ERRATA

Chapter 1, Page 12: **Quotes by Sylvia Katz not fully referenced -**
'Although this type of furniture is plastic in the broadest sense.....'
(Katz, 1987, p. 46)
'The cutting edge of Industrial design and therefore of rationalism....'
(Katz, 1987, p. 48)

Chapter 2, p.14: **Illustration no. 4: 'GRP' House -** The term 'GRP' although, introduced at a later stage, should have been explained here. It stands for Glass Reinforced plastics.
The above illustration is my interpretation of the Antonelli quote: 'Since the introduction of composites, structures look.' , and should therefore have been refereed to as such.

Chapter 3, p. 53 : **Hancock quotation not indented** - 'There is a tendency to run own the technical route.....'

Chapter 4, p. 54: Although the **chapter title** appears on this page the words 'Chapter 4' accidentally appear on the previous page.

Chapter 4, p.57, & p.58: **Quote not fully referenced-** 'The growing Kit plane industry....', & 'Lancair's goal is to continue to play....' taken from the Lancair Home page on the Internet, the reference should read: (Lancair, 1996. p.2)

Chapter 4, p. 69: **Illustration not fully referenced-** The solar powered aircraft is the Nasa Prototype 'Pathfinder'.

National College of Art & Design;

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Composites in Aviation Design - a Miraculous Exploitation of Materials

by

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INTRODUCTION AND METHODOLOGY

Composite materials have given a new direction to aircraft design, and this, in turn, has focused attention not only their physical properties, but also on the innate aesthetic of composite material.

This thesis is not a historical account of the development of composite materials in aviation design, nor is it merely a list of their advantages and disadvantages. These issues are examined briefly, however, and with the minimum of technicality necessary to give context to my central thesis above.

Discovering composites

The term "composite" seemed to crop up wherever I encountered an innovative form in something I had thought of hitherto as utilitarian and mechanical looking. I sought a definition. A composite material is, in fact, a combination of two materials, not a chemical or a physical mixture like an alloy, but rather a mixture where both materials retain their integrity in such a way that it results in something that is greater than the sum of the parts. More exotic composites of three or more materials exist, but for most practical purposes, and certainly for the purpose of this thesis, we need only look at binary composites of resin and fibre material.

So what is the connection with aviation ? I remember being fascinated by a piece of extremely light sheeted honeycomb construction lying on a beach in west Cork. It was immensely strong and stiff and was gently but deliberately curved. The lettering indicated a piece of aircraft construction, and so it proved to be. Tragically, it had come from an Air India Boeing 747 that had crashed out to sea some months earlier. On reflection I marvelled at the way in which lightness and shape had been combined without any compromise on strength. It was ingenious. If the required combination of properties was not

available naturally in one material, the obvious thing to do was to develop a composite, or a mixture, of two materials that could provide them.

Making further enquiries, I discovered that aviation was the proving ground for many new and wonderful materials. I have since observed the progression of composite materials to more and more demanding roles. They may be found forming interior structures, bulkheads and even replacing metal altogether in some aircraft. We will see how this progression has been accompanied by innovation in terms not only of performance but of form. I have marvelled also at how designers have adapted these space age materials to everyday products exploiting both their physical properties, and increasingly, their innate aesthetic.

Form

It is this potential for creative forms that most interests me, and this thesis will ask why, or what is it about, composites that offers such potential. We will try to determine what is the innate aesthetic of composites.

What scope, if any, could there be for design in aircraft manufacture beyond the purely functional aspects like aerodynamics and engineering ? Aircraft have not previously been thought of as having a 'designed' aesthetic form, but I hope to show that composites confer not only a performance or functional edge, but also an aesthetic one. If composites can introduce an aesthetic to something so obviously and necessarily functional as an aircraft, just imagine what it could mean for design in general. By illustrating how composites have effected aviation, its technology and form, I hope to give a glimpse of how it might affect the future of design as a whole.

It would appear that it is the 'leisure' or light aircraft industry, that holds the greater scope for an aesthetic make-over. These aircraft seem to be the only ones designed with appeal in mind. We will examine the role of composites here. By way of illustration, I will draw on the ideas of modern aircraft designers including the American, Burt Rutan. Rutan has emerged as a pioneer in the use of composites in aviation and I hope to show how he has endowed his aircraft with a unique form, mainly due to his use of composites.

To establish a basis for my discussion, we must address the following issues:

the factors dictating the choice of material for a particular application, the

innate aesthetic of individual materials, and, the extent to which new materials can impact on form.

the properties of composites, their application, manufacturing and aesthetic.

the determinants of aircraft shape and form and the structural constraints imposed by standard aerospace material.

We will then be free to discuss the main thesis, with reference to designer Burt Rutan.

Methodology

Practical research Initial research for this Thesis was of a practical nature, firstly working with composites during Summer vacation. This provided an insight into their behaviour, performance, and manufacturing. Secondly, observation and discussion of a Rutan designed aircraft, both under construction (Dave Ryan's 'Long-Eze') and in finished form. (Fiach ó Broldain)

Questionnaires sent to leading aircraft manufacturers to establish the reasons as to why they use composites. (See Appendix 4)
Closer to home, interviews were held with the president of the Society of Amateur Aircraft Constructors, Mr. Charles O Shea.

Literature survey Antonelli's "Mutant Materials in contemporary Design" and Ezio Manzini's "Material of Invention" provided a basis for the idea of how new materials are customised. The University of Limerick's Aeronautical Engineering and Materials Technology Department proved a useful source. Most notable were the conference Papers on Composites given by the American Society of manufacturing engineers. Finally, "Design with reinforced plastics" by Rayner Mayer was invaluable in gaining a full understanding of the properties and processes of composites. A complete bibliography is on page 77.

CHAPTER 1

THE MATERIAL OF CHOICE

This chapter analysis the relationship between material and form. We will determine the factors influencing choice of material. We also deal with the issue of identity or innate aesthetic of a material. Plastic will be discussed briefly as an example. We are also concerned with how new materials impacted on forms in the past.

Why do designers choose the materials they do, and how does this effect the form of the end product ?

A number of factors can influence the choice of material in the design of a product. Such factors include function, aesthetic value and cost. In some cases, the decision will be dictated purely by the function required to be performed and aesthetic considerations will be secondary or largely irrelevant. An example might be an internal component of a washing machine. In such cases, it is usually economics that underlie the decision, perhaps in terms of cost, based in turn on the physical properties of the material like its weight, strength malleability, ergonomics and safety.

In other cases, aesthetics will be an added consideration. An example might be a computer monitor.

There will inevitably be cases where aesthetics will be the primary consideration because the product simply will not otherwise appeal to the customer, but even here the dismal science of economics is never far below the surface. A glass slipper may be beautiful to behold but it will hardly be fit for the purpose for which it is intended. However, some materials will always be preferred because of their unique beauty, their finish or their ability to assume shape.

In short, a designer, whether the goal is primarily functional or aesthetic, will face constraints imposed by the physical properties of materials. The decision is driven by the need to optimise; the designer, like the rest of us, must trade one property off against another. As Mayer says, "Materials tend

to be used where either the economics are favourable or else there is an advantage to be obtained in terms of aesthetics, ergonomics or function." (Mayer, 1993, p. 13)

This is the essence of the designer's task; again in Mayer's words,
"It is a designer's task to realise one or more of the properties within a product as required by the market." (Mayer, 1993, p.2)

Form or function ?

Properties of a material determine its suitability for a particular structural form. However a material may be chosen because it best embodies a particular concept. Choices of structural form, however, have been constrained by the need to realise the basic concept of the form in some particular material or combination of materials.

How do we choose a material?

Some designers start by conceptualising a form and try to realise this form with whatever material makes it possible, others begin with a material and exploit its ability to deliver forms. When conceptualising forms we are, of course, constrained by the properties of materials but it may be that the properties of materials to some extent allow us to embody these concepts in the first place. As Masayaki Kwokawa Architects and Associates, Tokyo says : "Design is an attempt to capture both the struggle and the co-operation between the meaning that the material itself implies and the meaning of the form which is given to the material." (Ozborne, 1990, p.142)

Technology and manipulation of new materials is also a factor in the design process and relates to all four of the above , aesthetic, economics, communication of ideas, and function.
New materials generate new forms or aesthetic. Plastics have changed forever the way things look i.e. adding fluidity. Observe Verner Panton's cantilevered Stacking chair, the worlds first single piece plastic chair and compare it to a wooden or metal chair necessitating four legs .(figures 1,2) "The piece is a tribute to the unique properties of plastic" (Tambini, 1996. p. 37) It had "cleaned up the slum of legs" (Katz, 1987, p.43)

Figure 1 Cantilevered 'Stacking chair', (1960) by Verner Panton

Figure 2 'Superleggera' chair, (1957) by Allesandro Mendini

As Allesandro Mandini, of Milan says: "Once apon a time the artisan forced his object shape into the rigid rules of the chosen pre-existing material. Today's designers freely imagine the material before imagining the object" (Ozborne, 1990, p. 153)

Contemporary materials are developed to combine qualities that relate both to function and final form. Why restrict design possibilities by using only materials available naturally when we can custom develop a material with desired qualities ? - as Antonelli says in her book Mutant Materials "It will be interesting to see what forms composites will suggest to designers." (Antonelli, 1995, p17)

Identity

Until only a few decades ago, designers and architects (at least those comprising the Arts and Craft movement) believed in the absolute 'truth' of materials. They believed that each material had an "expressive soul enhanced by its physical properties and by the technique of its manufacture"

(Antonelli, 1995, p. 15). That is, each material has its own unique suitability for certain applications. Other designers at this point exploited new processes and materials and their ability to appear other than they were.

