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COMPOSITE MATERIALS: TOMORROW OR THE DAY AFTER TOMORROW

Pierre Condom

Translation of :"Les materiaux composites: demain.... ou apres-demain". Aviation Magazine International, No. 817, Jan. 1-14, 1982, pp 34-39.

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16. Abstract

A description is given of the history of the use of composite materials in the aerospace industry. Research programs underway to obtain exact data on the behaviour of composite materials over time are discussed. It is concluded that metal composites have not yet replaced metals, but that that this may be a future possibility.

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Pierre Condom

According to Cabinet experts Frost and Sullivan, use of carbon and Kevlar fibers by the aerospace industry ought to increase by 600%over the next five years. Certainly an impressive expansion, but it is only the beginning. In the 1990's, composite materials will be the only materials which will still allow substantial reductions in the weight of structures. But the engineering problems which must still be solved and the inertia of people and companies are working toward a slow development which everyone agrees is inevitable. /34*

It was in the mid-60's that the aerospace industry began to get interested in composite materials. These materials are composed of high-strength fibers (glass, boron, carbon, Kevlar) embedded in a matrix which is generally an epoxy resin, and because of their lightness and remarkable mechanical properties they can lead to very large reductions (25-50%) in weight when structural elements are being manufactured. However, in spite of the possibilities they offer, fifteen years later composites are still very far from winning the prize they were promised -- first place.

The latest of the Boeing aircraft, the 767, contains only 1533 kg of various composites out of a total empty weight of

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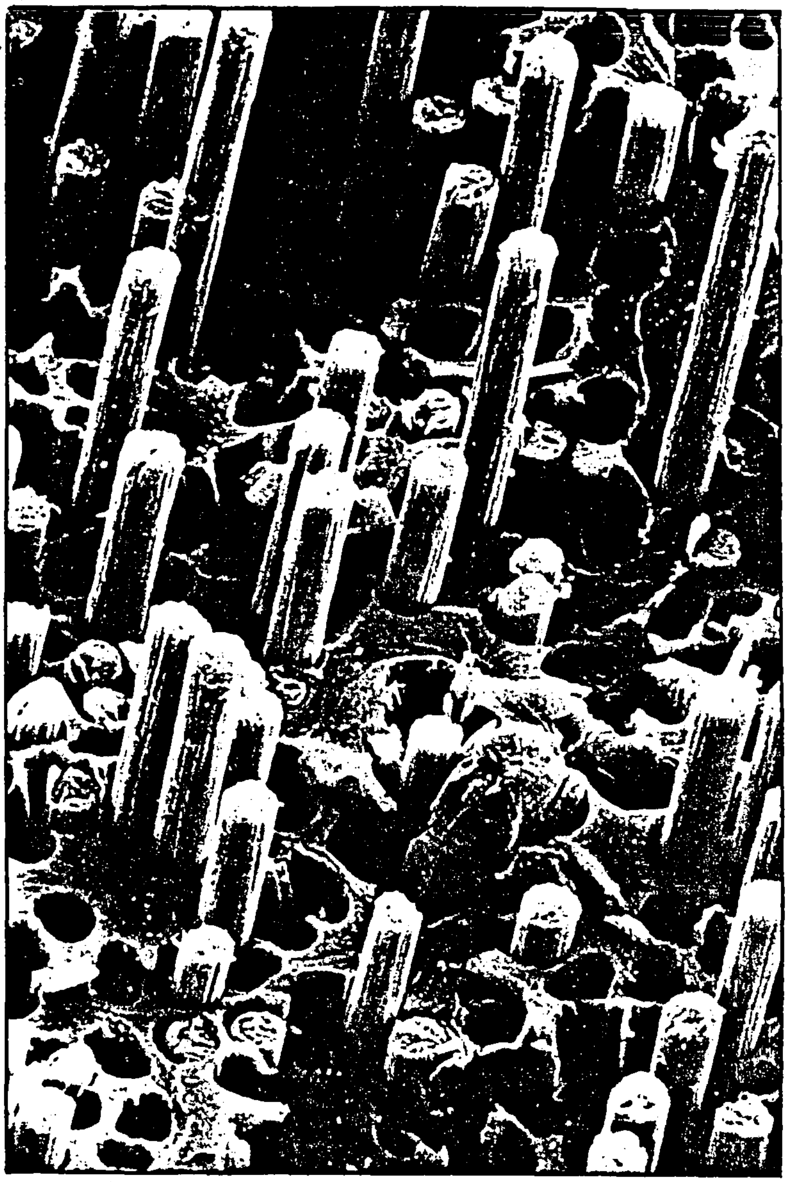


