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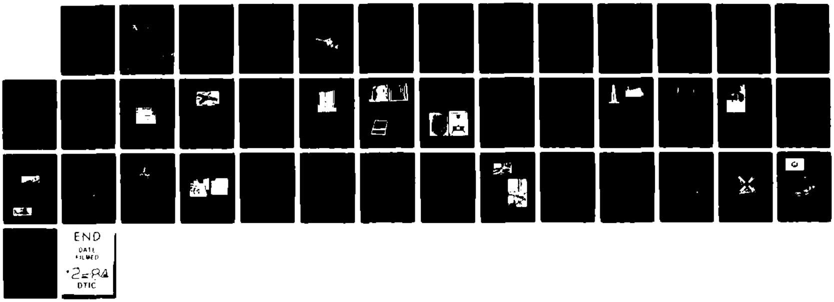

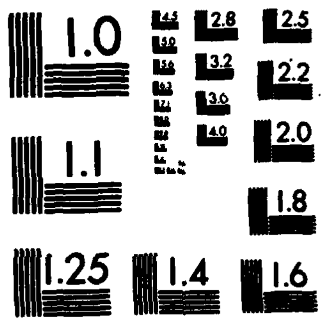

MICROCOPY RESOLUTION TEST CHART
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TRANSLATION

TITLE: APPLICATIONS OF COMPOSITE MATERIALS IN HELICOPTER CONSTRUCTION

LES APPLICATIONS DES MATERIAUX COMPOSITE DANS LA CONSTRUCTION DES HELICOPTERS

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APPLICATIONS OF COMPOSITE MATERIALS IN HELICOPTER CONSTRUCTION: THE DIFFICULTIES IN DESIGN AND MANUFACTURE OF HELICOPTERS*

*French version of the article written for the DuPont de Nemours International Symposium on Design and Use of Kevlar in Aircraft, Geneva, 12 October 1982

[Beziac, Gilbert;* Les applications des matériaux composite dans la construction des hélicoptères; L'Aéronautique et L'Astronautique, No. 98, 1983; pp. 21-40; French]

*Chief of Research Department, Aérospatiale, Helicopter Division

Compared with an aircraft of similar size, the helicopter is a much more complex machine and more difficult to construct, owing to several factors: /21*

--mechanical transmission elements which must provide a very great reduction of the main engine speed.

Order of magnitude:

30,000 rpm at the turboshaft engine;
250 to 400 rpm at the main rotor;
or 3 to 5 times more than for a twin turboprop engine.

--presence of an antitorque rotor placed in the rear of the craft at the end of a long and relatively flexible tail boom.

--presence of dynamic vibrations from the rotors of a level which is higher as the speed is greater, requiring the dimensioning of a number of transmission, control, and structural elements for "fatigue" as well as an optimization of the dynamics of the rotating assemblies and of the vibrational responses in the cockpit and the cabin (resulting frequently in the presence of vibration absorbers either at the rotor or between the rotor and the fuselage or in the cabin itself.

--finally, the imperative need for a given total weight to seek the minimal empty weight so that the machine can perform vertical flight with the best economy of operation possible (the "convenience" afforded by takeoff over more or less long lengths of runway does not exist for the helicopters).

This is the origin of the efforts conducted for many decades by designers of helicopters and turboshaft engines and which permitted a steady improvement in the operational capabilities in both the military and the civilian domain and a reduction in production and operating costs.

Objectives for Progress

The ability of a helicopter to perform stationary flight under good economy conditions, to fly at ground level with good maneuverability and

*Numbers in right margins indicate pagination in the original text.

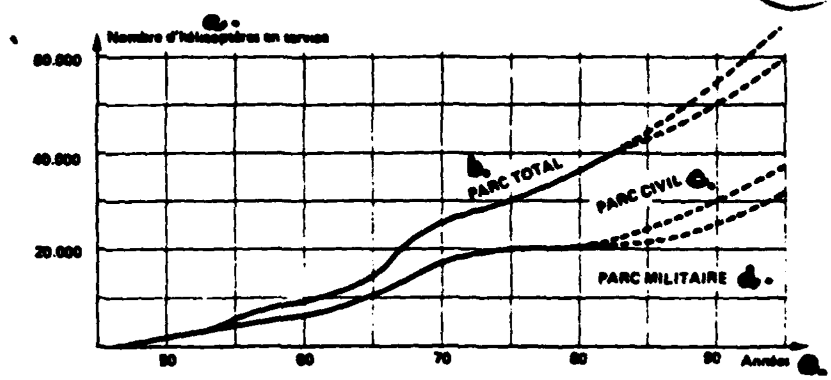


Fig. 1. Forecast of the growth of the helicopter inventory (non-USSR)

a. Number of helicopters in service b. Total inventory c. Civilian inventory d. Military inventory e. Years

Objectives for Progress

The ability of a helicopter to perform stationary flight under good economy conditions, to fly at ground level with good maneuverability and safety, and to reach zones difficult of access without the need for an elaborate infrastructure permitted a broad extension of the use of these machines during the last decade.

The market studies moreover are significant and show a great broadening of the need. The expansion of the helicopter as a product, especially in the civilian domain, is a relatively recent fact. Indeed, in 1970, 23,000 machines were in service in the world (outside the USSR), only 4000 of them for civil use. /22

The inventory has practically doubled to date and has seen the number of civilian craft grow considerably. This evolution ought to continue and to develop into a total inventory of about 60,000 craft in 1995 outside the USSR.

To better satisfy demand, the designers are pursuing three principal objectives, whose implications for the machine are summarized in the following table:

Principal Objectives	Implications
Reduction of the D.O.C.	Reduction of empty weight Reduction of purchase costs Reduction of maintenance costs
Improvement in performance	Reduction of specific engine consumption Reduction of parasitic drag Improvement of rotor performance

Principal Objectives (continued)	Implications (continued)
Improvement of operational qualities	Safety Comfort (vibrations and noise) All-weather flight Military aspects: --reduction of radar and IR detectability --reduction of vulnerability.

Of the solutions adopted to attain those objectives, the use of composite materials in helicopter construction has been and will continue to be determining. It permits increasing the overall performance of the machines while appreciably reducing purchase and operating costs, and also permits improving safety.

In order to facilitate comprehension of the report for the non-specialists, the following table and cutaway view will furnish the list of essential components of the helicopter:

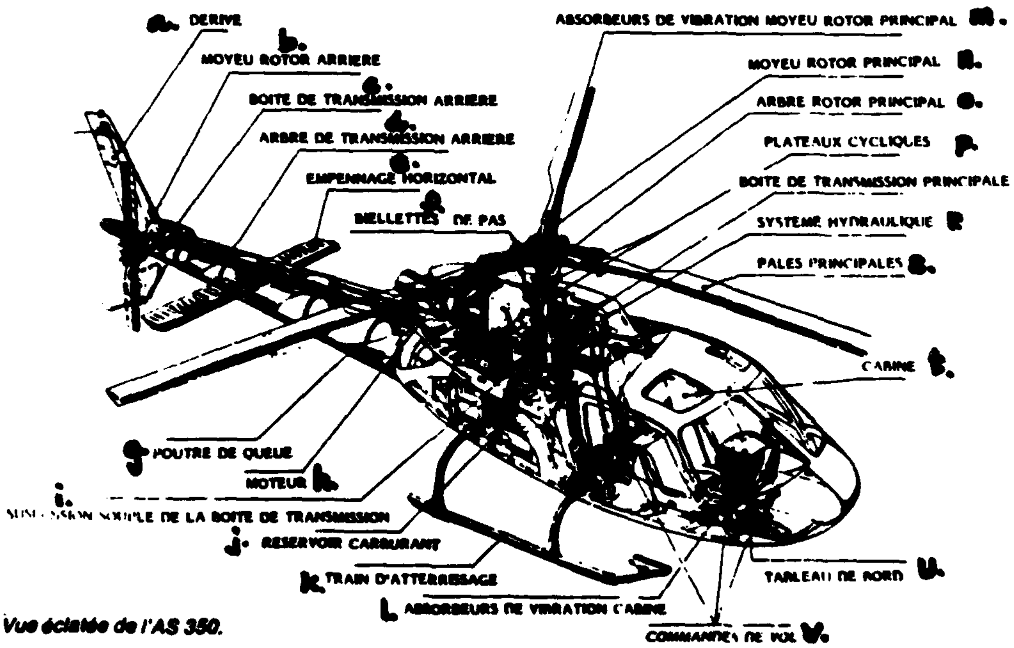


Fig. 2. – Vue éclatée de l'AS 350.

Fig, 2, Cutaway view of the AS 350

a. Tail fin b. Rear rotor hub c. After gearbox case d. Rear transmission shaft e. Tailplane f. Pitch control rods g. Tail boom h. Engine i. Flexible gearbox suspension j. Fuel tank k. Landing gear l. Cabin vibration absorbers m. Main rotor hub vibration absorbers n. Main rotor hub o. Main rotor shaft p. Cyclic control plates q. Main gearbox r. Hydraulic system s. Main blades t. Cabin u. Instrument panel v. Flight controls

--Structure

Cockpit — with their access hatches, ports, various hatches
Cabin — floors
Tail section
Tailplane
Vertical empennage
Rotor head and gearbox fairings
Landing gear
Fuel tanks

--Main rotor hub

With its associated cyclical control plates, its movable pitch control rods, its pitch levers

--Main blades

--Flight controls

They transmit the pilot's orders to the engine and the rotors.

--Rear rotor

Conventional or "faired propeller" type with its overall pitch control

--Vibration filters

Hub vibration absorbers
Suspensions between gearbox and airframe
Cabin vibration absorbers

--Engines

--Transmissions /23

Main gearbox
Rotor shaft
Rotor brake
Rear transmission shaft
Rear gearbox

--Equipment and systems

Onboard hydraulic and electrical systems
Specific systems linked to the mission

The Advantages Produced by Composite Materials in Helicopter Design

Those advantages have been the subject of a number of conferences, among others by Aérospatiale (cf. references), so that we shall be satisfied with recalling them briefly in this paper.

Mechanical strength of the composites high in the direction of the fibers, for the static strength as well as the fatigue strength.

In specific strength (strength/density), the advantage of the composite over the principal metal products used in aeronautics appears clearly in figs. 3 and 4.

