for using prepregs are now kown, the tools exist, and efforts being made in this field relate more to the rational organization of workshops in line with the desired objectives.

- **Cutting out**

  Here we shall mention for reference the computerized optimizations which exist in the aeronautic industry or are being developed, based on :

- Laser cutting as used for the STARFLEX hub,
- Automatic water jet cutting using a programmable robot ; e.g. robot developed by the Central Facilities of Aerospatiale at Suresnes (Fig. 20),
- Reciprocating blade cutting whose use is justified more for thick multi-layer laminates in aeroplane construction.

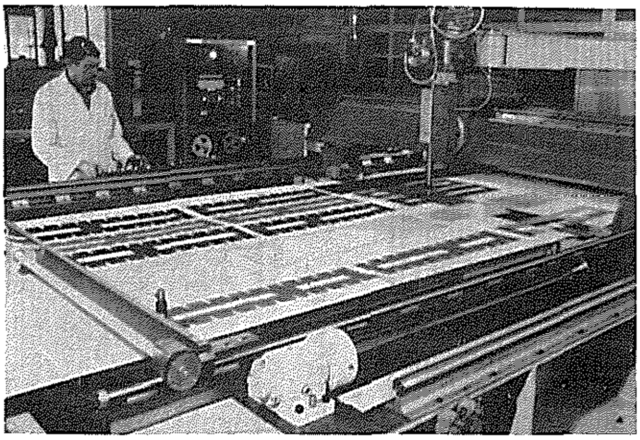


*Fig. 20 AUTOMATIC WATER-JET PREPREG CUTTING (SURESNES)*

- **Handling and transfer of cut-outs**

Due to the considerable time saving and greater accuracy of operation which mechanization can provide here, this phase has led the manufacturers to adopt various original solutions which may form a basis for future development in the helicopter manufacture (Fig. 21) :

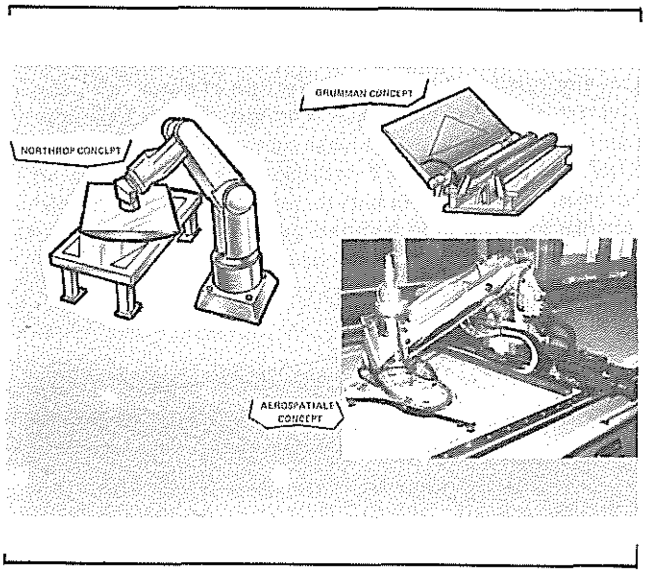


*Fig. 21 HANDLING AND TRANSFER OF CUT-OUTS*

- NORTHROP solution (selection suction of cut-outs on bench in form of «blotting pad»),
- GRUMMAN solution (transfer by turning over on mould of pallet carrying the cut-outs),
- And of course the AEROSPATIALE solution (swivel pick-up head for cut-outs for STARFLEX hub).

- **Draping**

Automation of draping work stations, clearly effective for multi-layer products, may be conceived at two levels of sophistication :

- Automatic cut out station with draping aid (Fig. 22)