This highly-magnified section shows the typical structure of a composite: the fibers, here unidirectional, are embedded in a resin which binds them together.

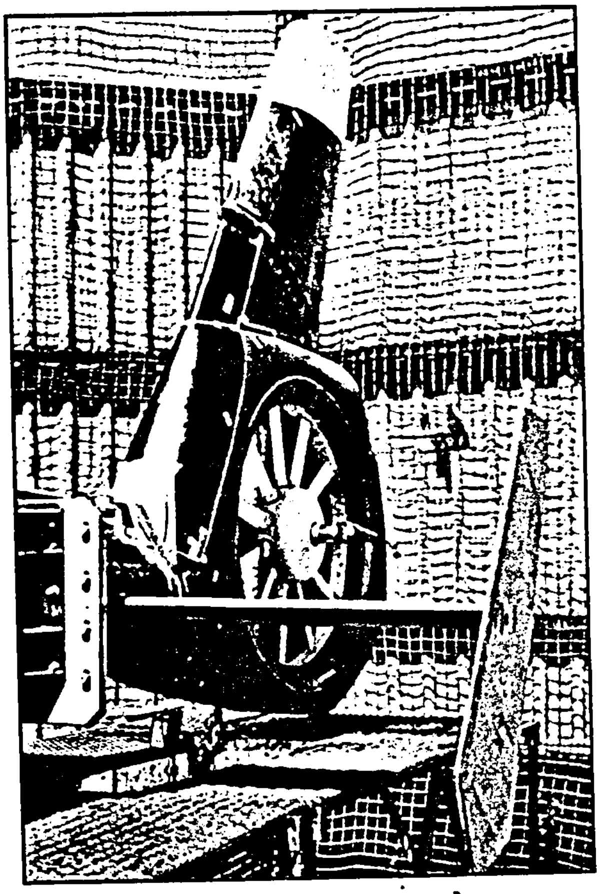
80 metric tons. However, there is a strong temptation to go much farther; the ton and a half of composites in the 767 has saved more than 500 kg weight over traditional metal construction. Engineers and industrialists have good reasons for resisting this temptation; they include both the nature of composite materials and the nature of the industrial system already functioning.

Acquiring Credibility

It was very quietly that the first composite left the laboratories for the production shops. At first investigators were taken by the possibilities offered by boron, a remarkable material weighing half as much as current aluminum alloys and three times as strong, but unfortunately impossible to use in sheet form like aluminum and its alloys. Because of this there was the idea of embedding boron filaments in a thermosetting-resin matrix to obtain a usable material; this technique has the additional advantage of allowing the mechanical properties to be modified at will by changing the orientation of the fibers.

Very quickly, boron showed its limits, due in particular to the fact that boron fibers are produced on a tungsten substrate which is difficult to cut. Investigators turned immediately to another material, also stronger and lighter than aluminum, but easier to work with -- carbon.

In spite of the difficulty of obtaining carbon fibers, and in spite of their high cost, the first results were so encouraging that some companies thought they could skip some steps; this led to some dismal failures. The best-known is certainly that of the Rolls-Royce, British engine manufacturer, who wished to lighten its RB 211 engine (20 metric tons thrust), and did not hesi-



Two Examples of the fabrication of aeronautical parts from composites. Left, a helicopter tail assembly built by Aerospatiale from carbon-fiber/epoxy. Right, a helicopter seat with sandwich construction: Febrelam, Aeroweb Nomex honeycomb, and layered glass-Araldite skin tate to build turbine blades out of carbon-fiber composite back in 1967. Rolls-Royce had to go back to metal blades very quickly after it had spent considerable money on the project.