There are those who are of the opinion that "man-made or man-modified materials are simply imitative or visually derived from 2 dimensional (or, at least, amorphous) substances lacking the inherent material integrity common in natural materials". (Ozborne, 1990, p.150) Wood comes either in its natural log form or in standard cuts but modern plastics come in liquid resinous form. It is easy to see why people might say that materials derived from it are developed merely for their superior performance characteristics or for reasons related to cost. Allesandro Mendini, speaking of artificial materials says -

(Again Allesandro Mandini:)

> The materials of the past with their great tradition had powerful identities; in the course of the radical shift in the idea of materials, identity has been replaced by its opposite: the new materials are indeed without identity. They are malleable ready for anything, a continuum of infinite possibilities.(Ozborne, 1990, p. 152)

Suggesting that because they can take on any possible form, new materials have no identity. This may be too strident; it may be that it is this very malleability and ability to assume any form that *is* the identity of the new materials.

When plastics were first introduced, it took a long time before they assumed a distinct identity of their own. They sought a parasitic identity, that is to say they pursued a course of imitation. This perception on the part of designers and consuming public alike was understandable in a world dominated by strong identities of existing materials. Perhaps it was because they could assume any forms or aesthetic associated with natural materials that designers first exhausted that avenue before turning to innovative uses.

After the war, designers began to exploit the new properties of particular plastics. Charles Eames(1907-1978) had worked with fibreglass during the

war and now produced a one-piece moulded seat shell supported on wire legs. Known as the DAR (Dining Room Rod) chair, it commanded immediate attention. It was one of a new organic style which grew out of new technologies in plastics. Chairs were now moulded to fit the contours of the human body. It was also the 1st plastic furniture design to be successfully mass produced. (figure 3)

Figure 3
Charles Eames' 'DAR' chair (1950)

It was with the introduction of resinous material, thus, that synthetic material first impacted on design with its resulting organic forms. Although Bentwood furniture, introduced by Thonet (1796-1871) in the mid 19th century, was organic, his achievement was a result of a process rather than a material. Steam bending, and drying in steel forms over a period of time. However resin bonded plywood made the artful furniture of Charles Eames and the Finnish Architect, Alvar Aalto (1898-1976) achievable in the 1950's. "although this type of furniture is plastic only in the broadest sense of the term, its beauty is a by product of the plastic materials." (Katz, 1987, p.)

Organic forms had existed or strived to exist in the streamlining of aviation, for functional reasons. Plywood was in fact developed for aircraft

construction.

> The cutting edge of industrial design and therefore of rationalism was the aircraft industry and its forms were biomorphic too. Furniture designers experimenting with biomorphic styling could point to the sculptors on one hand , and to the advanced technology on the other and use both to legitimise their otherwise capricious reasoning.
>
> (Katz, 1987,p.)

By the 60's and 70's that plastics had developed their own identity: 'Plastic' shapes, one piece objects, smooth and shiny surfaces in primary colours were now acceptable. This aesthetic was a result of their plastic (in the sense of their malleable or mouldable) nature. Designers had begun, in the words of Frank Lloyd Wright, to "work in the nature of the material".

A brief summary of factors influencing choice of material is:
Function, Cost, aesthetics. The weight of each factor varies with application.

So we have established that materials have an expressive soul with associated emotions . We have seen how new materials are developed and thus new innovative forms made possible Even though contemporary materials can now be developed with a set of requirements to fit a particular function, these materials too can have an unique aesthetic. Their forms are free of the constraints of previous materials. It is noted that once having gained acceptance , by proving to be as good or better than existing materials, new materials are free to express their innate aesthetic.

As we examine the use of composites, we will try to ascertain whether composites similarly, are more than a mere replacement for metal and we shall see if, rather than attempt to imitate the aesthetic of other material, composites have a distinct identity of their own.

CHAPTER 2

COMPOSITES

"Since the introduction of composites, structures look considerably different today. They appear very plastic yet they are not built of plastics but rather of an extremely strong high fibre content material " (Antonelli, 1995, p. 52)

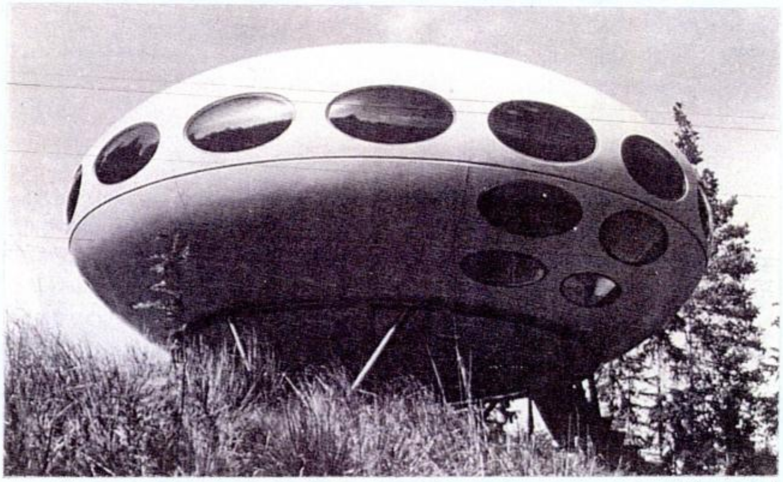


Figure 4 GRP house.

Such is the view of Burt Rutan, a pioneer in the application of composites to the aerospace industry. So what are composites & why do things look different today since their introduction? This chapter will attempt to define composites, to give an understanding as to why they posses the properties they do. We will then look at these properties in more detail, as we will manufacturing techniques. Both of these factors resulting in certain forms and aesthetic, we will see to be unique to composites. Thus this chapter gives an insight into the potential of composites to innovate, in terms of mere function or, as may be the case, an innovation of aesthetic and form.

"A Composite material, is one that is made of two constituent materials that are not chemically bonded" (Tsai, 1995, p.5). The term 'composites' can, strictly speaking, be applied to any mixture of materials in such

circumstances. A composite material can provide superior and unique mechanical and physical properties because it combines the most desirable properties of its constituents while suppressing the least desirable properties.

Traditional design and manufacturing materials are stone, wood, ceramic and metal. Polymeric materials (plastics) became available in the 1950's as a by-product of the refining of oil. Although on their own, there are limits to their stiffness and load bearing abilities, plastics have unique processability as well as aesthetic and lightweight qualities.

However, adding reinforcements to polymers in the form of fibres which are inherently stiff and strong has given rise to a unique family of materials which combine the properties of the reinforcements with the processing ability of the plastic. It is this family of materials we call 'composites' or 'fibre reinforced plastics'. The modern understanding of composites therefore, assumes a reinforcement of a plastic material like a polymeric resin by a fibrous substance such as glass or carbon fibres, rather than just a mixture of any two or more materials.

Composite Theory

We do not think of materials such as glass, carbon, and boron as having extremely high tensile and compressive strength. Rather the opposite. In fact, these materials have great strength, but in 'solid' form these properties are not readily apparent. This is due to the fact that when stressed, random surface flaws will cause each material to crack and fail well below its theoretical 'breaking point'. Indeed any material that can be manufactured as a fibre presents in the fibrous state far greater mechanical resistance and in simple mass state.

To overcome this problem the material is produced in fibre form, so that, although the same number of random flaws can be expected to occur, they will be restricted to a small number of fibres with the remaining exhibiting the material's theoretical strength. Any propagation of flaws, cracks etc. will therefore be contained and a bundle of fibres will reflect more accurately the optimum performance of the material. To make practical use of the high strength of these fibres it is necessary to isolate them from one another. If

this is not done, flaws will appear on the surface due to abrasion. The isolation is achieved by the resin system. It is the resin that transfers loads to the fibres, bind the fibres together and enables the material to be moulded to shape.

The origin of Composites

Although manmade composites have existed for thousands of years the high technology of composites have evolved in the aerospace industry only in the last thirty years. Developments of suitable synthetic plastics and fibres especially since 1945 has led to a growth of the advanced composite industry.