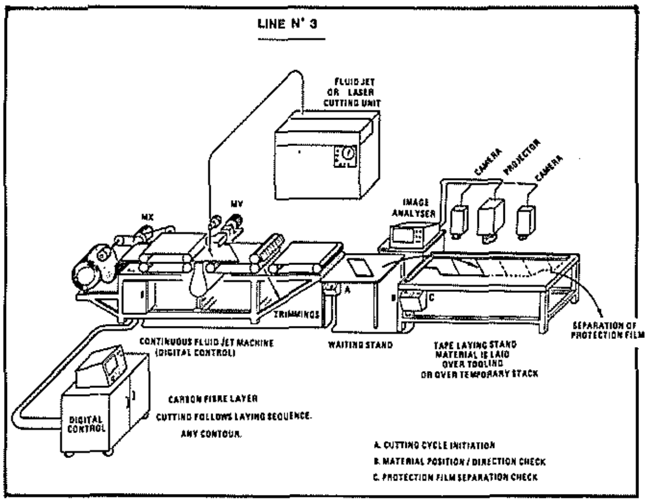


*Fig. 22 AUTOMATIC CUTTING SYSTEM WITH DRAPING AID*

- Fully robotized draping, with integrated control of cut-out storage, which is, of course, the ultimate level of perfection of a production line, and whose benefits are clear (Fig. 23 and 24) :
  - in respect of quality assurance, owing to the automation of all operations (except loading), and the attainment of a cut-out to final dimensions ;
  - in respect of productivity, since besides the automatic operation of the production line and obtaining cut-outs to final dimensions, the programmed storing unit makes for a large degree of flexibility in production.

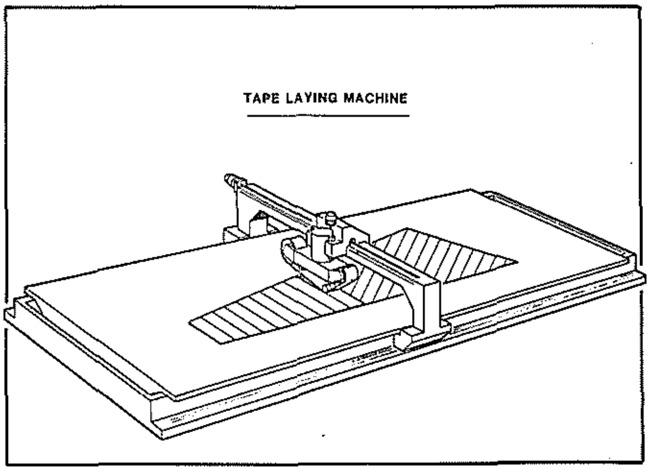


*Fig. 23 AUTOMATIC DRAPING MACHINE, INGERSOL L OR CINCINNATI TYPE*

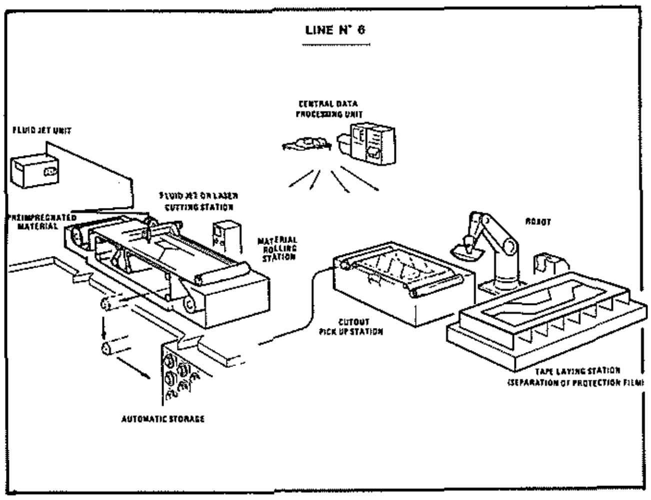


*Fig. 24 ROBOTIZED DRAPING SYSTEM*

On the basis of these solutions, various composite workshop organization projects may be worked out, as, for example, this compact production unit, designed by the Central facilities of Aerospatiale at Suresnes. ( Fig. 25 )