More cautious, aircraft manufacturers were advancing step by step; their care was strongly encouraged by the cost of carbon fiber: around $1500 per kilo (against $0.60 per kilo for aluminum at the time). And so the first components in the secondary structure made of composites were flight-tested: landing-gear doors, fixed leading edges, then airbrakes, and finally fins or vertical stabilizers.

At the same time, use of lower-performance composites using less expensive fibers was developing. Thus, components appeared more and more frequently in glass-fiber/epoxy, and then in Kevlar/epoxy after Du Pont had expanded production of this aramide fiber (1973), which was originally used to reinforce automobile tires (AMI No. 797, pp. 44-47).

In fact, it was only in the early 1970's that composites acquired their first journeyman's papers in the United States, especially for the YF-16 and YF-17 engineering development programs, and in Europe, mainly among Continental helicopter manufacturers.

Maturity

Right now, the situation has changed radically. Composites have become synonyms for technological advance, and there is no builder who does not make a show of the way he uses them in his machines. Nevertheless, as we have already said, this use is still at the level of a homeopathic dose.

Unlike metals, which have substantilly the same mechanical properties in all directions, composites are anisotropic by nature: their properties depend on the orientation of the fibers; they are similar to a traditional aeronautical material, wood.

They are made up of successive layers with a high elastic modulus and a low density of fibers embedded in a resin matrix. The fibers are either unidirectional or, in the form of cloth, bi-directional. Most used are boron, carbon, Kevlar 49, and glass. The matrix is composed either of thermosetting resins such as epoxy or of thermoplastic resins such as polyester. The basic difference lies in the fact that the latter can be reformed at an elevated temperature, while the former cannot be changed once they have polymerized.

The strength of composite parts is obtained by stacking many layers of fiber materials, suitably oriented according to the forces to be sustained. This construction "to measure" has one undeniable advantage and three drawbacks which are not less evident. For one thing, the adhesion of each layer to the next remains a weak point of the material -- this is the danger of delamination. Then, creation of the material and construction of the component take place during the same operation, so that it is not possible to inspect the material beforehand, as is the case for metals; it is therefore imperative to develop methods for inspection of the finished components. Finally, cutting and superposing the layers onto a "mold" (actually a form) lend themselves poorly to mechanization of the industrial process.

Insufficient Data

The few components already made from non-metallic composites give a fore-taste of the possibilities they offer. Lockheed-georgia has carried out a parametric study which gives quite a good idea about that. They have also made a separate study of the production of a transport aircraft capable of carrying a 68-metric-ton load over 8300 km, using regular metallic construction and construction based on composites. In the first case they arrived at a machine of 363 metric tons take-off weight, with a structural weight of 174.5 tons and carrying 120.5 tons of fuel. In the second case, they ended up with a plane of 245 tons total weight; 96.3 tons were structure and 80.7 tons fuel.

This example illustrates the succession of consequences from lightening the structure. The empty weight is reduced, so the engine power required is also reduced and less fuel is burned; thus there is a new and important saving in total weight. In the case studied by Lockheed, the composite airplane required 33% less fuel for the same basic mission.

Among the other advantages potentially offered by composites, their fatigue strength, corrosion-resistance, and capability for repair must also be mentioned. But these three points do pose problems which have still not been completely solved.

The objective of most of the programs in progress is precisely to acquire exact data on the behavior of composite components over time. In some cases, one can assume that maturity has been attained. Thus, Aerospatiale's helicopter blades made from a carbon-fiber composite filled with Nomex honeycomb have an unlimited service life, unlike the metal blades which they have permanently replaced. In other cases, doubt remains even though all tests made tend to demonstrate the longevity of composite components.