All advanced materials old and new have been developed to meet practical needs. Innovative materials and techniques often stem from space or military research. Military engineers test advanced materials in specific applications ; designers then apply their findings to the developments of everyday objects. Glass fibre was developed for use in the manufacture of aircraft nose-cones to house radar equipment during world war II. IN 1946 it was first applied to boat hulls. As we just saw, In the 1950's Charles & Ray Eames adapted Fiberglas to chair design

High performance carbon fibres (figure 5) were first introduced in the early 1960s by the Shindo company in Japan and by Watt at the Royal aircraft establishment in Farnborough, England. From this we can see that even the birth of composites was directly related to aviation. Kevlar was discovered in 1965 by Stephanie Kwolek a Dupont research scientist, **not by government but private**. It was developed for the marine and aerospace industries. (figure 6)

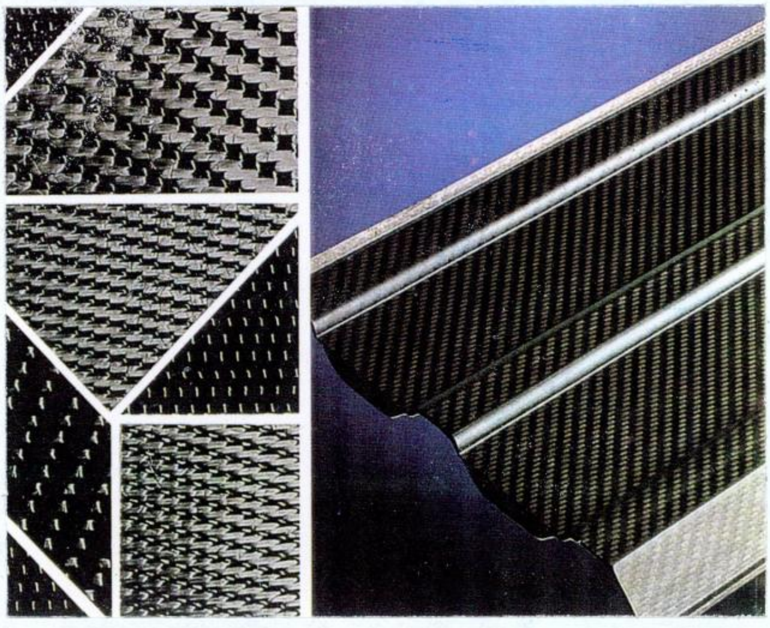


Figure 5

Carbon Fibre

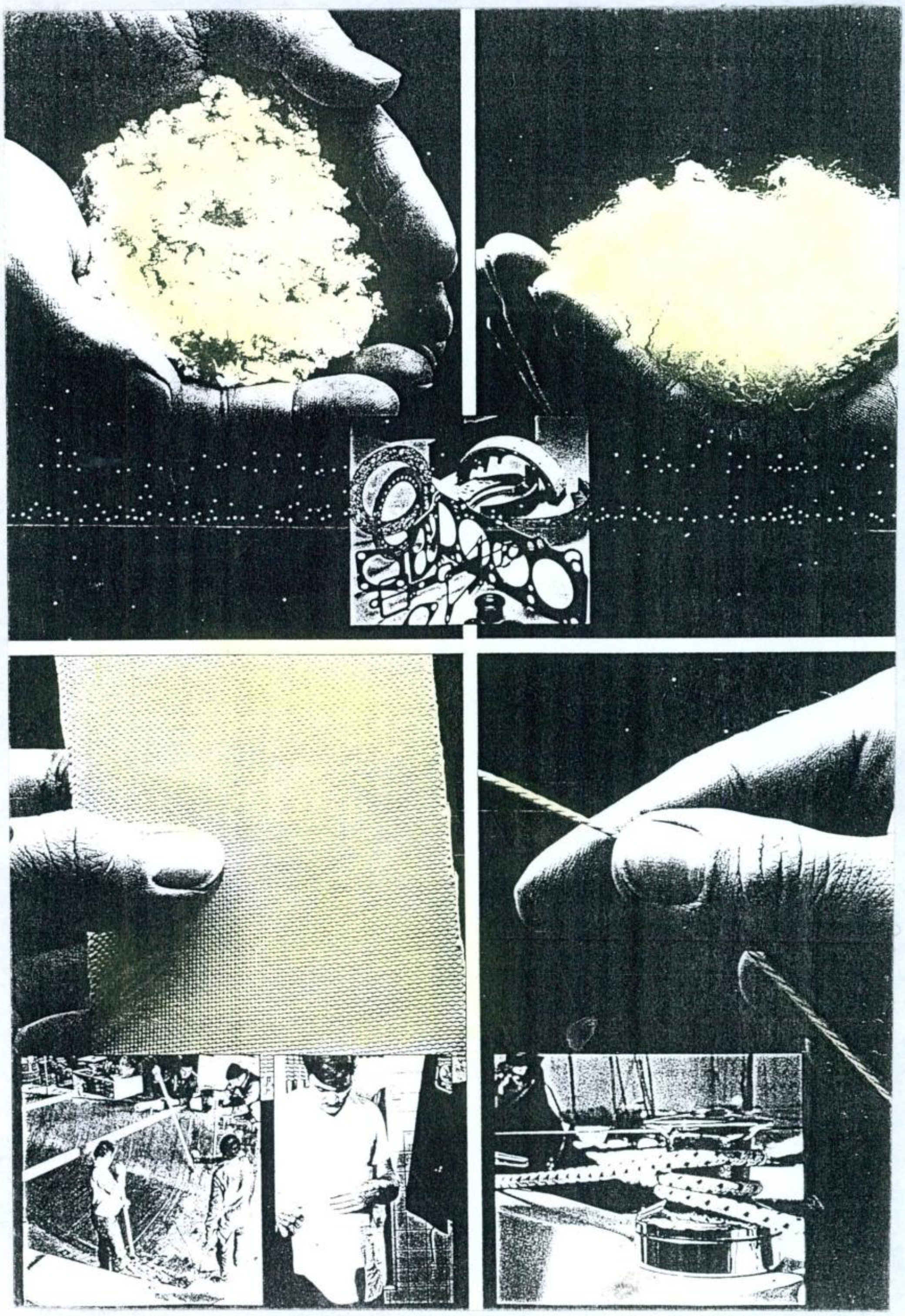


figure 6 Du Pont's Kevlar

To date most new developments in composite construction techniques and materials still originate in or for the aerospace industry. This is because such industries can meet the cost of introducing new and improved material.

Now that we have defined composites and determined their origin let us look at their physical properties, as these are, as we had earlier established, among the considerations taken into account when choosing a material.

Properties of composites - a comparison with other materials

- high strength(4 times that of steel by weight)
- low density (The density of graphite / epoxy is only 57% of that of aluminium)
- corrosion resistant
- stiffness
- good rigidity
- impact, vibration absorption
- resistant
- low thermal expansion

Initially in terms of stiffens, composites or glass reinforced plastics in particular couldn't compete with metal / wood. The introduction of carbon fibre however resulted in a composite that is 8 times as stiff as glass or engineering metals.

The impact absorption property is demonstrated by the horrific crashes from which racing drivers of composite cars have walked away." (Noakes, 1989, p. 121) Composites thus allow dangerous sports to be safer on impact.

In his book Design with reinforced plastics, Rayner M. Mayer gives the example of a hammer handle as a conceptual design consideration where composites could be used. Three properties are considered: the mass of the handle, ability to absorb impact energy (damping) and possible shrinkage of the handle within the head. Using these properties three principal types of material are compared in the table below:

property	wood	steel	GRP
mass	light	heavy	light
damping	good	poor	very good
handle shrinkage	progressive	nil	some initial shrinkage

It can be seen GRP provides the best balance of properties. It also offers the ability to mould and colour direct to final shape without the necessary finishing processes of wood or steel

Richard Mayer concludes: "GRP is an attractive alternative medium to wood or steel, and its technical quality is comparable or better than existing handles."
(Mayer, 1993, p.7)
This indicates that as well as aesthetic quality , functional properties are as good if not better. Composites offer the Industrial Designer more of a scope for aesthetics without the compromise of losing essential functional properties.

In comparison with traditional plastic, fibre *reinforced* plastics have two major characteristics:
1. they can have much greater mechanical strength (greater than any plastics) comparable on a weight basis with some metals.
2. They can be moulded without heat or pressure both essential for shaping traditional plastics.

It is a combination of these two characteristics that make possible the type and size of products not possible with other material.

As well as having a range of attractive functional properties, composites provide further advantages in terms of economics, manufacture and material usage. Integration of parts is possible. The Passenger aircraft Airbus A310 had 1800 fewer metal parts with the integration of composites in composite

replacement. This is an efficient use of material. As well as economical implications a design with minimal components also has an impact on form. The integration of parts is due to the formability of the material; "The greater formability of a material allows the integration of several operating parts in to a single item." (Manzini, 1989, p.) Composite bicycles for example have single piece frames.(figure 7)

figure 7
composite bicycle

Composites are not attacked by the environment like unmaintained steels. This provides durability- life cycle costs are reduced, for example costs of repainting could be avoided. Wide application of adhesive bonding minimises number of fasteners e.g. rivets necessary with aluminium. Moulding direct to final dimensions (i.e. no need for finishing) is possible. All of these aspects result in economy of production and manufacturing simplicity.