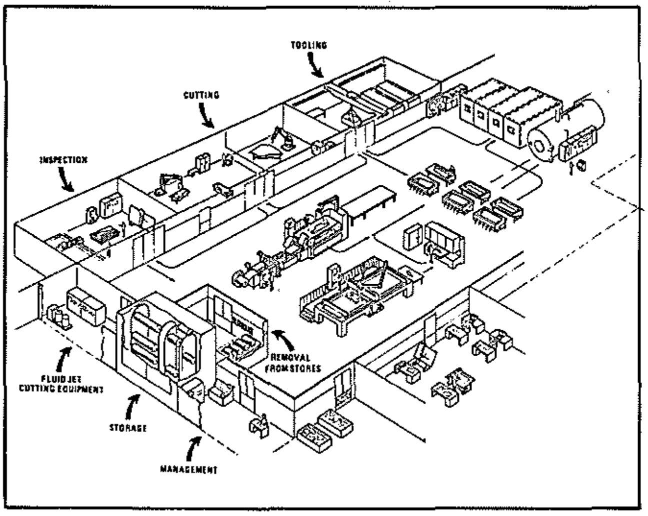


*Fig. 25 COMPOSITE MATERIALS WORKSHOP PROJECT (SURESNES)*

With respect to helicopters, these methods may be applied to the draping method of rotor mast manufacture if this technology, at present being evaluated together with other techniques such as winding, proves to be the best.

### 2.1.2 – Cutting out of laminates

The most suitable equipment for this operation exists : the water jet robot.

There could be two levels of perfection for this type of automation :

- Triggering of the operation by a computer loaded with the reference of the part to be cut (memory cassette),
- Triggering by computer linked to a reader of a bar code marked on the part.

**Fields of application** : all composite laminates up to 5 – 6 mm (1/4") thick, cutting speeds 1 to 2 m/minute.

Example : Cowlings, etc ... ( Fig. 26 )

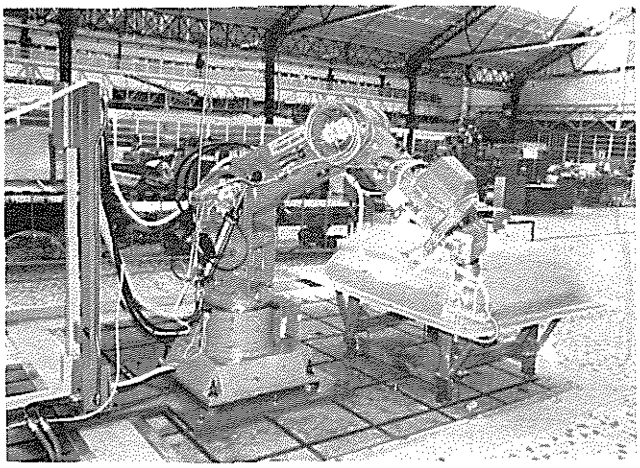


*Fig. 26 RENAULT ROBOT FITTED WITH WATER-JET CUTTING SYSTEM*

### 2.1.3 – Automated manufacture specific to rotating parts

- **Winding**

Although this process is now regarded as an established one and is especially well-suited to automation, it is generally restricted to the manufacture of pressurized containers (e.g. rocket booster casings). In the helicopter field, this technique has been successfully applied since 1973 on the GAZELLE stabilizer spar tube, where improvement of bending and torsion stiffness was studied, thanks to a machine featured by simultaneous laying of crossed and longitudinal ribbons (Fig. 27).

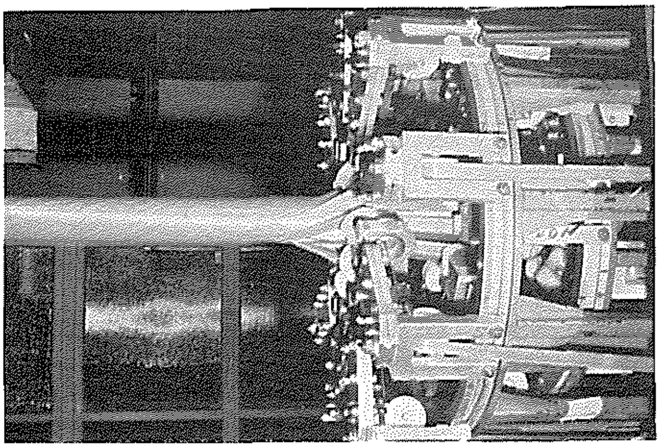


*Fig. 27 MACHINE FOR WINDING GAZELLE STABILIZER SPAR TUBES*

Transmission shafts and a rotor shaft are currently being studied in comparison, in the latter case, with draping techniques and the use of braiding.

Considerable problems remain to be solved, particularly regarding end-fittings and joining areas, not to mention the intrinsic characteristics and appearance of wound material (Fig. 28).