One weak point, however, is resistance to impacts, which generally lead to delamination. To increase this resistance, components have been made of hybrid composites containing alternate layers of very high-modulus fibers, boron or carbon, and lower-strength but more ductile fibers, Kevlar 49 or glass. The remaining problem, that there are not enough data on the development of delamination due to an impact, is what gives the difficulty as far as certification is concerned.

Among the items which are still insufficient and hold up use of composites are fracture propagation in the resin matrix, the properties of points, titanium (A-286) or stainless-steel (MP 35N) rivets subject to electrochemical corrosion, and resistance to lightning strikes and to mold growth.

From Handcraft to Industry

Another powerful brake is the slow development of the tooling necessary for working with composites. The first pieces were produced entirely by hand. The pieces of cloth, cut manually with special knives and metal templates, were placed on the forms in successive layers, then placed in an autoclave for polymerization of the resin. A procedure completely unsuitable for mass production.

Since then, the first automatic machines have been placed in service. At Aerospatiale's helicopter division a machine using a laser to cut cloth for Starflex rotor hubs has been developed out of a cloth-cutting machine, but the stacking and the inspection of the finished pieces remain manual.

With the assistance of Du Pont, machines for cutting Kevlar-based composites, using a small but powerful jet of water, have been developed.

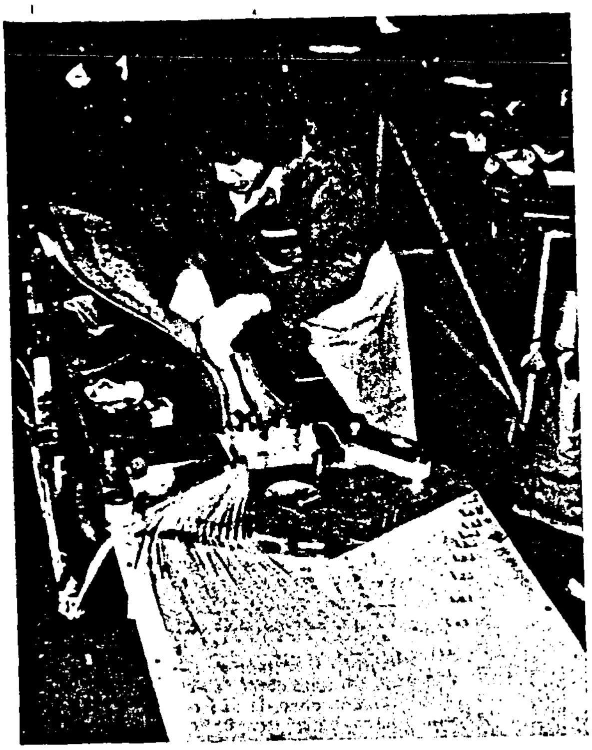
But much remains to be accomplished. Lockheed estimates that a 70% saving in labor costs is possible by application of robotics. Such a robot system remains to be developed: a long-running and expensive job which gives a basis for the optimism of the metals people who predict that the composite invasion will come only at the end of the century. A prediction which might well be contradicted by the facts if one judges by Northrup's example.

The American aircraft manufacturer has developed what it calls IFAC (Integrated Flexible Automation Center) under an Air Force contract -- a system which may foreshadow the plant of the future. It is a completely automated shop in which the pre-impregnated pieces of cloth (fiber + non-polymerized resin) are cut by a Gerber machine, placed on the forms by a Cincinnati-Milacron robot which can see the forms, and then placed in an autoclave. This shop allows production in a few minutes of structural components of the F-18A and the F-5G.