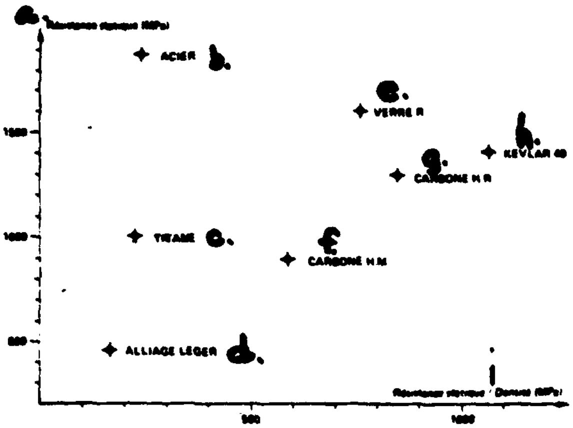


Fig. 3

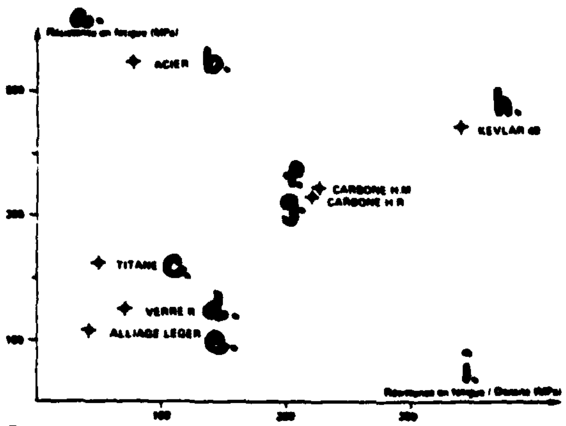


Fig. 4

Fig. 3. a. Static strength b. Steel c. Titanium d. Light alloy e. R. glass f. H. M. carbon g. H. R. carbon h. Kevlar 49 i. Static strength/density (MPa)

Fig. 4. a. Fatigue strength (MPa) b. Steel c. Titanium d. R. glass e. Light alloy f. High-modulus carbon g. High-strength carbon h. Kevlar 49 i. Fatigue strength/density (MPa)

Young's modulus for metals can always be equalled by certain composites. The interest in the latter resides in their specific modulus (modulus/density), as appears in fig. 5.

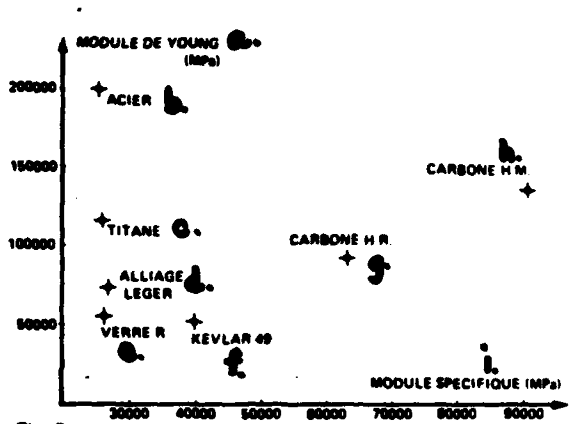


Fig. 5

Fig. 5.a.Young's modulus (MPs) b. Steel c. Titanium d. Light alloy e. R. glass f. Kevlar 49 g. High-strength carbon h. High-modulus carbon i. Specific modulus (MPa)

On aircraft airframes, history shows that advances appeared whenever a material attained specific mechanical characteristics higher than the material used before and its cost remained acceptable with regard to its performance.

That is what happened for glass about 1965, then later for carbon, then for kevlar.

Weight Savings

Composites permit weight savings owing to their good specific mechanical characteristics and their "fail-safe" character, which permit avoiding overdimensioning structures for static as well as fatigue strength.

Below we shall see some recent examples of the use of composites on helicopters which will show that the weight gains obtained go from 15% for secondary structures to 50% for transmission and control elements.

(see next page for fig. 6)

Improvement of Performance

The contribution of composites has been particularly felt in the rotor performance, thanks to the possibility of easy fabrication of blades of optimized dynamic forms and characteristics.

The technique of molding in fact permits making blade geometries more performing than those of metal construction, owing to:

--non-symmetrical profiles;
--the law of non-linear twisting;
--refinement:
--the end form,

which permit improving the stationary and the crusing flight performance and to reduce the rotor noise.

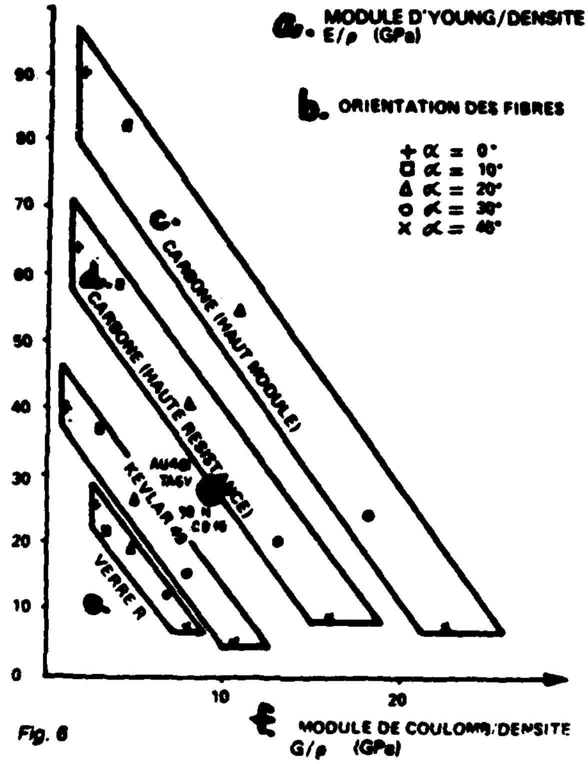


Fig. 6

Fig. 6. a. Young's modulus/density /24
E/ρ (GPa)
b. Direction of fibers c. High-modulus carbon d. High-strength carbon e. R. glass
f. Coulomb modulus/density
G/ρ (GPa)

At a given power, the optimization of a main rotor blade, compared with the conventional metal blade with a symmetrical constant profile and the law of linear twist, permits gains of the order of 8 to 10% in take-off weight and in optimal consumption per kilometer.

The anistropy of the composite materials facilitates producing the blade dynamics so as to permit minimizing the vibrations of the rotor hum and therefore to improve comfort in the cabin.

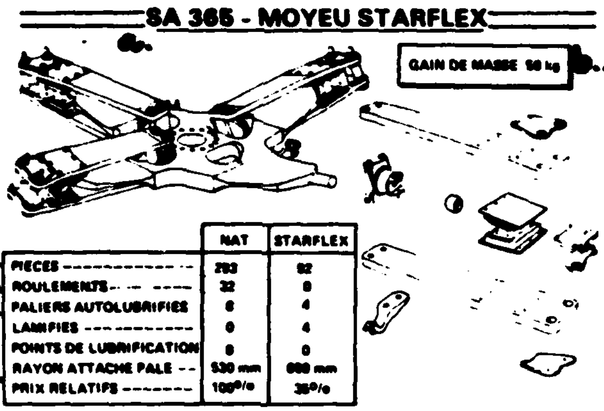
Improvement of Maintenance

The introduction of composite materials, particularly in hubs and blades, permitted a substantial reduction in maintenance.

Advances in:

--reduction in the number of parts of a given sub-assembly;
--the modular concept with easy exchange of different modules;
--the elimination or reduction in the lube and grease points;
--the increase in the life of the parts;
--maintenance depending on condition, facilitated by easy visual inspection and to slow spread of degradation.

The Starflex hub is a typical illustration of that progress (fig. 7).



	NAT	STARFLEX
c. PIECES	[illegible]	[illegible]
d. ROULEMENTS	32	0
e. PALIERS AUTOLUBRIFIES	6	4
f. LAMIFIES	0	4
g. POINTS DE LUBRIFICATION	6	0
h. RAYON ATTACHE PALE	530 mm	[illegible] mm
i. PRIX RELATIFS	100%	35%

Fig. 7. – Comparaison moyeu Nat/Moyeu Starflex (Dauphin).

a. SA 365 - STARFLEX HUB
b. Weight gain 50 kg c. Parts d. Bearings
e. Self-lubricating bearings f. Laminates
g. Lube points h. Blade attachment radius
i. Relative price

Fig. 7. Comparison of NAT/STARFLEX hubs (Dauphin)

Improvement in Security and Vulnerability

Linked essentially to the tolerance to natural and ballistic impacts of the structures made of composite materials as well as to the particular mode of propagation of the damage (slow propagation of cracks, breakdown by slow and apparent delamination, imparting a fail-safe character).

Reduction of Radar Detectability (Military Machines)

Composite materials lend themselves well to the absorption of radar waves in the structure and in the blades as well.

The composition of multilayer materials based on composite tissue and plastic foams or honeycombs permits effecting a reduction in the equivalent radar surface of the helicopters while preserving the characteristics of acceptable weight, strength, and cost.

Repairability

The elements of a helicopter can be subject to various types of degradation:

--erosion to sand or rain;
--shock (trees, birds..) or impact (stones, military projectiles) in flight; /25
--shock or impact during maintenance.

Composite materials offer interesting possibilities for the repair of damage.

The example of the blades is significant: the various repairs envisaged are justified in advance by the designer thanks to fatigue tests on the special sections. Two levels are then differentiated: repairs that can be made at the client's site and those requiring return to the factory or at an approved repair dealer.

The client is, for example, authorized to repair holes of small dimension by patching with one or two sheets of glass coated with epoxy resin.

Structures of composite materials can also be easily repaired.

Area of Application of the Various Fibers

At a given level of requirement for performance, safety, long life, and maintainability, a structure will have to be designed as light as possible at an equal production cost: lightening is a standing concern of the helicopter which "roots out the useless *kilogram.*" For a craft in the preliminary plan, development, or production stage, the maximum additional cost of fabrication which one is prepared to pay to reduce the structure weight by one kilogram by changing materials or technology can be defined. This cost, called the weight-price "exchange rate" (or "price per kilogram saved") permits the user to compare it to the service rendered by carrying one additional kilogram of useful load. It is of the order of 1500 francs for a helicopter of medium tonnage of the present generation (case of the DAUPHIN SA 365 N).

In 1979 a study was conducted by the Helicopter Division of Aérospatiale to determine the area of use for Kevlar 49 (an organic fiber developed by DuPont de Nemours).

The comparison was on the use of Kevlar in the area of non-stressed or slightly stressed structures and of stressed structures in relation to a light alloy and to high-strength glass or carbon composite materials in the criteria of price/weight/performance.

Some Characteristics of Fibers and Composites

	a. Masse volumique g/cm3	b. Résistance la traction Mpa	c. Module d'Young E Mpa	d. Allongement à rupture %
e. Fibre Kevlar 49	1,45	3 500	135 000	2,6
f. Fibre carbone H.R. T300	1,74	2 700	226 000	1,1
g. Fibre verre E	2,60	2 700	75 000	3,6
h. Fibre verre R	2,56	~3 500	85 000	≃ 2,8

a. Weight per unit volume g/cm3 b. Tensile strength Mpa c. Young's modulus E Mpa

d. Elongation at rupture % e. Kevlar fiber 49 f. High-strength T300 carbon fiber

g. Glass fiber E h. Glass fiber R

In the composites, Kevlar therefore is characterized by its lightness, rigidity between glass and carbon, and very good tensile strength.