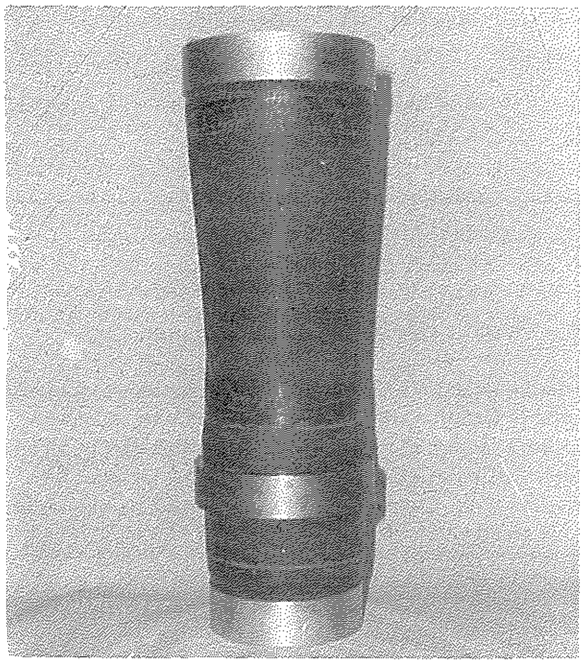


*Fig. 28 WOUND ROTOR SHAFT*

- **Braiding**

In situ braiding of reinforcements on inflatable mandrels of tapered section is a technique which may be associated with automated injection of liquid resin followed by curing.

However, it requires development by the weaving industry of braiding machines with a large number of bobbins to give an adequately compact network.

A machine with 240 bobbins is being studied by TVT in Lyon.

Impregnation difficulties have still to be overcome despite the development of several applications such as the hoist arm on the DAUPHIN (Fig. 29).

Other applications seem possible, such as rods, drive shaft sections and rotor shaft.

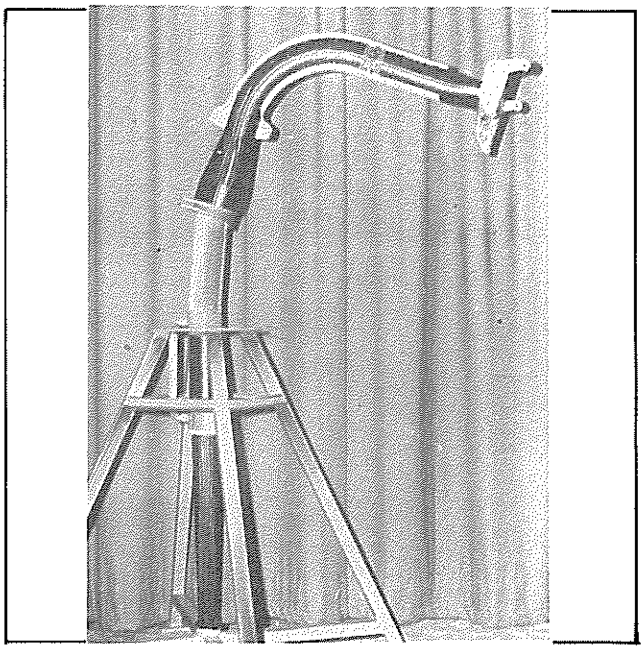


*Fig. 29 DAUPHIN HOIST ARM*

- **Weaving to shape**

« Sock » - type weaving for covering conical, ellipsoidal or other shapes is already being used successfully in the manufacture of radomes for aircraft, as for example on the MIRAGE 2000.

This type of reinforcement is associated with an impregnation technique involving the hot pressing transfer of resin to the external face of the preform. The preform can then be stored like a conventional prepreg. (Fig. 30 to 32).