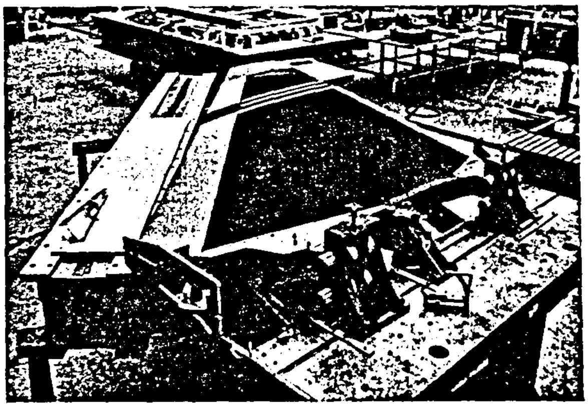
Expensive Composites

Over fifteen years the price of composite materials has dropped steadily as the market has grown and allowed production economies. At the present time, a kilogram of carbon fibers costs between $60 and $70. The downward price trend has been taking place more slowly than expected, but should continue over the next few years. However, it is hard to see how it can reach the comparatively low price of the aluminum alloys normally used, even if the cost of the latter should increase steadily with inflation.

Shops for fabricating components from composites look very much like textile shops. The techniques are also similar, and the fibers are used in the form of cloth. Left, a Dornier production shop in West Germany. Later on, these operations will have to be automated by robots. Right, assembly of a carbon-fiber rudder on an A-300.



Manufacture of a composite blade at Aerospatiale. Here one can see the sheets of fibers which make up the longerons. These blades have a stainless-steel leading edge and a Nomex honeycomb core.



At Aerospatiale, construction of a fin for the Mirage 2000: sandwich of Nomex honeycomb bonded to a titanium skeleton, with a carbon-covering fiber. Titanium works well with composites because of its expansion coefficient.

In fact, comparison of the costs of raw materials doesn't make much sense. It is the cost of the function performed by a given component which must really be considered. Such a value analysis, which takes into account the service lives of components, is quite complicated and involves many considerations which we can describe briefly.

First of all we must keep in mind that the greatest proportion of the metal received in aircraft plants leaves them again in the form of chips. Thus, Cegedur supplies about 8 tons of type 2214 aluminum alloy to Dassault-Breguet for each Mirage F1 to be produced, and about 180 tons to the Airbus Industrie partners to build one A-300, but 80-90% of the metal supplied disappears as cuttings from maching. Waste is significantly less for composites, since instead of cutting the components out of large pieces, they are instead produced by the piling up of layers, the number of layers being proportional to the strength desired.

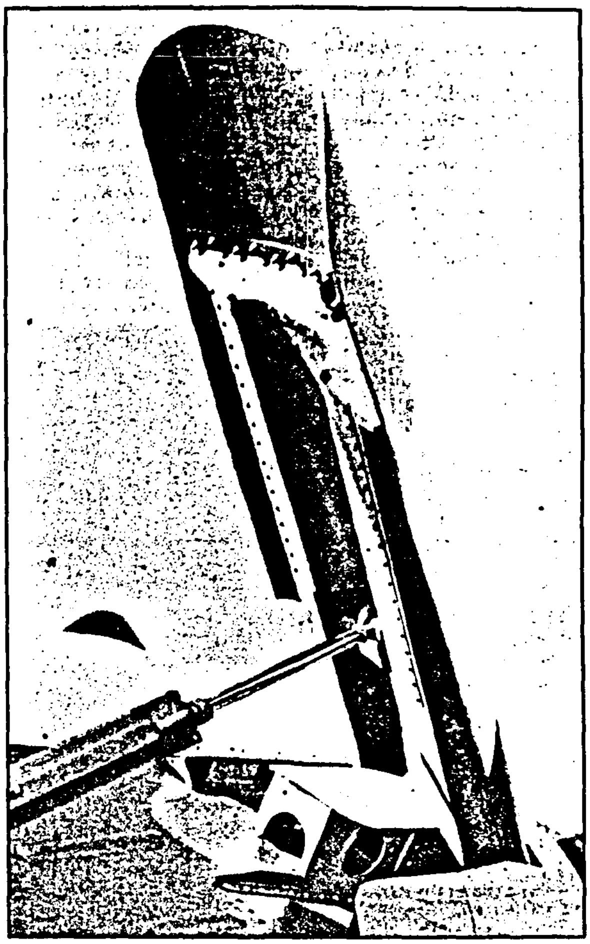
In addition, experience has shown that use of composites allows a substantial reduction in the number of components of structural assemblies. For example, the leading edge of a Lockheed C-5A Galaxy cargo plane contains more than 800 metallic components, but construction from composites allows the number to drop below a hundred. On the Rockwell B-1 bomber, the leading edge contains 70 components with ordinary construction, and only eight with composite-based construction. Lockheed has studied an even more conclusive case, that of the fin for the L-1011 TriStar. It is normally made up from 175 components assemblied with 40,000 rivets; in composite it requires only 18 parts and 5000 rivets.