Unfortunately, crush strength is low on sandwich structures whose glass covers are replaced by Kevlar (the loss in rupture strength can reach 50% in compression and 30% in bending).

Non-Stressed Structures

Most of the "glass" composites currently used in the aeronautics industry can be converted to Kevlar 49. The comparison will be made "under constant volume," which means that the thicknesses of the stratified parts remain unchanged.

The following table presents a comparison for the light glass E fabrics, Kevlar 49, and HR 1000 carbon filaments. The last is higher priced.

	a. Densité d fibre g/cm3	b. Tissu sec M/S g/m2 Satin de 4	c. Tissu sec $e = \frac{M}{Sd}$ m.10^{-6}	d. Résine g/m2	e. Masse surfacique g/m2 tissu préimprégné	f. Prix tissu préimprégné F/kg	g. Epaisseur tissu préimprégné mm	h. Δm/S g/m2	i. Ecart Δm/S en %	ΔP/S F/M2	j. Taux d'échange ΔP/Δm en F/kg gagné
k. Verre E	2,60	200	77	142	342	105	0,2	0	0	0	0
l. Kevlar 49	1,45	113	78	142	255	349	0,2	-87	-25,4	+ 53	+ 809
m. Carbone HT 1000 filaments	1,74	150	86	150	300	1186	0,21	-42	-12,2	+320	+7619

a. Fiber density d g/cm3 b. Dry fabric 4 Satin c. Dry fabric d. Resin

e. Specific weight g/m2 f. Price of pre-impregnated fabric F/kg g. Thickness of preimpregnated fabric mm

h. Δm/S g/m2 i. Difference Δm/s in % j. Exchange rate ΔP/Δm in Francs/kg saved k. E glass l. Kevlar 49

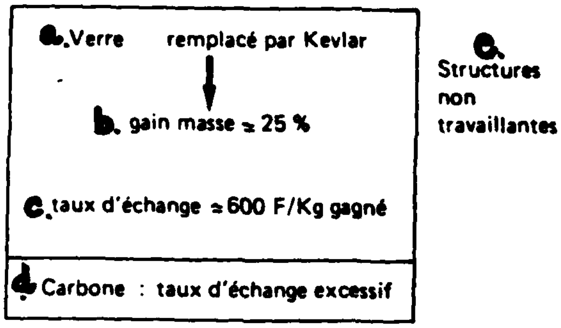
m. HT carbon 1000 filaments

The 3000-filament carbon threads give a satin fabric 5 of a thickness greater by 30% than satin 8 of glass or Kevlar, which is therefore not transferable "under constant volume" to existing glass or Kevlar fabrics. Its price is, however, three times lower than that of 1000-filament fabrics. /26

Other types of fabrics could be chosen for the comparison without however fundamentally changing the conclusions.

This table reveals that "under constant volume" the Kevlar fabrics bring a weight gain of the order of 25% over glass fabrics for a low exchange rate ≃610 F/kg, this while taking into account only the differences due to the price of the material.

In summary



a. Glass replaced by Kevlar b. Weight gain ≃ 25% c. Exchange rate 600 F/kg gained d. Carbon: excessive exchange rate e. Non-stressed structures

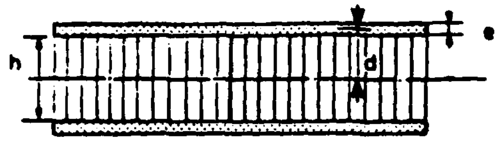
Structures Dimensioned for Rigidity

As a reference there was selected a sandwich structure with light-alloy covers 0.4 mm thick over a Nomex honeycomb core 10 mm thick.

This structure is compared to the isorigidity of the sandwich structures with glass fiber, Kevlar, or carbon covers.

Calculation

For fiber covers, the technological minimum is composed of two plies in order to provide good watertightness and a correct surface state.



Stiffness in bending: $EI \# Eed^2$ (disregarding the rigidity of the thin cover)

Index a: Light alloy Index e: composite

Isorigidity A

$$E_a \cdot e_a \cdot d_a^2 = E_c \cdot e_c \cdot d_c^2$$

whence:

$$h_c = 2 \sqrt{\frac{E_a e_a d_a^2}{E_c e_c}} - e_c$$

This formula makes it possible to calculate the thickness H_c of the honeycomb core in each case for a thickness e_c of the cover chosen by stacking two layers of fiber, and possibly three, so as not to exceed the value of 15 mm for h_e.

Price/weight comparison with isorigidity of sandwich structures with glass, carbon, or Kevlar covers with respect to light alloy.

The following table shows, for the example chosen corresponding to a standard case in a helicopter structure, that compared with the sandwich with a light-alloy cover:

the structures with a glass cover are a little heavier for an equivalent price:

Nature	a. Revêtements		Nids Nomex			d. Colle		e. Masse totale du sandwich g/m2	f. Prix total du sandwich F/m2	g. Taux d'échange F/kg	h. Ecart masse %
	b. M/S g/m2	c. Prix F/m2	d. Epaisseur e mm	b. M/S g/m2	c. Prix F/m2	b. M/S g/m2	c. Prix F/m2				
Alliage léger e = 0,4 mm i.	2240	100	10	900	300	560	200	3300	600	0	0
Verre E 3 tissus satin de 8 (e = 0,293 mm) j.	3072	192	13	650	390	//////////	//////////	3722	582	≃0	+12,5
Kevlar 49 3 tissus satin de 8 (e = 0,293 mm) k.	2292	612	11	550	330	//////////	//////////	2842	942	+746	−13,8
Carbone T300 1 tissu satin de 5 (e = 0,404 mm) 1 tissu satin de 4 (e = 0,21 mm) l.	1780	1156	10	500	300	//////////	//////////	2280	1456	+839	−30,9

a. Covers
M/S Weight/unit volume

c. Price Fr/m^2

d. Thickness e mm

e. Total weight of sandwich

f. Total price of sandwich

g. Exchange rate

h. Weight difference

i. Light alloy

j. Glass E
3 satin fabric 8

k. Kevlar 49
3 satin fabric 8

l. Carbon T300
1 satin fabric 5
(e = 0.404 mm)
1 satin fabric 4
(e = 0.21 mm)

--structures with carbon covers bring the maximum weight gain (30.9%), /27
but are by far the most expensive (2.4 times more than light alloy).

--the structures with Kevlar covers bring a more limited weight gain (13.8%), but have a clearly lower price than carbon covers for an exchange rate of the same order (≃ 800 F/kg).

From the example selected, the following values can be drawn:

	a. Masse totale du sandwich g/m2	b. Prix total du sandwich F/m2	c. Ecart de prix F/m2	d. Taux d'échange F/kg	e. Ecart de masse %
Revêtement verre E f	3722	582	0	–	–
Revêtement Kevlar 49 g	2842	942	– 360	+ 409	– 23.6
Revêtement carbone T300 h	2280	1456	– 874	+ 806	– 38.7

a. Total sandwich weight g/m^2 b. Total sandwich price F/m^2 c. Price difference F/m^2

d. Exchange rate F/kg e. Weight difference % f. Glass E cover g. Kevlar 49 cover

h. Carbon T300 cover

The values mentioned are of course only orders of magnitude, but, on the average, they permit the designer to direct his choice according to the additional cost which he considers acceptable to pay to lighten a structure of given rigidity (note that only the cost of material has been taken into account in this study and that differences can appear in the labor cost as a function of the parts to be made).

Structures Dimensioned for Strength

Considering the mediocre mechanical properties of Kevlar for compression and shear, the choice of carbon is imperative, except in case of a stressed part under pure tension (e.g., coiled capacitors, cables,...)

Conclusions

This study permits directing the choice of the designer in his attempt to lighten structures, whether stressed or not.

Each of the three widely-accepted fabrics, glass E, Kevlar 49, and high-strength carbon, has its area of application depending on the working mode of the parts and the cost that is considered acceptable to pay for lightening them.

Some Typical Composite Items

Chronologically, the glass/resin/epoxy composites first appeared starting in 1965:

--either on secondary structures such as fairings, owing to the savings in price over equivalent metal structures (moderate price of the glass fiber, spectacular savings in fabrication time;

--or on highly stressed parts such as blades, for which they contribute decisive improvements in fatigue strength and safety.

The carbon covers appeared starting in the seventies on the blades of the DAUPHIN I, then of the PUMA, for which great torsional stiffness was desired.

Since 1975, the field of application of composites broadened considerably among all the designers aiming at savings in weight and price, with Kevlar completing the range of fibers ordinarily used in helicopter construction.

Products for blades and hubs of the main rotors, the conventional rear rotors, have been the subject of a number of papers in France and in the United States. Let us mention as typical examples:

--the main blades of the new range of craft of Aérospatiale: ECUREUIL, DAUPHIN, SUPER-PUMA (fig. 8);

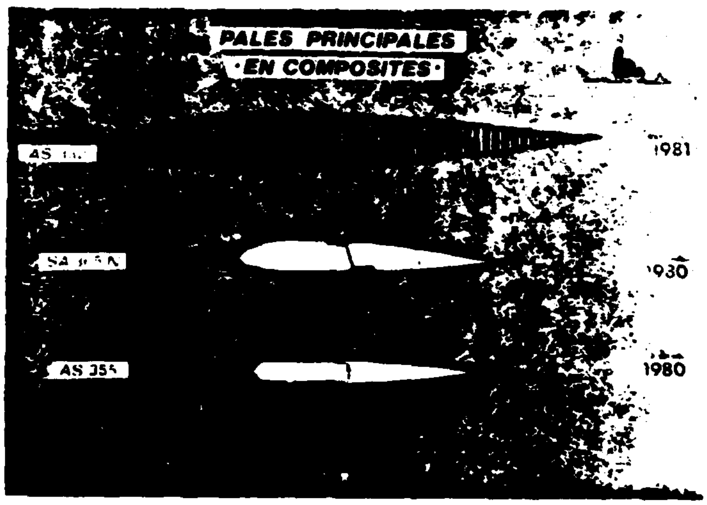


Fig. 8. a. Main blades of composite materials
b. Put into service

--the STARFLEX main rotor hubs of Aérospatiale on the ECUREUILs and the DAUPHINs (fig. 9);

--the conventional rear rotor of the CROSSBEAM type at Sikorsky or the twin-bladed rotor of Aérospatiale, using the torsion of a glassfiber blade to vary the pitch.