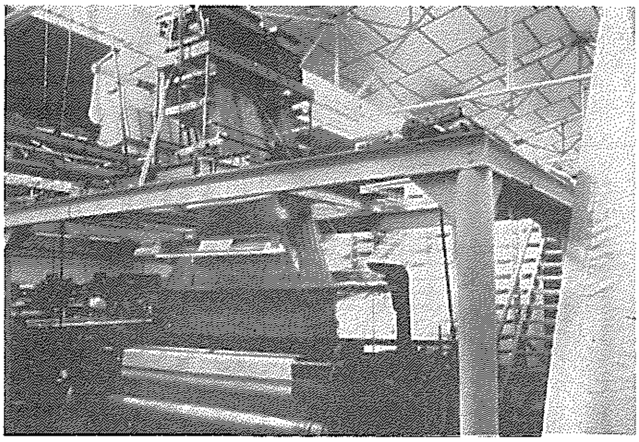


*Fig. 30 WEAVING LOOM*

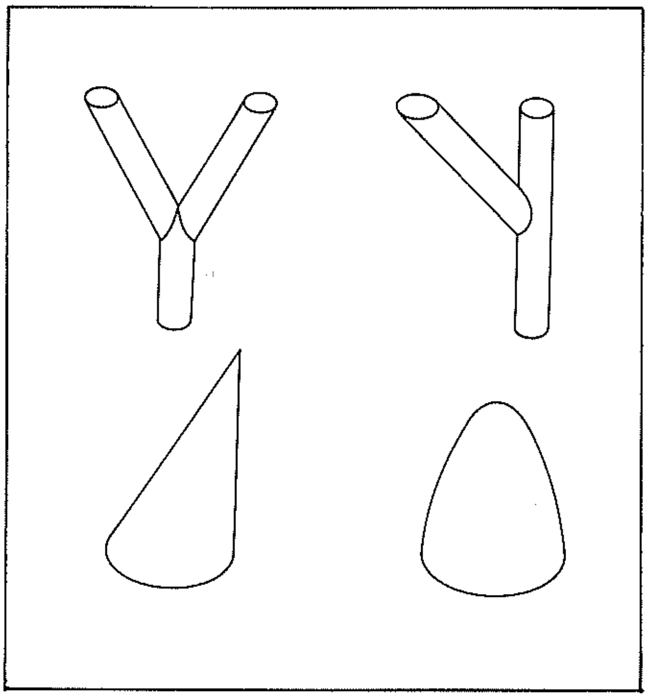


*Fig. 31 WOVEN REINFORCEMENTS*

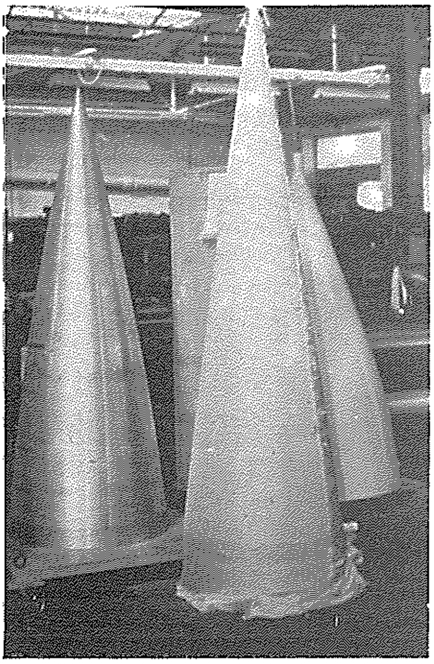


*Fig. 32 VIEW OF WOVEN PREFORMS*

This technique is currently being evaluated at Aerospatiale Helicopter Division on a graphite rotor shaft, in association with a M.G.B. installation with a single bearing. (Fif. 33)

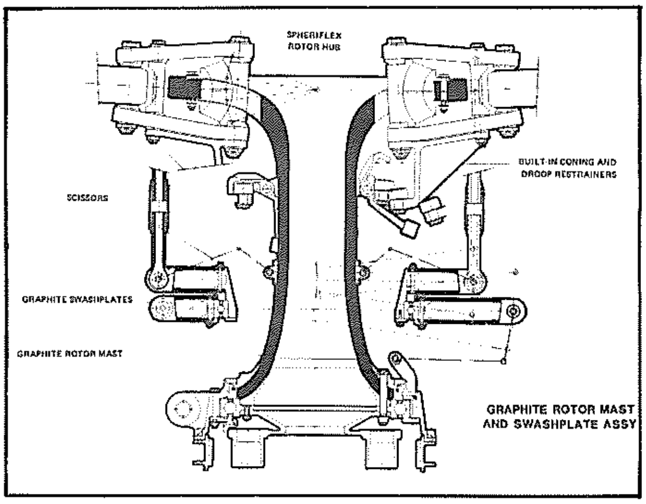


*Fig. 33 ROTOR/SHAFT ASSY (FOR MEDIUM-WEIGHT HELICOPTER)*

### 2.1.4 – Specific case of TRIFLEX-type production

The design of the Triflex hub, whose flexible arms provide the pitch, flapping, drag hinge and damping functions, is based on a lay-up of layers of rovings embedded in injected elastomer using a technique well-suited to automation. The development of this technique is currently being finalized (Fig. 34 to 38).