So where are composites used? Obviously where these unique properties are required or where the unique aesthetic is desired.
Some of the major market niches at present for composites include:

1. Sports / recreational goods such as fishing rods, skis and tennis racquets for reasons of function (stiffness, aesthetics)
2. Motor vehicle for aesthetics (shape, aerodynamic) and function (integration of parts, reduction in weight) (figure 8)
3. Boats for aesthetics and function (ease of manufacture, resistance to sea water)
4. Aerospace for function (integration of parts, reduction in weight)

(For illustrations and more detail on these applications, see Appendix 5)

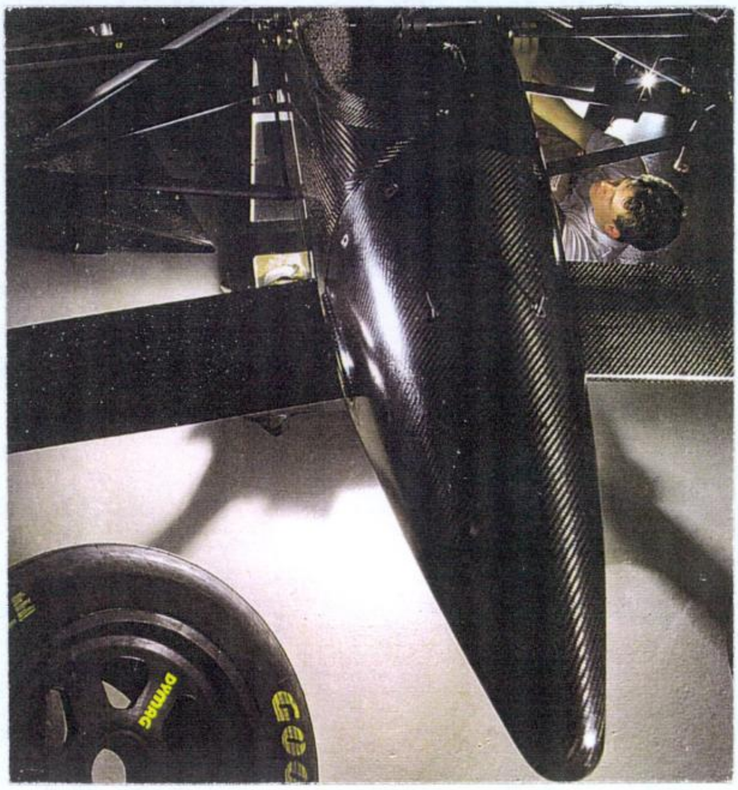


figure 8 Racing cars constructed in carbon fibre

Very resent and future applications include civil engineering for bridges etc., and the biomedical industry, for example prosthesis.

Manufacturing

It is necessary to look at manufacturing as this is an other important factor in the choosing of a material. Firstly, true cost cannot be measured without taking it into account, as fabrication costs vary with methods and in turn which vary with material. Also, as established previously , the manufacturing process itself can be a factor in the final properties and aesthetic or form; " The way things look is, in the broadest sense, a result of the conditions of their making." (Forte, 1986, p.7)

We will see that this is particularly so in the case of composites.

The difference between designing in composite and in metals becomes clear when we consider manufacturing techniques.
When using composites, the material is manufactured at the same time as the component (i.e. the resin and reinforcement are combined) , so selecting a suitable manufacturing process is crucial for the success of the design.

However, before the resin is applied to the fibres , they must be held together in some way. Fibres are woven into a cloth or fabric or left as a mat of random chopped or continuous strands. The purpose of this is to facilitate the handling, placing and orientation of the fibre reinforcement in many fabrication processes. They provide the designer with greater flexibility in locating the reinforcements in new but repeatable ways. (figure 9)

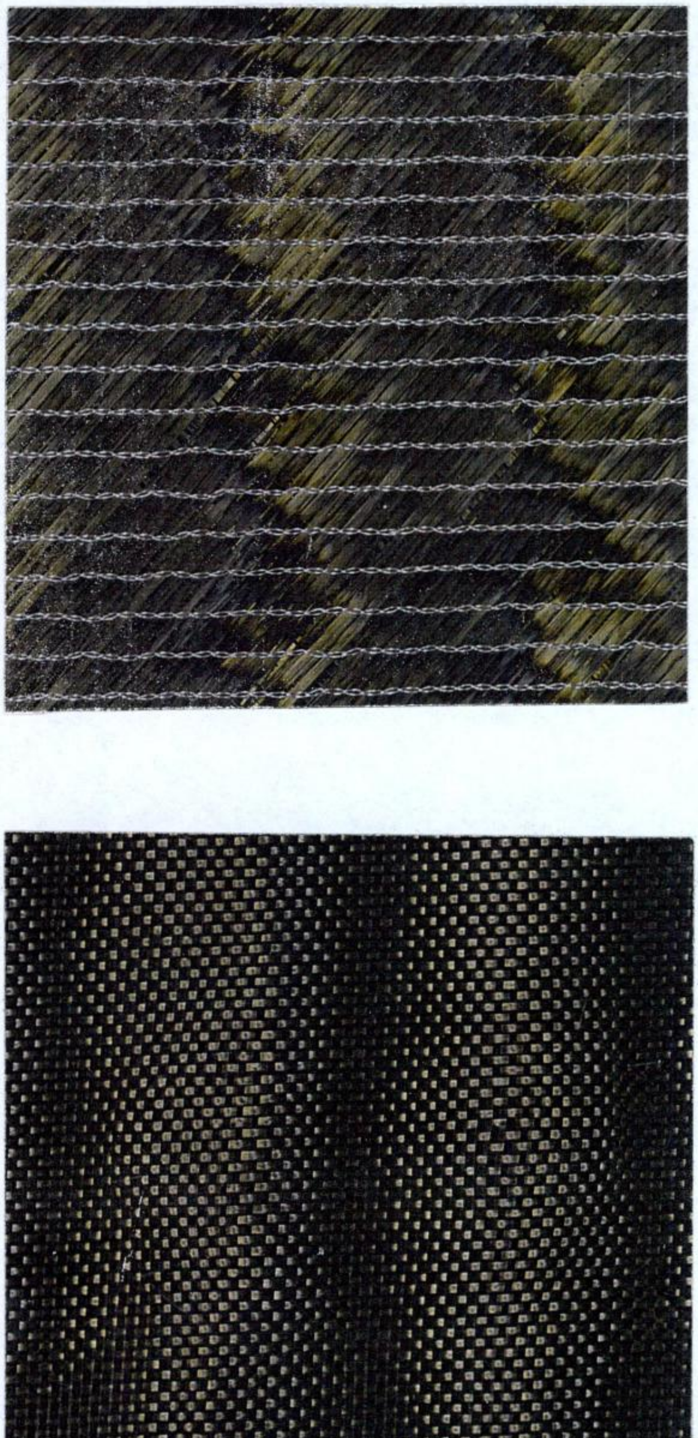


figure 9 Different weave styles of carbon fibre fabric

The particular characteristics of fabric include: Drapability , or the ability to conform to the shape of a component. Conformity to compound curves is now possible. Variations in weave styles can mean a great flexibility in design. Designers are not only offered different drape characteristics but also various degrees of strength and enhancement of properties in different directions. For example where strength in one plane only is required, then unidirectional fibre cloth is used, but for areas where strength in two directions is required then bi-directional cloth is used. Plies are laminated to give strength in multiple direction. (figure 10)
Depending on how the fibres are oriented or interwoven within the matrix , composites can be fabricated to have structural properties specifically tailored for particular structural use. Of course, various ratios of reinforcement to resin and various reinforcements, or combination of reinforcements i.e. Hybrids also contribute to the possibility of tailoring to specific mechanical or structural requirements. Hybrid is a fabric where each layer in the fabric is a different type of fibre, or the warp and weft fibres within a layer are different, for example a carbon / kevlar hybrid fabric.

Disadvantages

The factors that contribute to the advantages of composites to be specifically tailored to application requirements, and having great design flexibility also however result in certain disadvantages. We saw how strength, stiffness and other properties are different depending on the orientation of the composite material. i.e. stiff / strong in the direction of the fibres only. Composites are highly anisotropic. This poses a challenge to the designer who uses composites in structures that place multi-directional forces on the structural members.

It is almost impossible to get isotropic properties in practice in fibrous material because it is difficult to get fibres to pack tightly <u>and</u> point in 3 dimensions at once. Theory indicates that the strength of a 3 dimensionally random arrangement of fibres would be 1/6th of that of an all parallel system anyway. For this reason composites will not replace isotropic metal in crankshafts for example but for shells and panels it is ideal, where metal would be inefficient as light thin shells.