In this report we shall stress structures of composite materials and some recent products such as the new fin/fenestron assembly and various /28 accessories and equipment of the Aérospatiale DAUPHIN II version intended for the US Coast Guard.

The data relative to costs are to be taken as orders of magnitude, and should be treated cautiously.

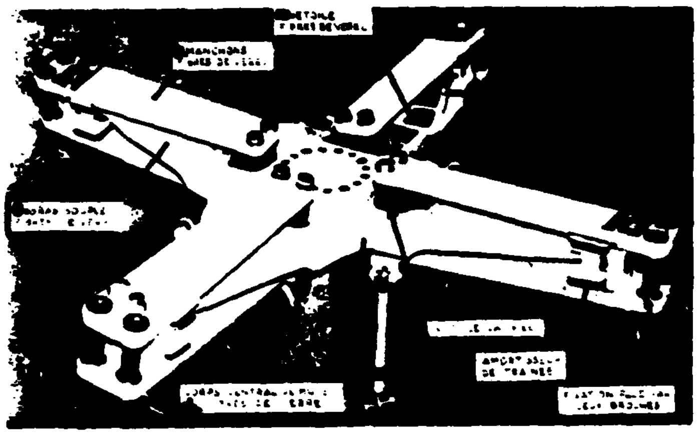


Fig. 9. The STARFLEX hub of the DAUPHIN N

a. Glassfiber center b. Glassfiber cover c. Glassfiber flexible arm
d. Glassfiber main hub body e. Laminated joint f. Drag damper
g. Blade attachment by two pins

Evolution of the Structures

We shall describe here the evolution at Aerospatiale. Other builders have followed or will follow similar developments.

Besides the weight savings obtained by the use of composite materials, it is appropriate to stress the reliability, the resistance to corrosion and the safety (impact strength, slow propagation of cracks, slow and visible degradation by delamination) which those materials bring.

A summary of structural failures detected on the metal structure of the UH 1 for example (reference 5) illustrates the contribution of composite materials on those points.

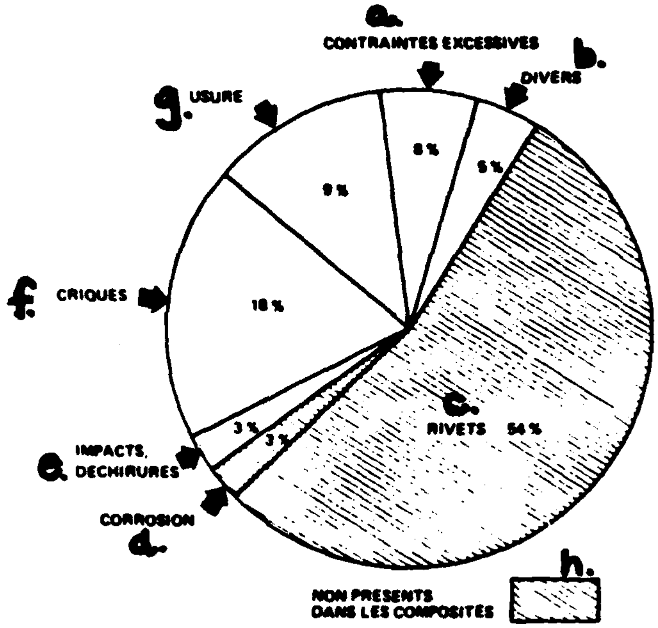


Fig. 10. Percentage of structural failures detected on the UH 1

a. Excessive stresses b. Various c. Rivets d. Corrosion e. Impacts, tears f. Cracks g. Wear and tear h. Not present in composite materials

Evolution of Secondary Structures

The chronological evolution of secondary structures of Aérospatiale can be summarized in the following table:

Year	Craft	Type of Structure
1955-1960	ALOUETTEs	--Welded or riveted light-alloy structure monolithic --Glassfiber structures
1960-1974	SUPER-FRELON PUMA GAZELLE DAUPHIN I	--light-alloy structures --glassfiber composite structures ·monolithic resins: polyester or epoxy ·Nomex sandwich
1974	ECUREUIL	--light-alloy pressed structures --thermosetting polycarbonate structures --foam/glassfiber sandwich structures
1978	DAUPHIN II SUPER PUMA Future craft	Metal structures replaced by: --carbon-Kevlar monolithic composite structures · Nida Nomex or Nida paper or foam · Kevlar skins

A few examples illustrate this evolution on cowls, cabin doors, canopies, cabin floors, and the paneling with the indication of the relative price or weight savings obtained by the evolution of design.

Fig. 11. Engine cowl of the SA 330

/29

	Cowl 330 Engine	Cowl BTP 350	Cowl Engine 365 N	Cowl BTP 366 G
Year of Design	1965	1974	1978	1980
Type of Structure	Metal (dural)	Glass fabric or foam	Glass fabric and Nida	Kevlar fabric and Nida
Weight/m^2 (kg)	2.8	2.3	1.5	1.3
Fabrication time (per m^2)	100	2.3	3.8	5.0
Price of material (per m^2)	100	200	600	800
Total Cost (per m^2)	100	5.	11.3	15

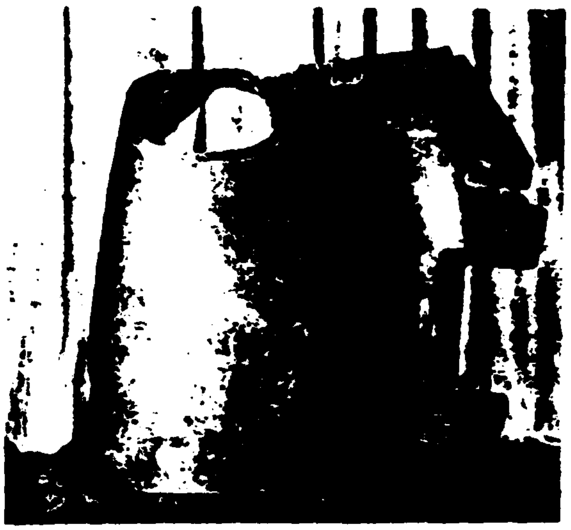


Fig. 12. BTP SA 366 G cowl

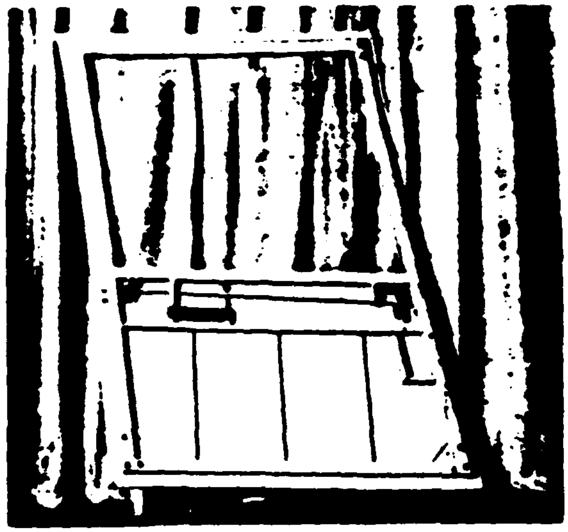


Fig. 13. SA 365 C sliding door

Cabin Doors

	SA 365 C DAUPHIN Sliding Door	AS 350 ECUREUIL Passenger Door	SA 366 G DAUPHIN Sliding Door
Year of Design	1974	1974	1980
Technology	Light-alloy with welded frame and riveted cover	Pressed door of light-alloy (A.SGM) plate	Monolithic door of Kevlar fibers reinforced w/carbon
Weight, kg/m^2	6.1	5.2	4.2
Price ratio	100.	33.	31.

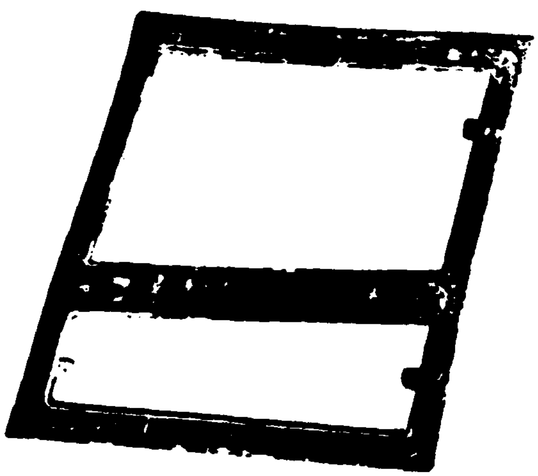


Fig. 14. SA 366 G sliding door

Canopies (Cockpit Structures)

	ECUREUIL AS 350	DAUPHIN SA 360 SA 365 N	DAUPHIN II
First Flight	1974	1972 1979	Future
Type of fabrication	Fuselage structure stiffened with poly-carbonate with glass-fiber, thermoformed. Assembly by gluing and "ultrasonic" welding or resistance welding	Welded tubular structure, AG 5	Carbon-reinforced Kevlar structure obtained by molding
Price Ratio	1	4	2
Advantages	No risk of corrosion Ease of fabrication Great reduction in number of parts	Weight slightly below 5%	Weight savings 20% Improvement of interior and exterior esthetics. No risk of corrosion.

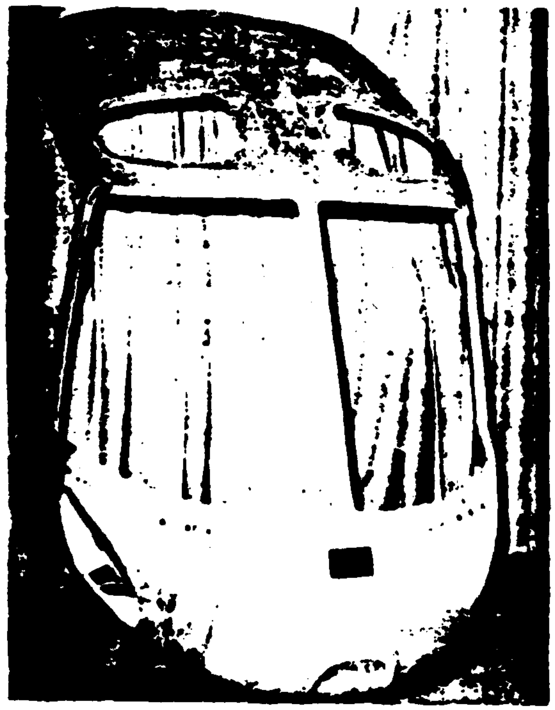


Fig. 15. Canopy of AS 350

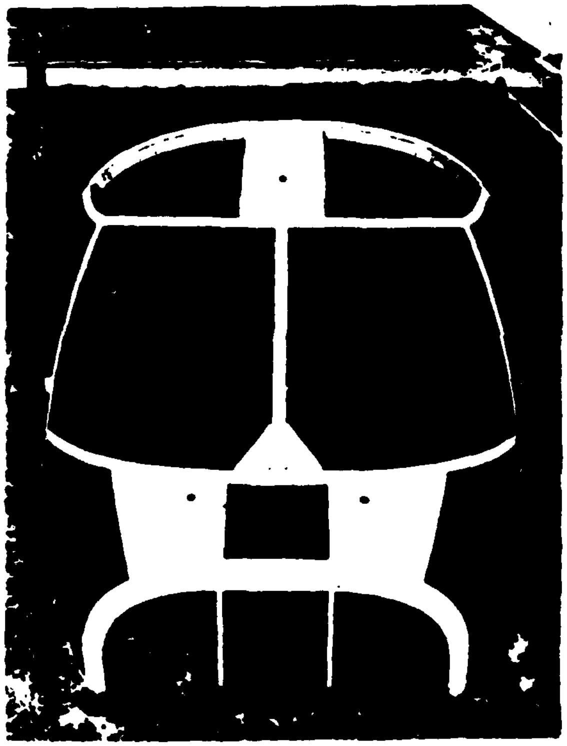


Fig. 16. Canopy of SA 365 N /30

Cabin Floors

For the SA 366 G, the quest for a weight savings resulted in the development of an all-composite cabin floor in place of the metal sandwich construction of DAUPHIN N.