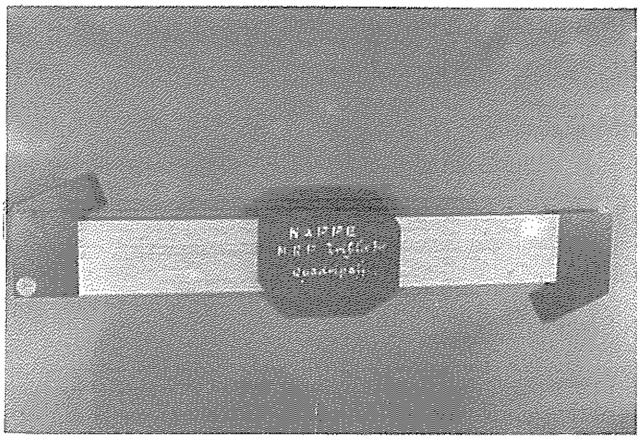


*Fig. 34 TRIFLEX ROTOR HUB : UNIT PLY*

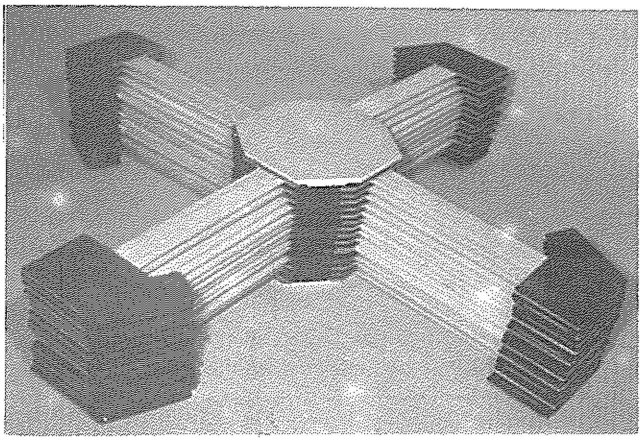


*Fig. 35 THE ARMS PRIOR TO INJECTION OF ELASTOMER*

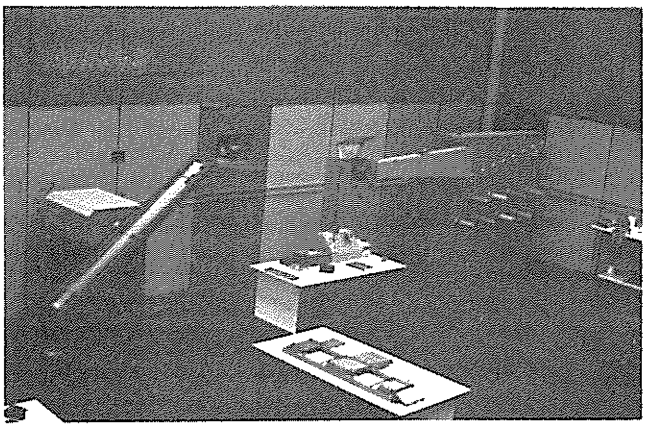


*Fig. 36 MACHINE FOR MANUFACTURING ROVINGS AND UNIT PLIES*

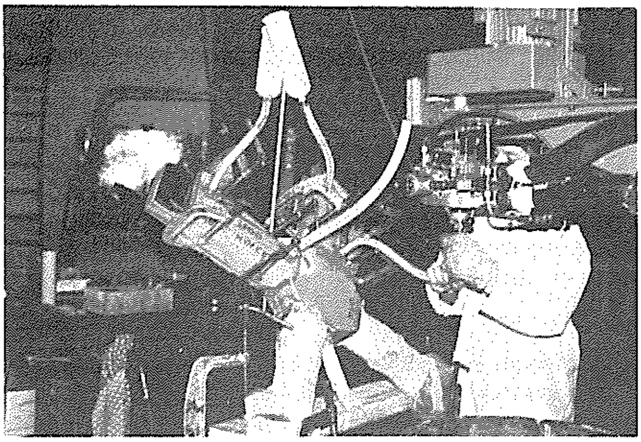


*Fig. 37 INJECTION OF ELASTOMER*

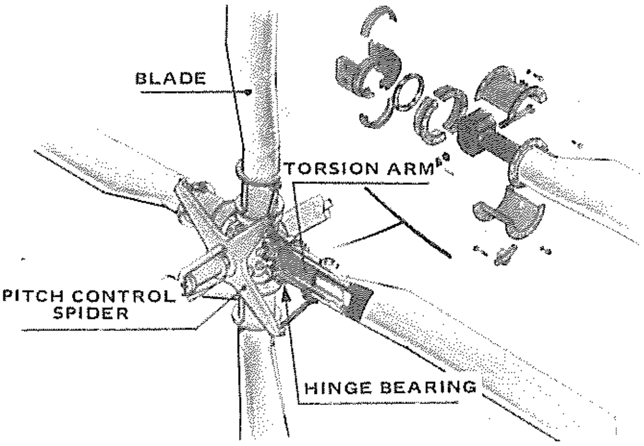
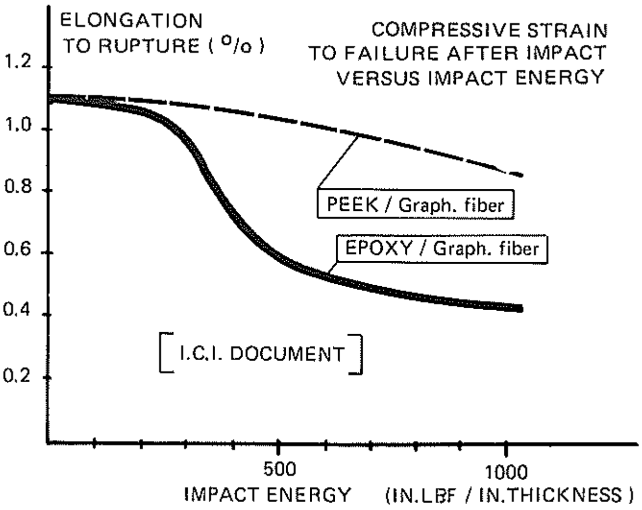


*Fig. 38 SUPER PUMA TAIL ROTOR PROJECT*

## 2.2 – POSSIBILITIES OFFERED BY FUTURE MATERIALS

### 2.2.1 – Reinforced thermoplastics