But to obtain the greatest possible advantage from composites, it is essential to "think" the structure in composite, and not be satisfied with copying an ordinary metal structure. This revolution, which must take place in the design groups, is turning out to be relatively difficult. Habits of thought are hard to break, and in addition it must be acknowledged that adopting new methods of calculation and manufacturing processes and inspection procedures which are also not well-established does present a danger that aircraft manufacturers will, justifiably, accept only under the pressure of necessity - economic or technical. This is what justifies the cautious attitude of most of them, and explains the resolutely innovative attitude of companies such as Lear Avia/Lear Fan, which must at any cost win themselves a portion of the market solidly held by their competitors.

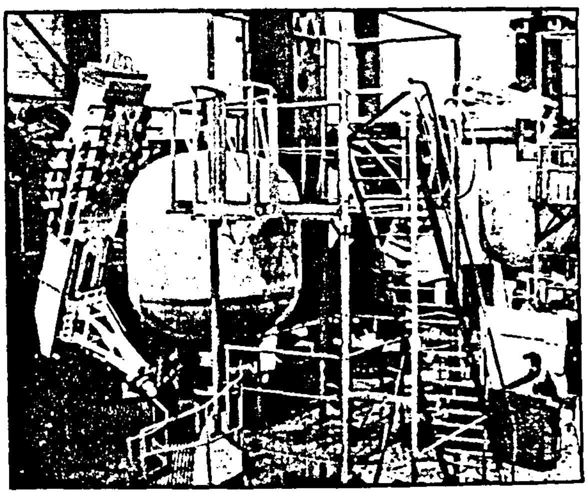
Metal Is Not Dead

Aware of the inertia of the industrial system (and of the weaknesses of composites), metals producers are not getting excited about this. To the considerations just mentioned, they answer that the large machines bought by the aircraft manufacturers still haven't paid for themselves, and it will be ten or twenty years before metal will be seriously challenged.

Aside from this, there is still a very large volume of business for the producers of special aircraft alloys. Part has already been lost by them for secondary structures and certain specific areas such as helicopter blades, but they are holding on in the area which constitutes their largest market - that of main structures. Composites have cut into production of thin sheet, of profiles, and even of medium sheet, but the market for thick plate remains attractive even if the panic of 1978-79 lead all the large companies



Dornier has undertaken a large program for use of carbon fibers, centered on the Alpha Jet. The first stage is mass production of air brakes (photo), the fin, and the horizontal stabilizers. Finally, a wing will conclude the program.



A Well broken-in technique - winding (here, glass fibers) for production of missile or rocket tankage.