Bending strength
Shear resistance
Better ball impact strength
Weight savings: 1 kg/m^2 or 20%
Relative cost: 170%

Interior Paneling

	SA 365 N	SA 366 G
Year of design	1978	1980
Technology	Thermoforming	Molding
Material Used	Royalite	Preimpregnated glass or Kevlar
Relative Weight Savings	Ref.	Preimpregnated glass +17% Preimpregnated Kevlar +44%
Relative Cost	Ref.	Preimpregnated glass x1.55 Preimpregnated Kevlar x2.14

Evolution of Primary Structures

As for the secondary structures, the composites are beginning to be used on primary structures. This evolution really got underway only when the designers thought they had enough experience to:

--design and calculate the composite parts;
--manufacture them commercially while assuring good steady quality;
--check them;

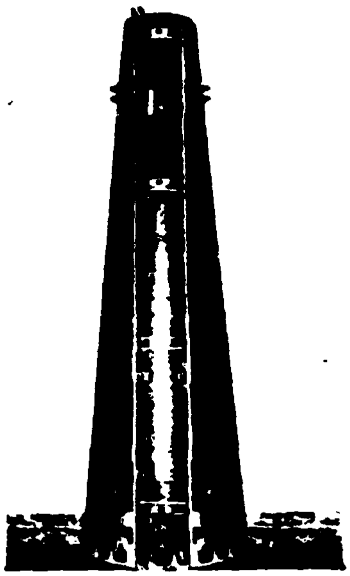
all this, of course, at an acceptable cost for the advantages obtained.

Years	Craft	Type of Structure
1955-1960	ALOUETTEs	Latticework structure of welded steel tubes
1960-1974	SUPER-FRELON PUMA GAZELLE DAUPHIN I	Conventional light-alloy structures: --stiffened thin plates --assembly by riveting or welding
1974	ECUREUIL	Light-alloy structure: --thin plates stiffened by stamping --assembly by mechanical riveting
1978	DAUPHIN II N	Sandwich structure: --Nida Nomex covers of very thin light alloy, glued --assembly by mechanical riveting
1980	DAUPHIN II N1 Futurecraft	Metal structures replaced by: --Carbon-Kevlar composite structures --Assembly by gluing

Some examples illustrate this evolution on the tail section, the horizontal empennage, the vertical tail fins.

Tail Section /31

	SA 360C DAUPHIN	AS 350 ECUREUIL	SA 365 N DAUPHIN	SA 365 C Project
First flight	1972	1974	1979	
Type of Structure	Rigid sheet cover Thickness 0.6 mm Light alloy	Slightly stiffened sheet cover Thickness 1 mm Light alloy	Honeycomb sandwich Thickness of covers --0.5 mm ext. --0.1 mm int. --light alloy	Wound carbon
Specific weight	4 kg/m^2	4.2 kg/m^2	3.5 kg/m^2	3.4 kg/m^2
Price ratio	100	13.6	11.1	40
No. of parts	295	90	52	10



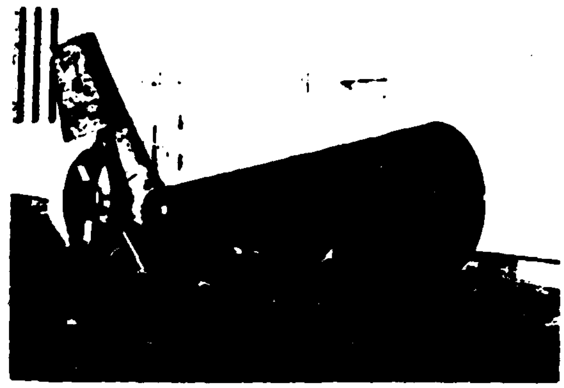


Fig. 18. Carbon tail boom project for SA 365 C

Fig. 17. SA 360 C tail boom

A wound carbon tail section for the DAUPHIN C has been evaluated in static tests and for fatigue. The 15% weight savings objective over the metal tail section of the SA 365 C was met, with a price reduction of 60% (fig. 18).

The technique used for the DAUPHIN 365 N therefore permits clearly greater price savings with about a 15% weight savings.

Research is being conducted on the all-composite tail sections for the purpose of defining the most suitable fabrication process (draping, winding...).

Tailplane and Vertical Tail Fins

Horizontal Empennage

	DAUPHIN SA 360	DAUPHIN SA 365 N
First flight	1972	1980
Type of structure	Two semi-empennages of light alloy assembled by a tubular steel longeron going from one end of the tail boom to the other	Monolithic empennage, twin longerons of carbon fiber going from one end of the tail boom to the other
Unit weight	16 kg	9 kg
Total price	100	45
Labor	100	7
Material	100	560
No. of parts	63	24

Fig. 19. Horizontal empennage and vertical tail fins (SA 365 N)

Lateral Tail Fins

	AS 350 ECUREUIL	SA 360 DAUPHIN	SA 365 N DAUPHIN
Technology	Pressed sheet Light alloy ASGM·0.3	Sandwich Light alloy Honeycomb	Sandwich Carbon fabric Foam
Design	1974	1972	1978
Weight/m^2	8.8 kg	5.1 kg	4.2 kg
Material cost (%)	10	15	100
Fabrication time (%)	160	240	100
Total cost (%)	60	90	100

Equipment and Accessories /32

A new technology was developed for the fabrication of the frame of the rescue hoist of the SA 366 G. It is based on the use of stranded carbon.

Those strands, which have the advantage of being able to take on complex forms, are deposited dry on a silicone mandrel in the form desired, and then it is all placed in a metal mold. The epoxy resin is then injected under pressure and then polymerized at 120° C.

The weight savings obtained on that part compared with the metal construction is great--40%, for a 20% increase in cost.

Metal Project	Frame	Composite Frame
Welded 15 CDV 6 steel	Materials	Carbon strands
18 kg	Weight	11 kg
100	Fabrication time	60
100	Cost of material	300
100	Total price	120

Fig. 20. Rescue hoist of the SA 366G (the hoist fairing is of Kevlar)

Other equipment or accessories are made of composites. We can mention:

--for the SA 366 G, the flotation units, the battery supports, the hoist motor support (carbon), the external rescue baskets (glassfiber), a pilot seat design of Kevlar;

--for the DAUPHIN N, some winch cables and cargo sling cables of Kevlar 29.

Metal Design	Part	Composite Design	
	<u>Front Unit</u>		
Light alloy	Materials	Carbon fabric	
Glass fabric			
Steel tubes	Weight savings	25%	
	Relative savings	56%	
	<u>Rear Unit</u>		
Light alloy	Materials	Carbon fabric	
	Weight savings	24%	
	Relative cost	50%	
	<u>Rescue basket of SA 366 G</u>		
Welded mild steel	Materials	Glassfiber	
17 kg	Weight	12 kg	
	Fabrication time	60	
	Cost of materials	120 in %	
	Total price	90	
	Weight savings	30%	
	<u>DAUPHIN pilot seat design</u>		
Welded metal tubes	Materials	Glass fabric Injected epoxy Resin	Kevlar 49 Fabric Epoxy resin
9.3 kg	Weight	11.5 kg	8.8 kg
∓6 g	Load factor	∓6 g	∓20 g
	Relative cost	12 %	20%
		Better esthetics, no corrosion	
	<u>Winch cable project for DAUPHIN N</u>		
Steel	Materials	Kevlar 29	
1500 daN	Rupture	1500 daN	
7.3 kg	Total weight for 75 m	3.3 kg	
	Weight savings	55%	
	Cables for cargo sling project DAUPHIN N		
Steel	Materials	Kevlar 29	
8000 daN	Breaking strength	8200 daN	
13.1 kg	Total weight	6.6 kg	
	Weight savings	50%	

Control Lever

For the SA 365 G, Aérospatiale has also developed a pitch control lever made of carbon. This is a vital part heavily subject to fatigue which has replaced steel levers and has permitted:

--a weight savings of 45% /33
--a cost reduction of 20%,

with an endurance limit of more than 10,000 hr (fig. 21).

It was determined by fatigue tests that the deterioration of the part was revealed by the appearance of slow delamination in the zone of greatest curvature.

Fig. 21. Carbon pitch control

A Recent Example of Application of Composites: the fenestron of the DAUPHIN SA 366G

The rear rotor solution, integrated and dubbed "fenestron," was adopted for the first time in 1968 on a production 341 GAZELLE in place of the conventional rear rotor. Since then, that solution has been applied on several Aérospatiale craft, in view of its interest in ground and near-ground safety, with notable improvements over the initial definition, particularly on the aerodynamic performance in stationary flight (figure of merit).

In view of the use of the 4-t DAUPHIN N, it was necessary to launch a fenestron with a diameter increased from 0.9 to 1.1 m in 1980 with the main objective of reducing to the strict minimum the load from the fenestron/fin assembly by the use of carbon/Kevlar composites, the molding technique moreover easily permitting the making of blad and section forms resulting in an aerodynamic improvement of the rotor (more than 10% gain in stationary performance, more than 30% for stall).

As for the main hubs, the use of composites has also permitted a simplification of the design, resulting in a cost reduction.