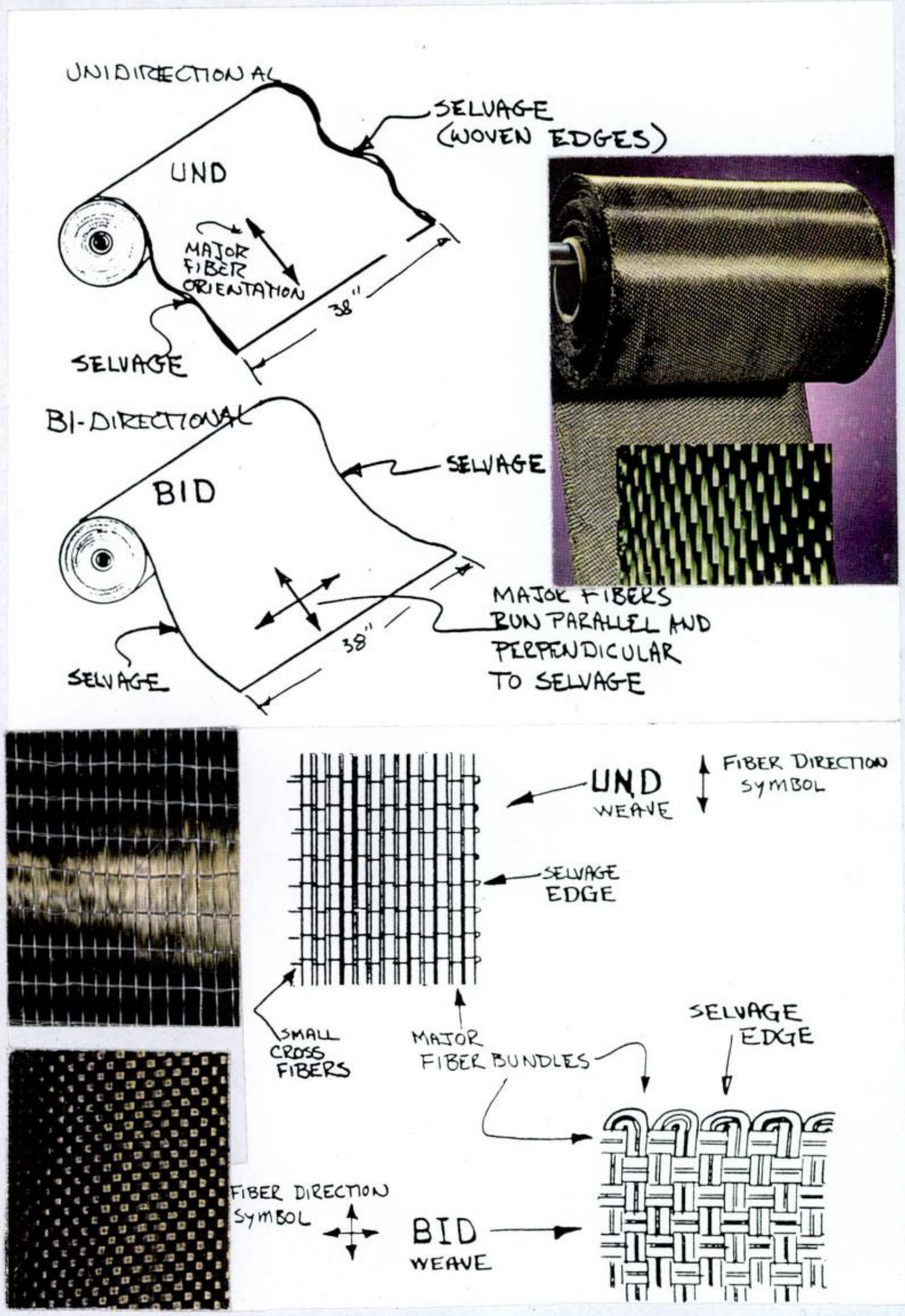


figure 10

Fabric, uni and bi-directional

Another disadvantage, again related to the stiffness / strength in fibre direction only property (anisotropy), is that unless accuracy is ensured in the placing of the fibres, the desired properties will not result. As Rutan says: "The careful & intelligent planning of fibre placement is the basic method for improving composites" (Antonelli. 1995. p.52)

The characteristics of the final product are produced 'on site' during the manufacturing phase. Exact quantification of properties thus cannot be predetermined. I.e. it is difficult to control properties.

It is for this very reason that hand lay up in open moulds, we will look at next, is still the most utilised method of fabricating components. And that the more advanced, automated processes, where fibre alignment is not totally accurate, are not being adopted so readily.

Fabricating Processes

This involves applying resin to the mat / fabric of fibres and then moulding to shape. There are various methods of processing composites These include: Pultrusion, Filament winding and Contact moulding. (figure 11)

Factors which dictates the use of the various methods of processing for a particular application include: cost, size and complexity of form, precision of properties, time; "The material form dictates the process just as the process dictates the material form" (Jackson, 1987, p.7)

Contact moulding- This is the most common process. It involves hand laying up shell sections in an open mould of the appropriate shape, the outer surface being in contact with the mould surface. Heat and pressure are not required, it is therefore a relatively simple manufacturing technique. (figure 12)

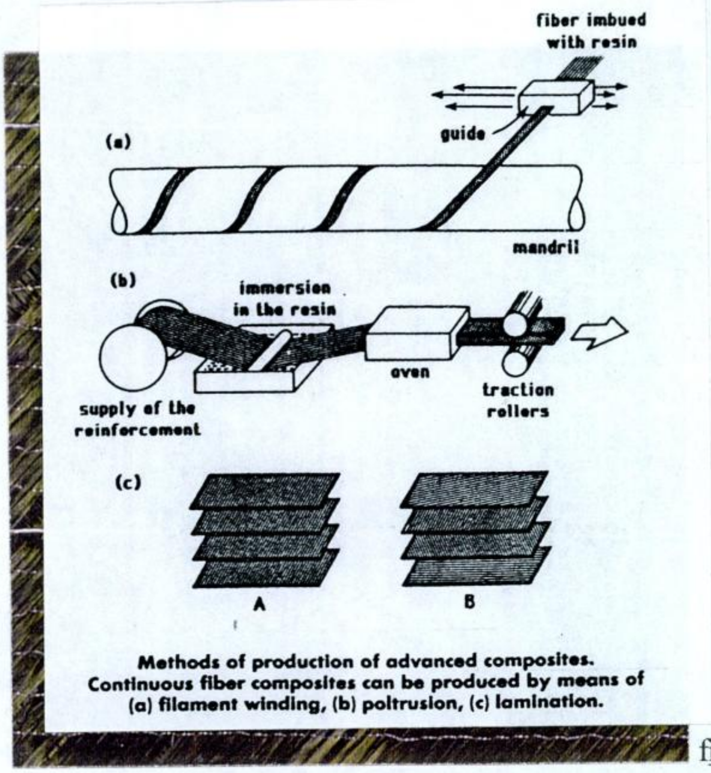


figure 11

Manufacturing techniques

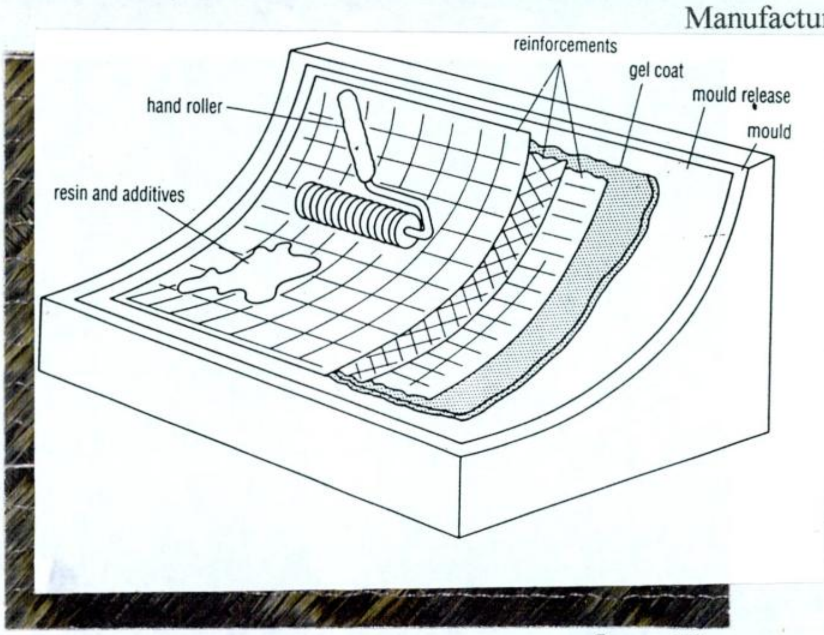


figure 12

Hand laminating(Contact moulding).

The process of laying up a component begins with the application of the gel coat to the surface of the mould. The resin rich layer provides a smooth, hard surface, prevents the fibre reinforcements appearing on the surface and can be pigmented to colour the part. Gelcoat can be applied by spray gun or by hand with a paint brush.

The fibre reinforcements are then laid on over the gel coat surface by hand and the resin is applied to the reinforcements by brush or roller, layer by layer, building up the moulding to the correct thickness. Various reinforcements can be laid up in layers . Fore example, the thickness of a kayak might have a layer of glass fibre, and a layer of Carbon fibre. Composites can be tailored to specific mechanical requirements. During this stage, the material is continually worked and rolled to ensure proper wet out of the fibres, expulsion of air and consolidation of the material.

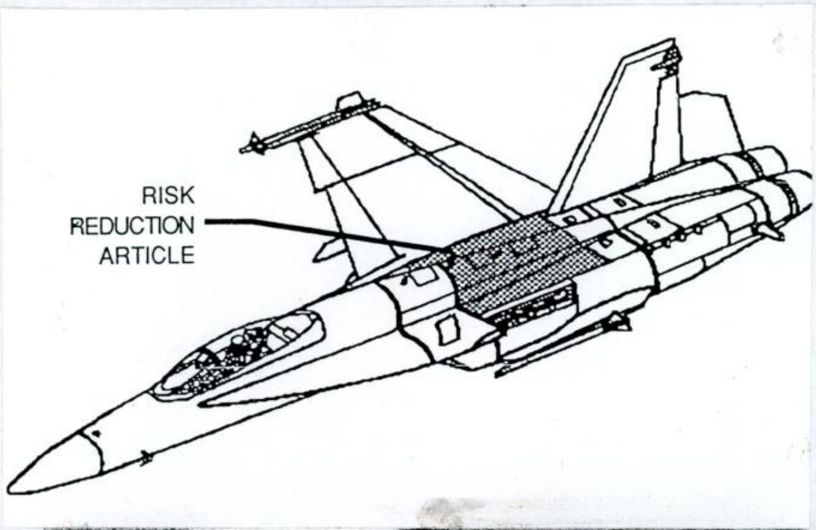
Typical reinforcements (glass / carbon) to resin ratios is 15-20 % by volume using random mats and up to 45% using fine fabric. The moulding is then left until the resin is fully cured. Time taken for curing depends on the resin, catalyst, temperature, humidity, and thickness of the moulding.