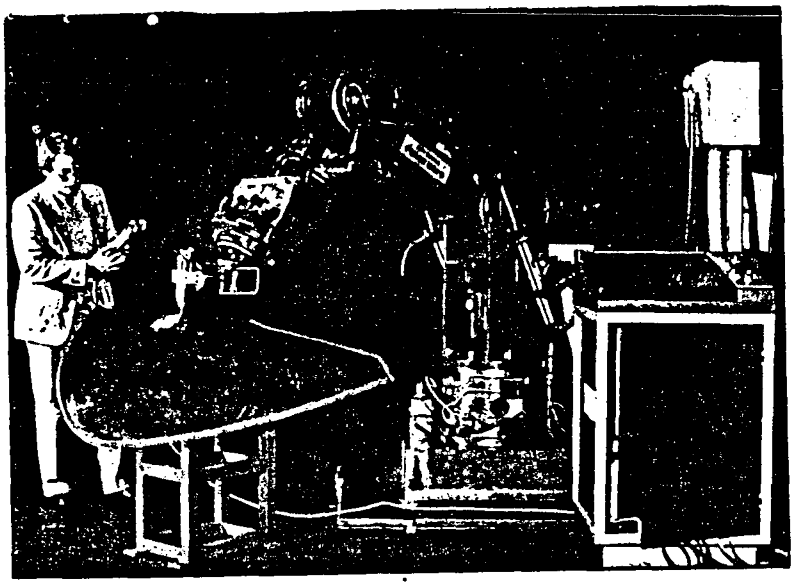
in this sector, Alcoa, Reynolds, Kaiser, and Cegedur, to invest in production facilities which may well be working under capacity in 1984-85. The simultaneous start-up of new programs by Boeing and Airbus Industrie brought about this equipment-buying; the slow market for commercial aircraft because of the air-transport crisis may well bring about the temporary overcapacity anticipated for the next few years.

While composites have elastic moduli higher than aluminum and practically limitless fatigue resistance, which allow weight savings, metal has the advantage of being better understood. Problems of fatigue have been well mastered, as well as problems related to machining. And progress is still /38
possible in elastic limits and strength. Very promising new techniques are being explored, especially powder metallurgy. In its Voreppe research center (near Grenoble), Cegedur is studying aluminum-lithium alloys produced by powder metallurgy, which have very interesting properties. There is still the step to industrialization to be made, that is, obtaining large-sized plate. In addition, all the metals manufacturers are looking into the possibilities of themselves /39
producing metallic composites in which the resin matrix is replaced by an aluminum matrix.

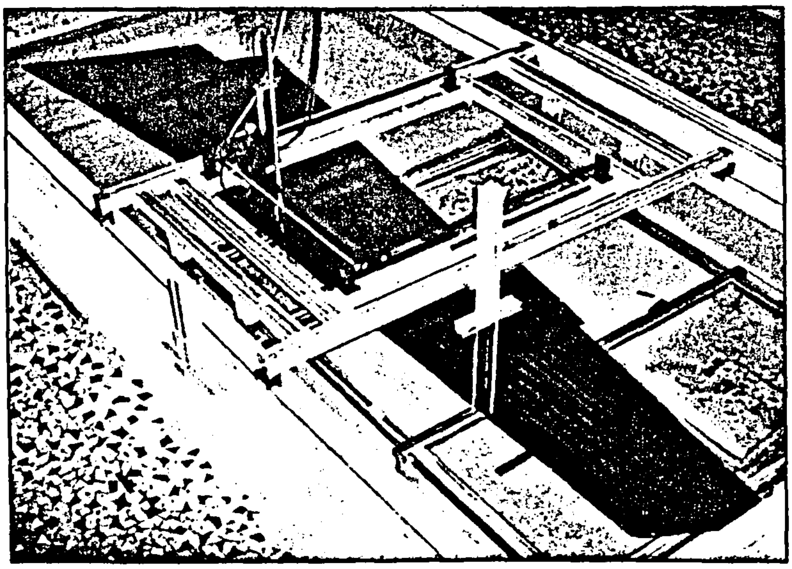
Metallic Composites.

Just as non-metallic composites are plastics reinforced with strong fibers, metallic composites are composed of metal, generally aluminum, reinforced with fibers, whiskers, or particles.