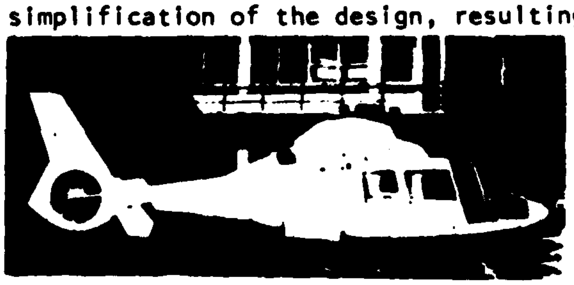


Fig. 22. Enhanced DAUPHIN fenestron

Technological Solutions

Rotor (fig. 23)

The technology used on the first-generation fenestrons (GAZELLE-DAUPHIN) was relatively conventional, with 13 metal blades, a stacking of torsional steel sheets to transmit the centrifugal forces, and various stamped and machined parts.

The enhanced fenestron rotor, developed for future versions of the DAUPHIN, has only 11 blades. This reduction in number of blades was made possible by the relative lightening owing to the composite materials, which in each blade compensates for the chord increase effect on the centrifugal forces.

The blade longeron, made of Kevlar, extends into the central zone of the hub in the form of a wound cluster which transmits the centrifula forces and therefore advantageously replaces the stacking of the metal sheets of conventional technology.

EVOLUTION OF THE REAR FENESTRON ROTOR
COMPARED WITH 0.9-M ISODIAMETER

Original 1972 Fenestron

Enhanced 1981 Fenestron

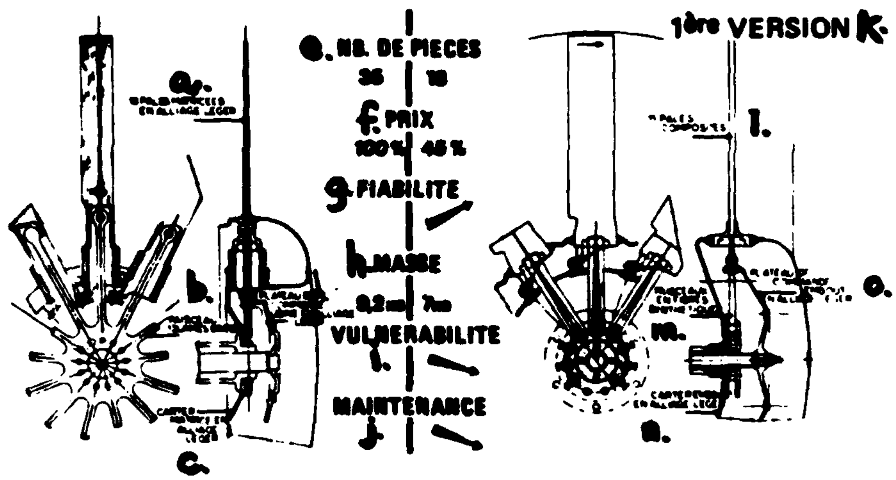


Fig. 23. Evolution of the fenestron rotor

a. 13 stamped light-alloy blades b. Cluster of 13 steel blades c. Light-alloy stamped casing d. Machined light-alloy control lever e. No. of pieces f. Price g. Reliability h. Weight i, Vulnerability j. Maintenance k. First version 11. Composite blades m. Synthetic fiber cluster n. Stamped light-alloy casing o. Stamped light-alloy control plate

The hub body and its front fairing are made of pressed light-alloy /34 sheet. The control plate is a molded part made of carbon fabric and equipped with 11 metal rings to receive the spherical end fittings of the blade levers.

--Structure (fig. 24)

Like the rotor, the rear structure assembly including the end of the tail boom, the duct and its fairing, the rotor support and the vertical tail fin has seen its technology evolve fundamentally.

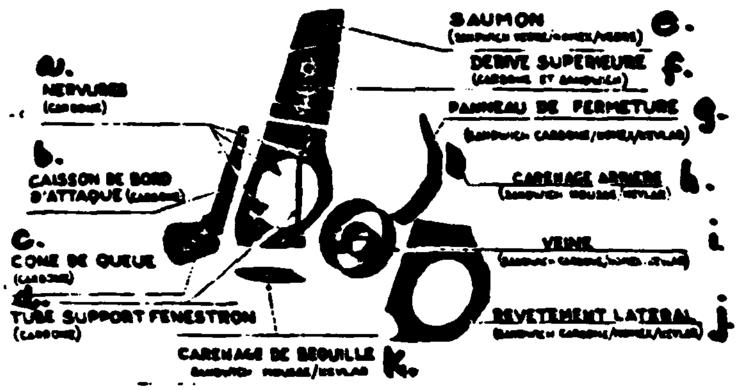


Fig. 24. Exploded view of the after structure

a. Ribs (carbon) b. Leading edge spar c. Tail cone (carbon) d. Fenestron support tube (carbon) e. Tip fairing (glass/Nomex/glass sandwich) f. Upper fin (carbon and sandwich) h. Lid (carbon/Nomex/Kevlar sandwich) h. Rear fairing (foam/Kevlar sandwich) i. Duct (carbon/Nomex/Kevlar sandwich) j. Lateral sheathing (carbon/Nomex/Kevlar sandwich) k. Lever fairing (foam/Kevlar sandwich)

On the first-generation (GAZELLE-DAUPHIN), the construction was conventional; the structures were metal, light-alloy sheet, stiffened by frames, ribs, and longerons, and assembled by riveting.

Composite materials have been used for the construction of the assembly of the rear structure of the new, 1.1-m fenestron, either in the form of monolithic carbon parts for the highly loaded zones or in the form of a carbon/honeycomb/Kevlar sandwich.

This rear structure includes several detachable sub-assembles:

The shaped vertical tail fin, made of carbon fabric preimpregnated with epoxy resin. The architecture presents a stressed cover stiffened by a honeycomb/Nomex sandwich built on a main longeron and a rear rib.

The fin tip made in the form of a glass/Nida Nomex sandwich.

The duct and its aerodynamic fairing is the most complex element, both as to form and the loads it has to transmit. This element is composed of several molded parts of a more or less complex geometry, which are then assembled by gluing:

--the main part, monolithic and made of carbon, is a compartment forming the end cone of the tail boom and the leading edge. It is molded in a single operation in a "hollow mold," an inflatable balloon on the inside which provides the necessary pressure for the fabrics.

--the duct proper, including a rounded lip, a cylindrical part at right angles with the blade ends, a light 10° divergent, conical diffuser, and an evolutive outlet radius, is in the form of a carbon/Nida/Kevlar sandwich;

--the stiffeners and the ribs are molded carbon:

--the panels are in the form of a carbon/Nomex/Kevlar sandwich.

With respect to dimensioning, the essential problem was to select the necessary overdimensioning to consider, given the effects of aging on the composite materials in the relatively hot environment linked to the presence of exhaust gases. As to the development of the products, the not

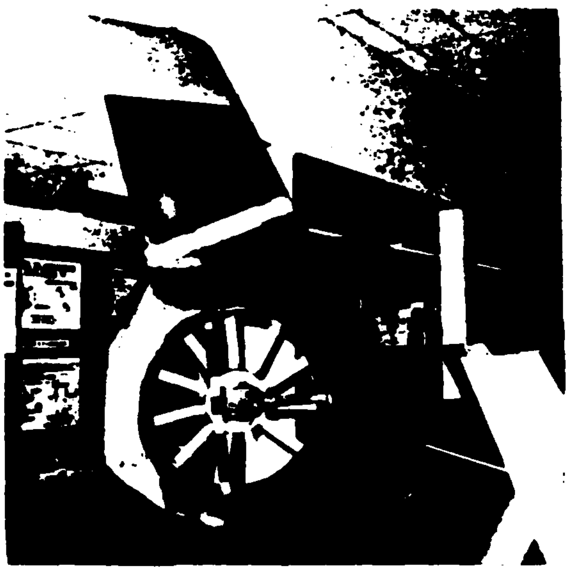


Fig. 25. SA 365 N1 tail fin

Fig. 26. Fenestron duct

insignificant difficulty encountered is that linked to the geometry of the molds, whose dimensions must be evaluated with care, taking into consideration the differential expansion effects during the polymerization cycle. /35

With respect to technology, the use of high-strength composites based on carbon and Kevlar made it possible to attain relatively ambitious objectives: it has been confirmed that their use, on the rotor and on the structure, permits weight savings of 20 to 25% for a rotor of the same diameter.

The simplification and the reduction in the number of parts permits a substantial reduction in the fabrication cost, as well as in the maintenance

Light-alloy tail fin SA 365 C		Composite tail fin SA 366 G
1971	First flight	1981
231	No. of parts	88
5900 rivets	Assembly	Gluing, 2 phases
100	Weight with same diameter (%)	78
	Fabrication cost (%)	
100	Material	200
100	Labor	50
100	Total	66.

Recapitulation of Work Completed

The following table and fig. 27 show, for the examples mentioned in this paper, the weight savings resulting from the use of composites and the relative cost in relation to the equivalent metal parts.

Except for the blades, the weight savings of from 15 to 50% compared with the metal parts. The cost of the composite part frequently exceeds that of the metal part when carbon is used; however, when the design can be sufficiently simplified by the use of composites, a lowering of the cost can be obtained (example of the carbon and Kevlar fin of the fenestron of the DAUPHIN SA 366 G).

Kevlar, used along or in association with high-strength carbon, broadens the field of application of the composites, owing to its lower density and cost compared with those of carbon, and the trend is to increase its use, as the cost analysis conducted by Aérospatiale in 1979 indicated.

Development Methodology for Elements of Composite Materials /36

The production of elements made of composites requires:

--new methods of design and calculation (owing to the anisotropy and the heterogeneity of the material);

The methods for calculating by finished elements permits in particular a fine analysis of the deformations in the critical zones (zones of attachment, zones of sharp curvature...).