Large mouldings are possible such as the hull of a boat and tooling costs are low . However it is labour intensive and skill dependant. Therefore it is not really suitable for mass production. Boats, kayaks, and aeroplanes are constructed this way. More advanced processes include:

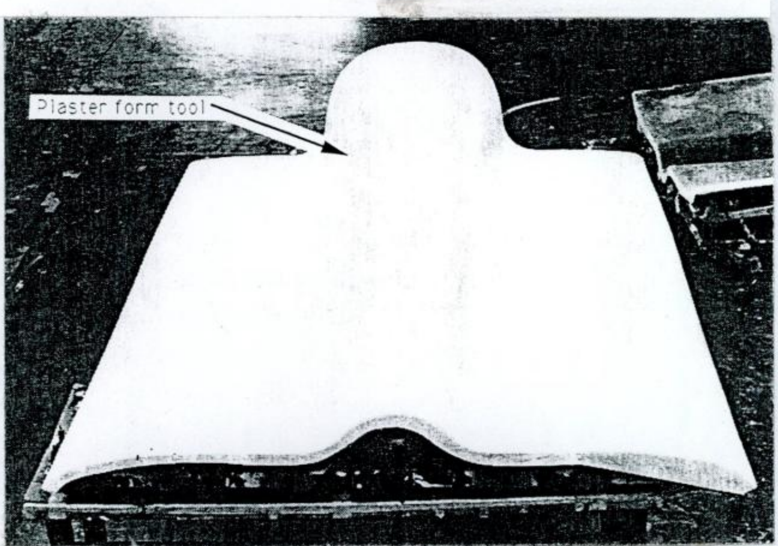
Press Mouldings- hot press (RPM)
Resin Transfer moulding (RTM)
Centrifugal Moulding
Filament Winding
Pultrusion
Prepreg Moulding
Injection Moulding.

See Appendices for a brief explanation of each process.

An aircraft component is manufactured by contact moulding in figure 13 below.

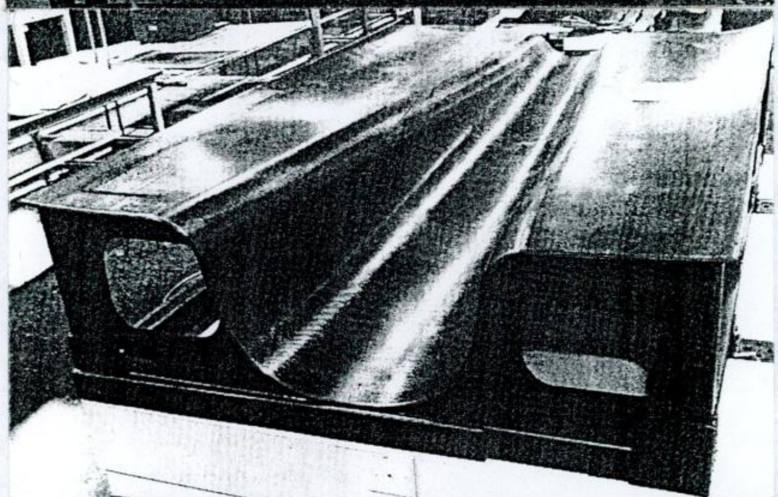


Component to
be manufactured

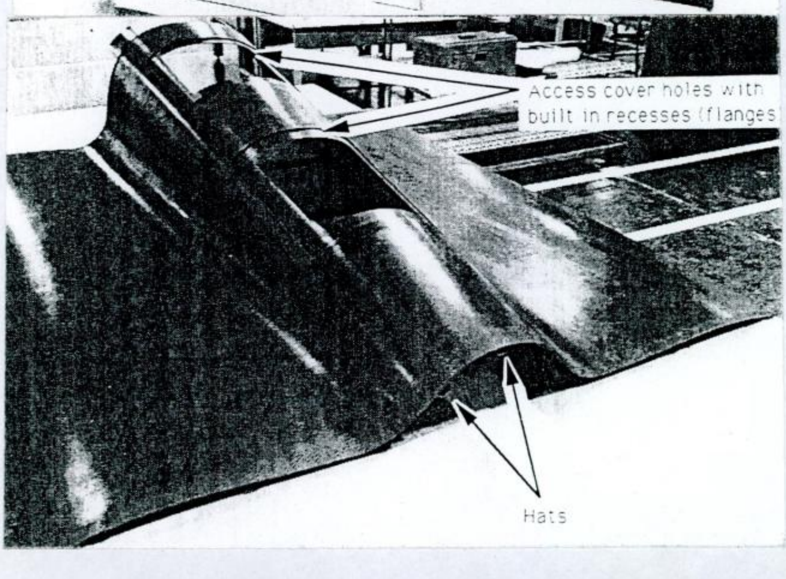


Plaster form tool
(to make the mould from)

Component laid
up in mould



Trimmed component



<u>figure 13</u>
Manufacture of
aircraft component

A recent addition is 'Prepreg' , where the catalyst resin pre impregnated but needs heat and pressure applied to cure. Accurate alignment of fibre is possible with prepregs because there is minimal flow during moulding. Applications include high performance requirements like car bodies, aircraft wings, helicopter rotors.(figure 14)

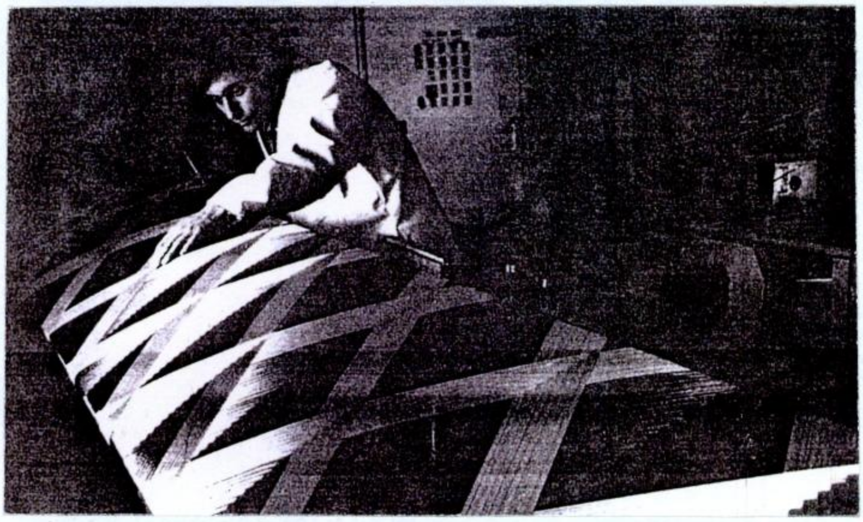


figure 14 Helicopter rotor constructed from filament Prepreg tape

Another technique which will be of interest to us in the application of composites to aircraft design is 'Sculpting '- This technique was developed by Rutan for one-of-a-kind fabrication where foam is sculpted to shape using hot wire and then fibreglass is laminated to the surface. This is a very simple manufacturing technique that also facilitates home building.

The simplicity of manufacturing of composites i.e. with the hand laminating and sculpting techniques, has made amateur building possible. Those who have always dreamed of owning their own boat or aeroplane but were restricted by the financial implications can now build it themselves. The idea of a kit plane has stemmed from this, at a parallel with the growing leisure industry.

It would seem then that then that high strength to weight ratio, as well as stiffness to weight ratio, are the unique mechanical properties exploited most in applications. "Matter loses its old heaviness , its bulky volume, while

increasing its resistance and force." (Manzini, 1989, p.13)
For example composites have helped double the pole vault record from 3.62 meters with a wooden pole to 6.13 meters with a composite pole.

Fabricating of composites is simpler than that for other materials, however it is as yet labour intensive, as automated processes are not accurate enough in the placing of fibres.

Properties and form are a result of material and process . The innovation forms of composites are a result."A characteristic of invention and innovation is the profound integration between material and process" (Manzini, 1989, p. 82)

Aesthetics

So now that we have established the properties of composite material , what forms result from the use of composites? Is it possible to say that they possess an 'expressive soul ' or innate aesthetic?

> As early as 1950 the Eames use of the newly conceived Fiberglas even though experimental, displays a faith in the material and a philosophical approach: (which was) an exploration of the material to learn from it not only about structure and function but also about form and beauty.
> (Antonelli, 1995, p. 16)

Composites have very good formability. By formable we mean the highly drapeable fabric we just saw, which is able to assume complex curves and an infinite variety of shapes. (see figure 15.) When one considers this in terms of aesthetics one only need consider one piece mouldings to begin to imagine the fluid shapes which are possible.