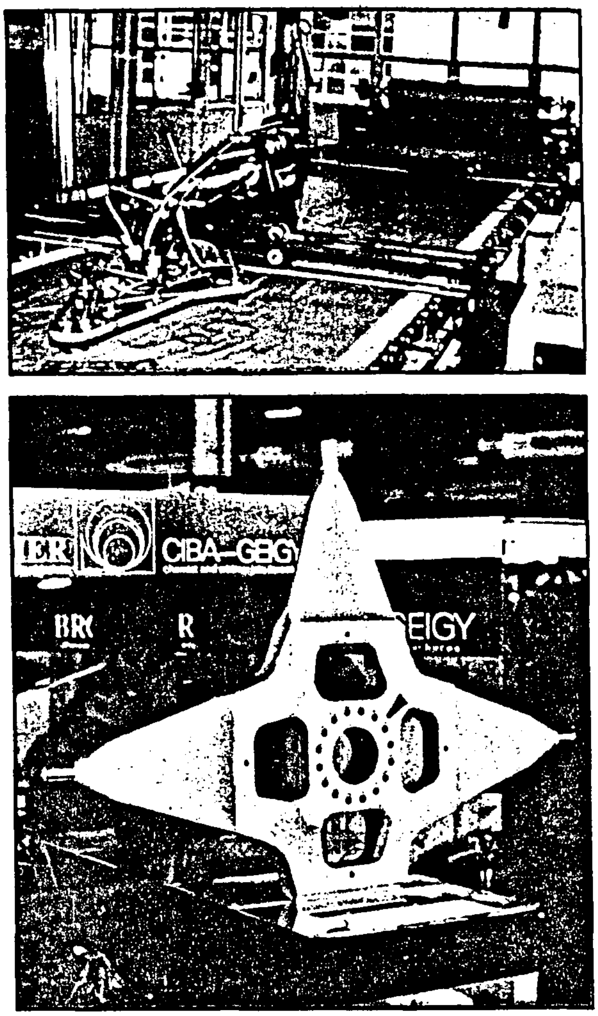
The fibers experimented with up to now have been silicon carbide, alumina, or boron in order to resist the high tem-



Composites have required development of specialized tooling. Here, a cutting machine which uses a jet of water under very high pressure as a tool.



One of the major problems remains inspection, which can be performed only on finished components, since the material is formed at the same time that the component is fabricated. Here, ultrasonic inspection of a carbon panel of a Falcon wing.



Example of automation: at Aerospatiale, Marignane, automatic laser cutting of glass cloth (above) used in fabricating Starflex·hubs like the one for the SA-365 Dauphin helicopter (below).

peratures needed to create the material.

Metal composites have higher resistance to delamination than do fiber-resin materials. Their environmental resistance is identical to that of the metal making up the matrix. The galvanic effects found at rivets in ordinary composites disappear. They also solve problems of lightning-strike resistance (their conductivity avoids use of a conductive layer as generally recommended for reinforced plastics (Lear Fan)).

But the most important advantage of metallic composites is certainly the fact that they still make use of all industrial experience. Manufacturing methods for metals remain usable, as does the tooling.

Up to now, metal composites have had only very limited applications because of availability and cost, but their range of utilization could grow greatly.

For example, Lockheed has studied construction of high aspect-ratio wings (12 to 20) for a transport aircraft, using current aluminum alloys, aluminum-lithium alloys, carbon-epoxy composites, and boron-aluminum composites. The latter were found to be the most promising by far. While the weight saving compared to ordinary construction is of the order of 20-30% with aluminum-lithium alloy, it is 40-50% with carbon-epoxy construction, and varies between 60 and 70% for production based on boron-aluminum composite.

For all that, it is still not true that metal composites are on the way to replacing competing metals, but there are things to think about. Composites will come in, but perhaps not in the form expected today. They do not suggest a downfall for aluminum, which has ruled the aeronautical world for close to half a century.

Carbon Fibers: PUK-Hercules Agreement

Pechiney-Ugine-Kuhlmann and the American Hercules Company have decided to form a partnership to produce carbon fibers in Europe. A company owned 60% by PUK and 40% by Hercules will be created for this purpose. This company will build a plant in France with a capacity of 200 metric tons per year; it is expected to be on-stream by the end of 1983.

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