The calculation margins must take into account the cumulative effects of aging and of the dispersion of the mechanical characteristics of the base materials. A good knowledge of the material with respect to aging

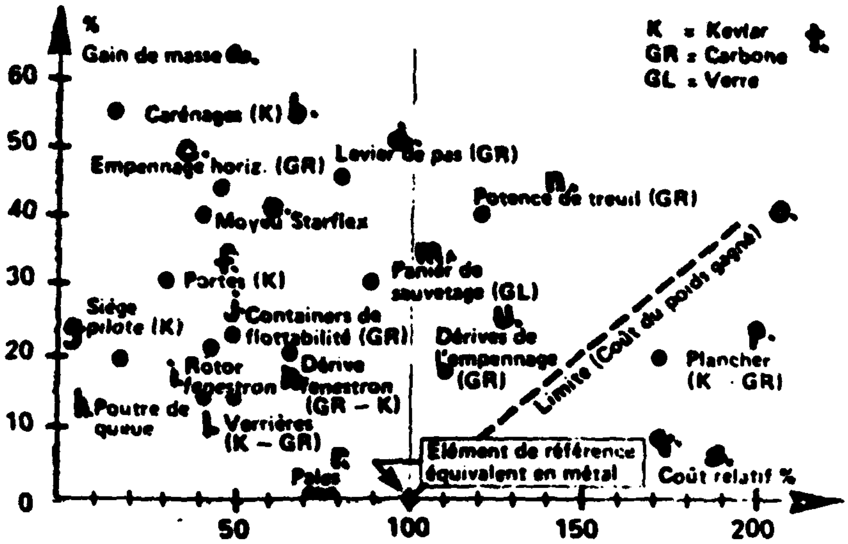


Fig. 27. Recapitulation

a. Weight savings b. Fairing c. Tailplane d. Pitch control e. STARFLEX hub f. Doors g. Pilot's seat h. Tail boom i. Fenestron rotor k. Fenestron fin l. Cowls m. Rescue basket n. Winch frame o. Limit (cost of weight saved) p. Floor q. Equivalent metal reference element r. Blades s. Relative cost % t. K = Kevlar Gr = carbon GL= glass u. Empennage fins

		Weight Savings(%)	Relative cost (%)
Main rotor	STARFLEX hub	40	40
	blades		70 to 80
Secondary structures	Cowls* (Kevlar)	55	15
	Doors (Kevlar)	31	30
	Canopy (Kevlar and carbon)	15	50
	Floor (carbon and Kevlar)	20	170
Primary structures	Tail boom (carbon)	15	40
	Tailplane (carbon)	44	45
	Tail fins (carbon)	18	110
Accessories and equipment	Winch frame (carbon)	40	120
	Buoyancy container (carbon)	≃25	≃50
	Rescue basket (glass)	30	90
	Pilot seat (Kevlar)	20	20
	Winch cable (Kevlar)	50	
Controls	Pitch control lever (carbon)	45	80
Fin/fenestron assembly of DAUPHIN SA 366 G	Rotor	24	45
	Fin (carbon and Kevlar)	22	66

*In relation to glass cowls, the weight savings due to Kevlar would be 13% and the relative cost, 130%.

in temperature and in presence of moisture) and to fatigue (damaging and fracture mechanism) is necessary.

--new methods of fabrication for cutting fabrics (laser or fluid jet) for employing fibers or fabrics (draping, winding...) for gluing reinforcements, in particular for the introduction of loads;

--new methods of non-destructive testing (ultrasound, holography, IR spectrography, acoustic emission, scanner....).

Experience shows that it is difficult to obtain elements of composite materials with constant characteristics in production. It is therefore indispensable, for parts requiring a certain level of quality, to put into place an organization making that guarantee, which implies checks on the base materials when composites are used and on the polymerized product.

Future Prospects for Composite Materials

New Materials

For the helicopter, two types of new products can be developed in the years to come.

Reinforced Thermoplastics

Without questioning the future of thermohardening resins in high-performance aeronautical composites. the thermoplastic formula offers a certain interest in medium and large-scale production.

Indeed, the use of epoxy-type thermohardening resins requires a polymerization treatment under high temperature (120° C at a minimum) which is performed in an autoclave or a convection oven. The length of the treatment, one or two hours, allowing for the time needed for warming up and cooling of the chamber and the mold, indeed amounts to an end to tooling, which now takes six to ten hours. /37

In aeronautical production, this operation, which is often performed during "masked" time or outside the normal work day, does not pose very serious time equipment problems so as to cause a bottleneck in the production cycle.

The thermoplastic formula represents a process in which the material is formed by a simple softening by heat of very short duration, the final appearance being acquired by the return to ambient temperature (forming at a temperature of 200 to 300° C and a pressure of 10 to 100 bars).

The essential advantage which it has therefore bears on the length of the treatment, which can be reduced from several hours to a few minutes, even a few seconds.

Thermoplastics reinforced with glass filaments are already used in helicopter construction (case of the canopy on ECUREUIL, for example) in the form of materials molded by compression or thermoformed sheets.

The reinforcement is generally composed of dispersed short filaments and imparts a mechanical strength to the material which is greater compared with pure resin, but still relatively modest. The strength at the points of attachment and the introduction of stresses notably remain subjects of concern.

The most interesting formula for aeronautics is effective reinforcement by dispersed filaments of great length and in heavy proportion, or, better, by layers of ordered and directed filaments (based on presently commercially available fibers and on polyamide, polycarbonate, or polysulfone, or other resins).

Beyond the advantage of production mentioned above, these materials would be characterized by the following properties:

--very high elongation at rupture of the resin (more than 30%);

--mechanical strength which ought to attain at least 80-85% of those obtained with thermohardened resins in an equivalent proportion of the reinforcement content;

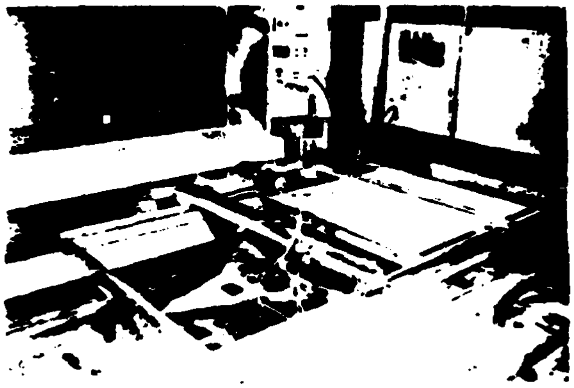


Fig. 28. Ultrasound testing of the STARFLEX star plate

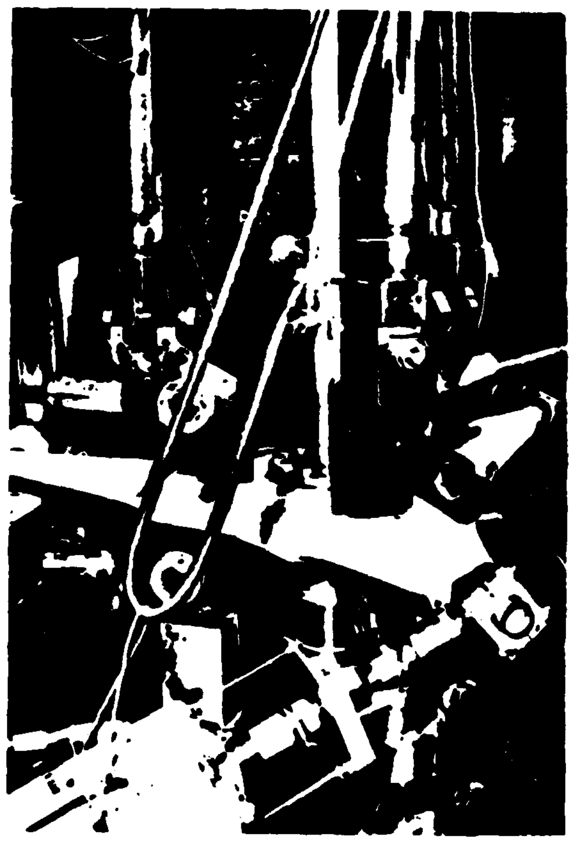


Fig. 29. Fatigue test of the STARFLEX star plate

--good stability in aging and against chemical agents;

--resistance to shock higher than thermohardened resins;

--moderate heat resistance.

The technique is at present the object of many identified research activities, notably in the automobile industry, but no base product truly meeting the definitiion of plastic reinforced by filaments of sufficient length and proportion is yet commercially available.

The use of reinforced thermoplastics ought to prove advantageous for products of a repetitive nature. The application of filament windings can be interesting for elements of the transmission structure and of flight controls.

Metal-Matrix Composites

Composite materials, resins reinforced with glassfiber, carbon, or Kevlar have been substituted in a number of cases for metal materials owing to their strength and their high specific modules as well as to the ease of use.

However, those materials present certain weaknesses which limit their use: resistance to temperature, weak resistance to interlaminar shear, partial loss of their original qualities after aging.

The reinforcement of metal materials with fibers makes it possible to obtain fibers which preserve the properties of the metals with a notably improved resistance to temperature and mechanical characteristics at the level of the best conventional composites.

The reinforcing fibers can be of various types. There are now on the market or about to be marked composites based on:

--boron fibers;

--silicon carbide;

--aluminum fibers (F. P. fiber of Dupont de Nemours).

Magnesium and its alloys are particularly compatible with the F. P. fiber, which they wet naturally, allowing good impregnation and a solid bond between fibers and metal.

Fig. 30 shows the gain in the longitudinal direction brought to the magnesium alloy QE 22A-T5 by a 50% reinforcement with FP fibers. In the transverse direction and in shear, the characteristics are close to those of the metal.

For the helicopter, this type of composite offers great interest for various devices, such as:

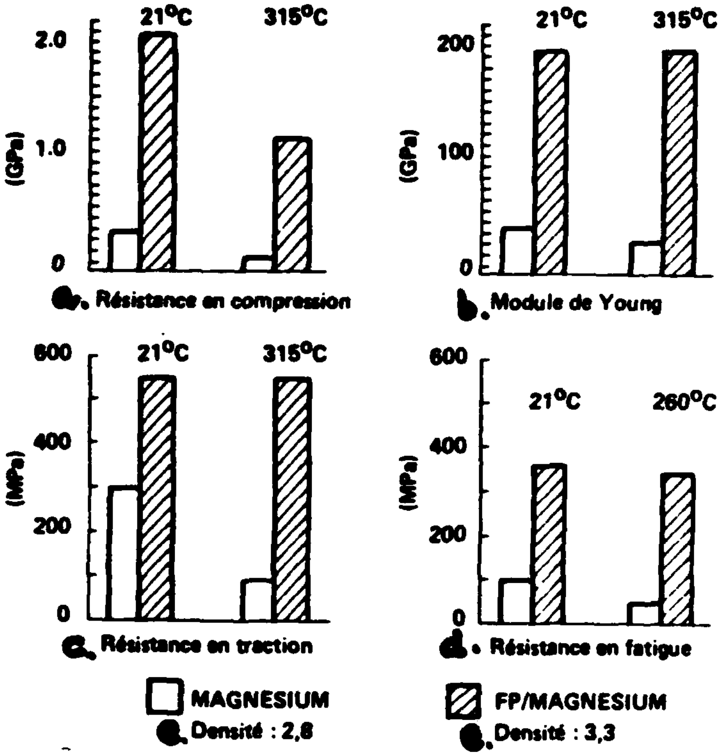


Fig. 30. Comparison of an FP/magnesium composite of 50% by volume with a non-reinforced magnesium alloy (QE 22A-T5)

a. Compressive strength b. Young's modulus
c. Tensile strength d. Fatigue strength
e. Density

--the main gearbox, where the fiber improves the strength and permits a rigidification over that of magnesium:

--elements of the rotor control linkage (pitch control lever, for example);

--the main rotor shaft, mainly owing to the reinforcement resulting from the fibers in the zones connecting with the gearbox and the hub.