Matrix composite materials of the polyether-ether-ketone (PEEK) or possibly polyamide type may well take the lead in the near future due to their promising properties of resistance to all types of damage (environment, impact, etc.) and their formability. ( Fig. 39 )



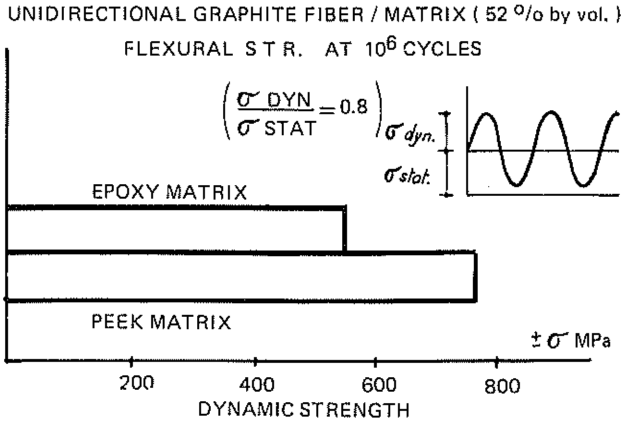


*Fig. 39 REINFORCED THERMOPLASTICS DATA*

For this class of materials, automation techniques will be particularly simplified since they will be derived directly from metal forming techniques :

- Press forming
- Stamping
- Continuous shaped section forming.