Joints and seams are unnecessary, as parts can be bonded together during lamination, i.e. one piece mouldings. This is desirable not only economically but also aesthetically. The drapability (above) allows for complex shapes, but one piece mouldings mean these complex shapes will posses a simplicity of form. (figure 16) Larger one piece mouldings are possible than with other

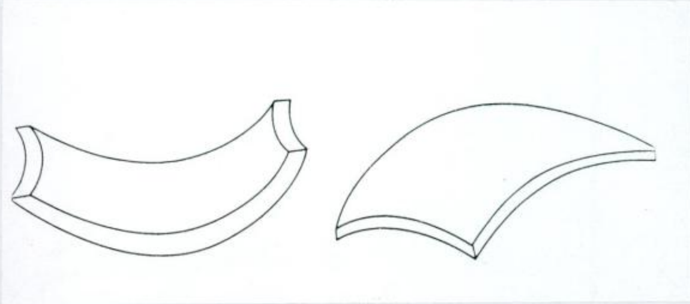


figure 15
Compound curves made possible with composites

Figure 16
Moulding of a complex form

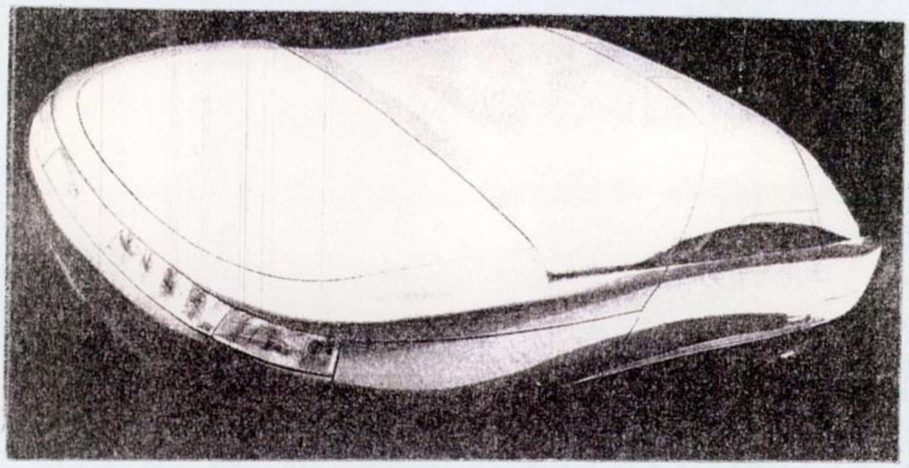


Figure 17
Ford 'Probe V' concept car

materials because heat or pressure i.e. presses are not necessary. A single piece moulding is inherently stronger than something that is fabricated from individual components. For example the attachment of a wing-root to the fuselage or body of an aeroplane results in a structural weakness, but if the wing and fuselage are one piece, as opposed to cantilevered, the structural integrity is enhanced. It is visually more attractive too, in that the form as a whole is more uniform. Again resulting in a simplicity of form. Less is more is also a design maxim.

Interestingly it is these same properties that contribute to the aesthetic that also contributed to a more economical production process.

Because of the formability / flexibility of composites they also naturally provide aerodynamic shapes. For example "the Ford 'Probe V' concept car, with composite body panels and 'space frame' design, has a drag coefficient (Cd, a measure of aerodynamics) better than that of the f-15 jet fighter plane. (figure 17, above) Another application of this property are the helmets illustrated below. (figure 18) The speed-Ski helmets almost look like the cockpit of an aircraft.

Plasticity

If composites technology have the ability to take up an infinite variety of complex forms, is there a preferred solution? Victor Papenek suggests_"only those forms congruent with nature can be both beautiful and functional."

'Hyper organic' and 'Mutant' are terms that have come to be applied.(Evamy, 1993, p.23)

So why do biomorphic forms appeal?, As Eva Zeisel, says of The Straight Line & The Curve, 1984: "Straight lines (of modernism) were far from the emotionalism that had been communicated by the compound curve which Walter Crane called 'the Expressive Line' " (Greenhalgh, 1993, p. 23)

Organic forms are also friendlier, they attempt to humanise the machine .

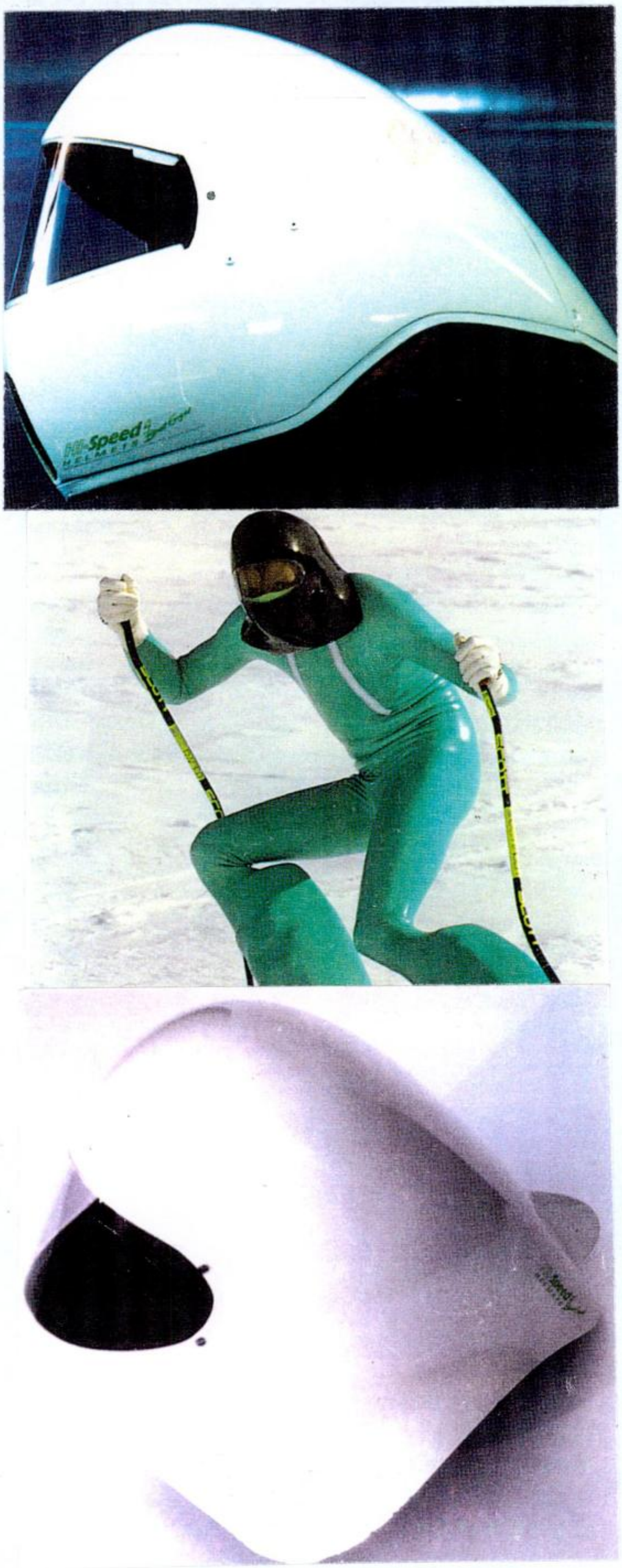


Figure 18 Aerodynamic forms of Speed ski helmets

It has been suggested, by Mendini, that this formability of new materials negates identity or 'truth to material', one of the corner stones of modern design. However, if we consider this formability in relation to Frank Lloyd Wright's timeless lesson: 'to always work in the nature of the material.' Could it be suggested that it is their very ability to adopt forms freely which is their nature and becomes their identity?

Another element of their aesthetic is one perceived as high-tech. Sometimes the gel coat is clear leaving the fibres or cloth visible underneath. The aesthetics of a Fiberglas chair is described in 'Mutant Materials' as "Celebrating the power of technology" (Antonelli, 1995, p 56) The weave of the fabric is visible, as it is in the helmets illustrated below. (figure 19, 20) This has been termed the "aesthetic of a technology". It is also used where products display the inner workings, for example in the fashionable 'Swatch' watches. In fact Eames combines both the organic forms and the visible fibres in his chair, reflecting the technology associated with the war, and aircraft technology. This aesthetic too then originated from aerospace as do the streamlined shapes composites naturally express. Although interestingly, it did provide a function in aviation,- the transparency facilitated visible examination for damage.

This 'high tech' aesthetic has been readily adopted by the sports / leisure industry because they want to be perceived as using advanced technology, and perceived as enhancing performance.

By now taking an aircraft as an example, we can examine what determines its form. We can then compare the design and manufacture of aircraft before and after applying composites to it and establish any innovation in terms of performance, function and aesthetics. Composites offer this performance edge *and* the aesthetic quality to make a product all that more attractive to the purchaser.