Future Possibilities

The new paths offered by the new materials like reinforced thermoplastics and metal-matrix composites, the broadening of the application of the well known composites based on glass, carbon, and Kevlar, will bring advances in performance, economy of operation, and safety.

In the United States, under ACAP (Advanced Composite Aircraft Program) of the US Army, a contract was awarded in April 1981 to Bell and to Sikorsky to develop, starting with the Bell 222 and the S76 respectively, airframes of composite materials meeting the military crash specifications, vulnerability to 12.7 and 23 mm, resistant to the laser weapon and low radar detectability, with the objective of a weight reduction of 22% compared with the base metal model.

In France, Aérospatiale is now evaluating within its research program various composite elements, such as:

--the Triflex hub, whose flexible arms are composed of glass/epoxy resin rods embedded in a polyurethane or silicone elastomer (figs. 31 and 32);

--the rotor shaft and the drive shafts of wound carbon (weight savings of 30 to 40% over metal);

--elements of the control linkage of carbon: fixed plate, mobile plate, in the form of a carbon box filled with foam (weight savings 40% over metal);

--landing gear wheels made of a glass or carbon compound.

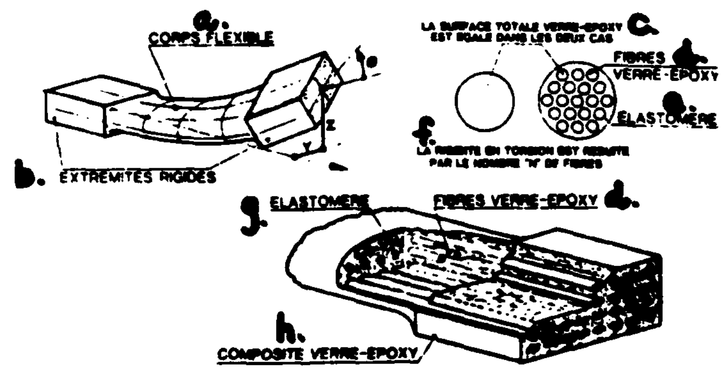


Fig. 31. Flexibility of the Triflex arm under torsion

a. Flexible body b. Rigid extremities c. The total glass-epoxy area is equal in the two cases d. Glass-epoxy fibers e. Elastomer f. Rigidity under torsion is reduced by the n-number of fibers g. Elastomer h. Glass-epoxy composite.

The composite elements of the DAUPHIN SA 365 NI appear on the exploded view in fig. 34. They account for 19% of the empty weight of the equipped craft, which is M_{ve} = 2038 kg.

It is of interest to calculate the percentages of the other materials for that and to estimate what they might be on a future DAUPHIN coming off the assembly line in five years:

	Today on the SA 365 N1 % of M_{ve}	Future DAUPHIN % of M_{ve}
Light alloys	34.5	32
Steel	31	30
Titanium	1	1
Composites	19	22
Other	14.5	15
	M_{VE} = 2038 kg	M_{VE} = 1950 kg

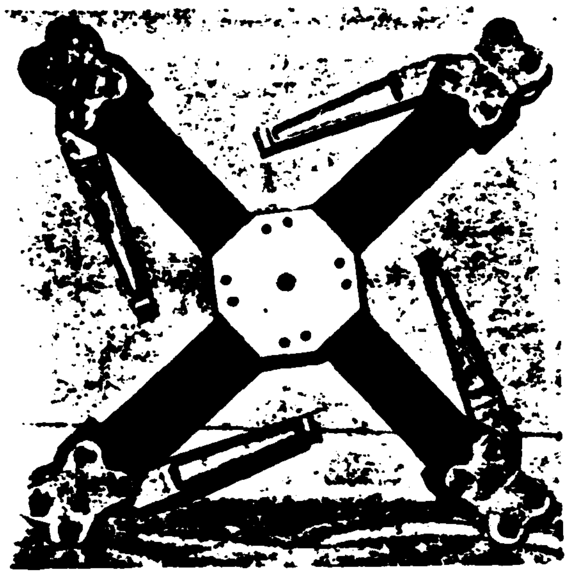


Fig. 32. Main triflex rotor hub for the SA 349.2

Compared with a reference weight m_{ref} defined by:

$$m_{ref} = M_{VE} - \text{weight power installation} - \text{weight auxiliary units} - \text{weight of control and navigation instruments}$$

the percentage of composites for various craft is given in fig. 35 as a function of the year of their production. The curve indicates the evolution of the percentage of composites in the structural and machinery weight; a value of 30% is within the realm of possibility in 1990.

Conclusion

For the savings in weight, maintenance, safety and, frequently, in purchase price that they bring, composites based on epoxy resin and glass,

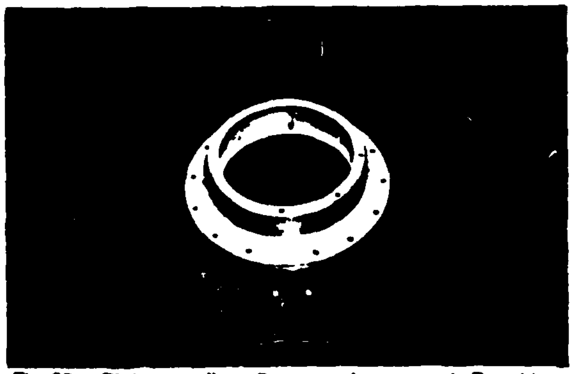
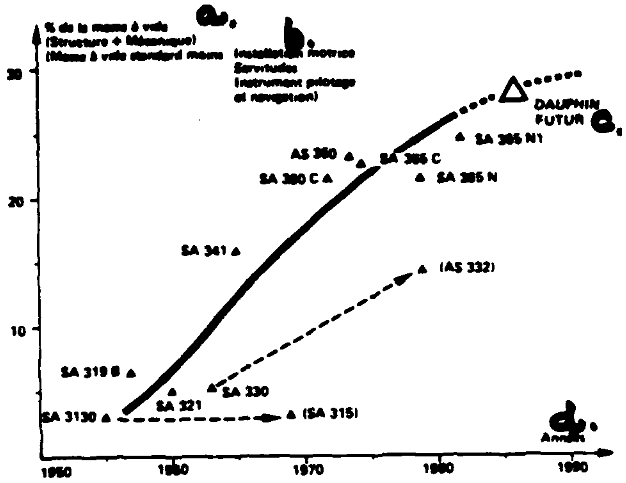


Fig. 33. – Plateau cyclique fixe en carbone pour le Dauphin.

Fig. 35. – Evolution de l'application des composites sur les hélicoptères de l'Aérospatiale.



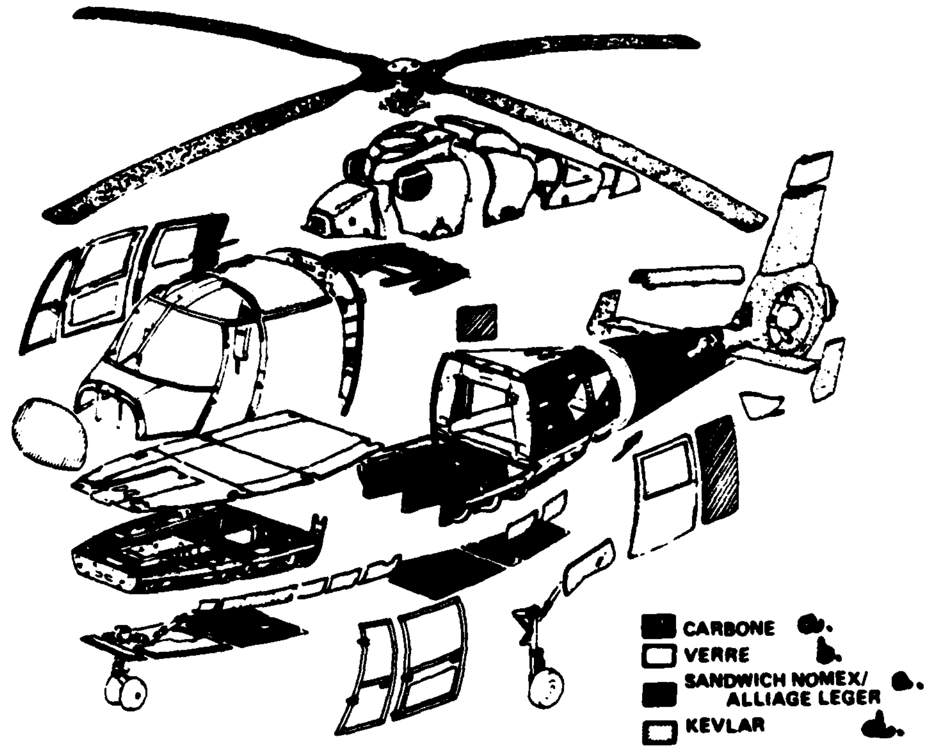


Fig. 33. Fixed carbon flange for the DAUPHIN
Fig. 34. Exploded view of the DAUPHIN N1

a. Carbon b. Glass c. Nomex/light alloy sandwich d. Kevlar

Fig. 35.a.% of empty weight (structure + machinery) (standard empty weight less b. Power installation, auxiliary units, control and navigation instruments) c. Future DAUPHIN d. Years

Evolution of application of composites on the helicopters of Aérospatiale ca.bon and Kevlar fibers have permitted advances in helicopters and expansion of their civil and military markets.

The weight savings over equivalent metal parts go from 15 to 50%. Glass fiber was the first used chronologically and continues to be particularly in blades; on primary and secondary structures and on various accessories and equipment, the trend today is to develop the use of carbon and of Kevlar with higher moduluses and lower densities, that as a function of the engineering and financial assessment made case by case.

It may be noted that, if the composites have allowed certain elements to be radically simplified owing to new designs (case of the STARFLEX hub, for example), the general architecture of the helicopter and particularly its preparation by elements remains what it was with metal construction. It is probable that in case of a larger production run, for a small craft, for example, the builder would find it profitable to integrate certain elements of the structure.

Their wide use poses more problems, for example: crash strength, resistance to 23-mm shells, but the savings elsewhere are sufficiently significant for that problem to be solved by adapting structural design principles rather than returning to traditional metal structures.

For the future, the broadening of the applications of the composites now used and the new possibilities offered by reinforced thermoplastics and the composites in metals will make the helicopter a remarkable machine with respect to its use of new materials.

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