The re-introduction of tried and tested hot forming techniques for this new generation of composites, makes it possible to envisage the manufacture of structural components, or even mechanical components for helicopters as for example the swashplate, currently being evaluated in a graphite/epoxy - foam sandwich (Fig. 40)

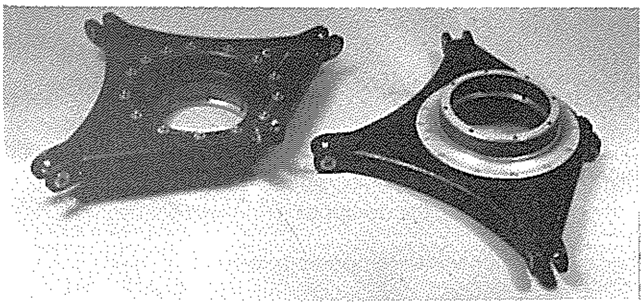


*Fig. 40 SWASHPLATE (SHOWN HERE IN GRAPHITE / EPOXY CONSTRUCTION)*

Mention could also be made of high deformability fabrics, made from fibres coated with thermoplastic resins, which could lead the way to high-rate mechanized production.

### 2.2.2 — Metal matrix composites

These materials under development are interesting for several reasons since they have improved heat resistance and transverse direction strength compared with traditional organic composites, and high specific strength compared with metals.

The reinforcing fibres may be of several types. Composites with the following fibre bases are now, or will soon be, available commercially :

- boron fibres
- silicon carbide fibres
- aluminium fibres (FP of Du Pont de Nemours).

Figure 41 shows the gain achieved in longitudinal direction over the magnesium alloy QE 22A-T5 with a 50 % FP fibre reinforcement. Its properties are very similar to those of the die forging in shear and transverse direction.

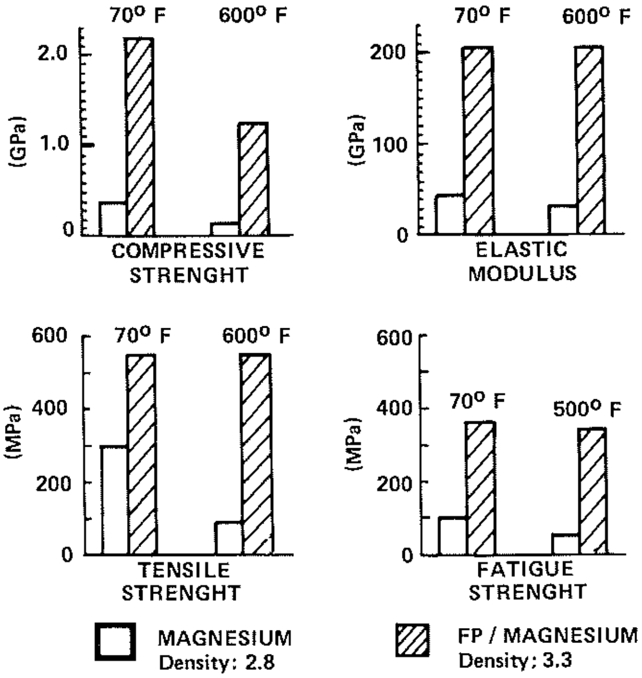


*Fig. 41 COMPARISON OF UNIDIRECTIONAL 50 % FP / MAGNESIUM CASTING WITH UNREINFORCED MAGNESIUM ALLOY (QE 22 A-T5)*

In view of these qualities, applications may be found on the helicopter for the design of :

- either mechanical components such as
  - Main gearbox casing
  - Main rotor shaft

  due particularly to the possible optimization of the properties at junction and connection zones with other components,
- or for structural panels and all components subjected to relatively high complex stresses (mountings, rods, etc .)

To this generation of products reinforced with long or short fibres will correspond application techniques similar to those used for metals : shell moulding, die forming, forming or welding, as appropriate.

## CONCLUSION

On helicopters, the absolute necessity of achieving minimum empty weight for a given gross weight has led to the development of audacious solutions, among which the use of composite materials has played and will continue to play a decisive role.

The commercial success of these aircraft, in both the military and civil fields, is linked both to a considerable reduction in production and operating costs and to the improvement of reliability.

This indicates the considerable importance attached to finding optimum production methods to achieve these objectives, and to the rational application of automation in particular. The application must be rational since automation must fall within the global production tool envelope where the production rate notion occupies the prime place among the industrial options to be selected.

Considering the current production rates and the investments involved by automation, the latter is generally limited nowadays to some sequences of the production line.

Nevertheless, constant technological improvement, elaboration of appropriate concepts, efforts towards constant production quality, as well as the introduction of new materials are all factors, which should favour rational development of the automated production of composite materials in the helicopter industry.

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