Figure 19 Carbon / Kevlar Hybrid motorcycle helmet

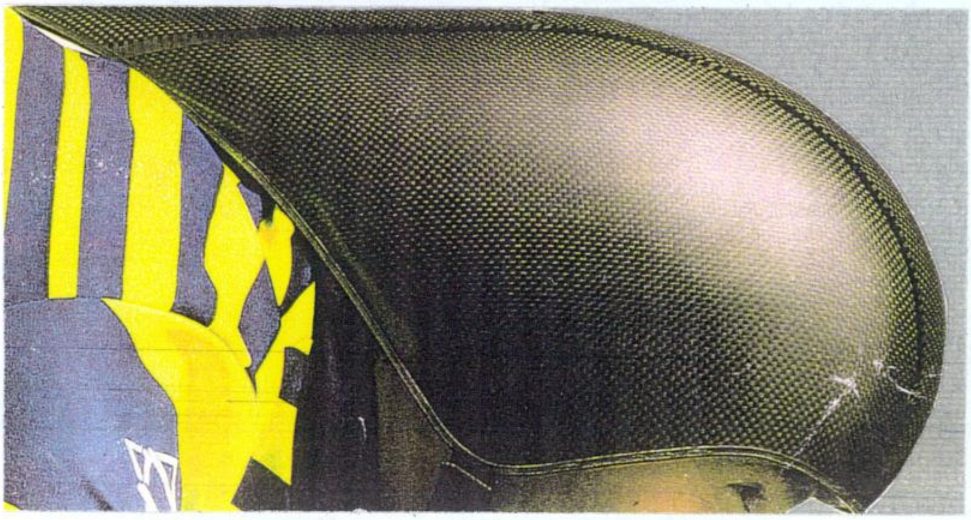


Figure 20 Carbon fibre cycling helmet with visible fibres

Chapter 3

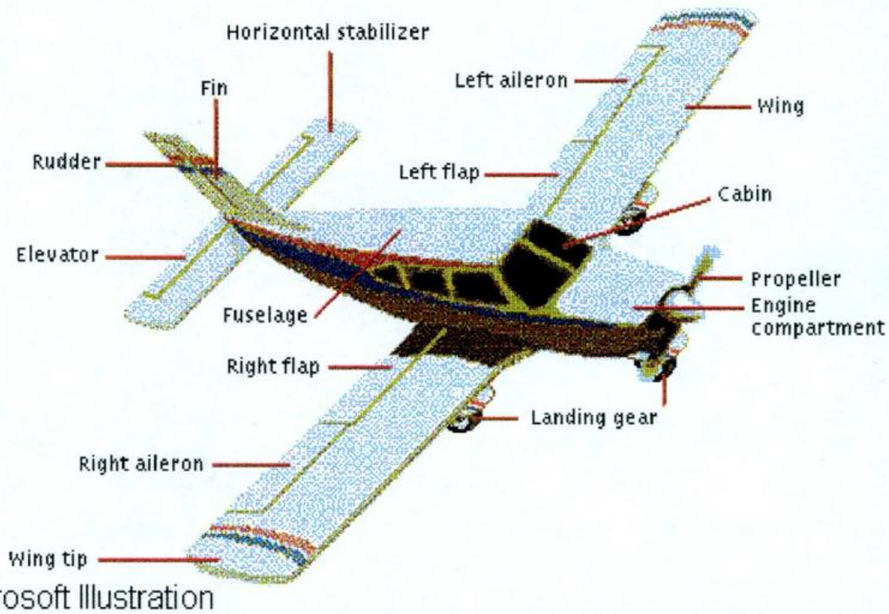
What determines the form of an aircraft ?

"Design in aircraft construction ? But the form of the planes is surely only subject to the laws of aerodynamics ? " (Peter Burgeff, 1996, p31)

If Mr. Burgeff is correct, this would be a good example of the maxim that form follows function. However, in this chapter we will see that there is something more to it than that.

The form of an Aeroplane

Despite a bewildering variety of shapes, we are all familiar with the typical aeroplane configuration. The streamlined exterior of modern aeroplanes hides a complex balance of form and function. The basic components include the fuselage, wings, tail assembly, and, except for gliders, the engines. The fuselage, or body, houses the pilot, passengers, or cargo. The wings provide the lift that enables the plane to fly. Movable portions of the wings (ailerons) help control lateral motions. The tail assembly includes movable parts that help control vertical motion and fixed parts that increase stability during flight. Engines provide forward motion, or propulsion. (figure 21, below)



Microsoft Illustration

Figure 21 The basic form of an aeroplane

Within the confines of this familiar configuration, there are sleek fighter aircraft, large and bulky transport planes, light pleasure aircraft, thin graceful gliders, and odd looking experimental or purpose built aircraft like the US airforce's 'Stealth' fighter.

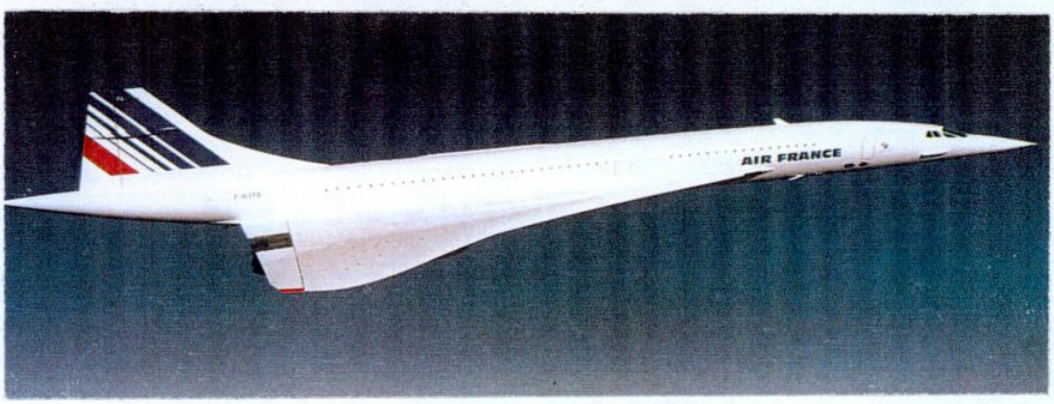
Function

It is thus to function that we now turn. It seems intuitively obvious that aeroplanes whose function it is to go very fast are long, pointy and sleek. Those designed to carry heavy loads, where speed is not of the essence, tend to look bulky and ungainly.

Compare the Lockheed company's C.130 Hercules (figure 22) below with the Anglo French Concorde beside it (figure 23). Both are very well known, the first is famous across the globe for its load carrying ability, and the second for its Mach 2[1] speed on long distance passenger routes.

figure 22 Lockheed's Hercules C1-30 Cargo Aeroplane

figure 23 Anglo-French Concorde



It is interesting to note that designers, when faced with the same functional requirements, and technical constraints, usually come up with the same form. Look at our examples again. At about the same time as the BAC-Aerospatiale team began work on the Concorde at Toulouse (figure 25), The Russian Tupolev design team were planning the TU-144 (figure 26). Concorde was an engineering triumph, but the TU-144 (by now christened "Concordski") experienced considerable difficulty[2]. The remarkable thing, however, is that they look so alike, although they emerged in different parts of the world, and in competing power blocks.

Figure 24 Anglo-French Concorde Figure 25 Tupelev TU -144

A routine examination of published anthologies[3] shows that the same functional requirements and same material constraints will result in the same basic form. Function is therefore the basic determinant of the form of an aircraft..

The reason aircraft appear similar in general terms is because designers are constrained by such factors as weight, drag, engine power. However when ever a new material or technology comes along, new doors are opened, once again allowing designers to conceive new forms.

Technology

In the case any one function, however, it is evolving technology that has driven the change in form i.e. better materials, engines and advances in aerodynamics. In the late 1930's and 40's, increased engine power meant planes could fly higher, farther and faster. This required a pressurised fuselage and hence a round cross section[4]. This change from square or box like fuselage to round was a major innovation in form. A better example is the introduction of jet engines and swept-wing technology after W.W.II. The Douglas company's DC-7, (figure 26. below), was designed as a trans Atlantic transport in the 1950s. By 1962, the same company's DC-8 (figure 27) featuring the now familiar swept wing and jet technology, represented a radical shift in form.

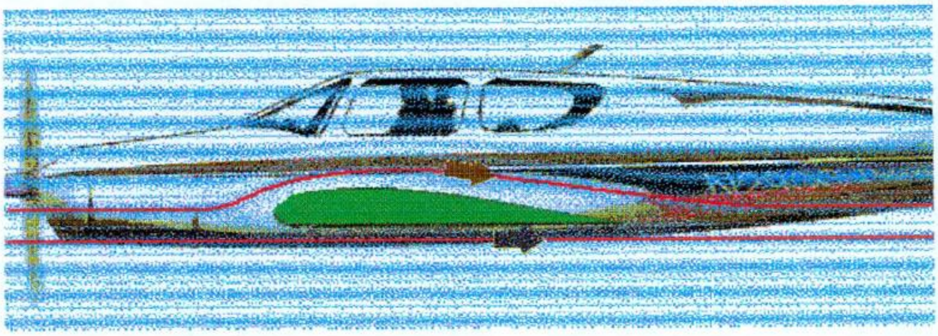
Figure 26 Douglas DC-7, (1953)

Figure 27 Douglas DC-8 (1962) with jet engines, & swept wings

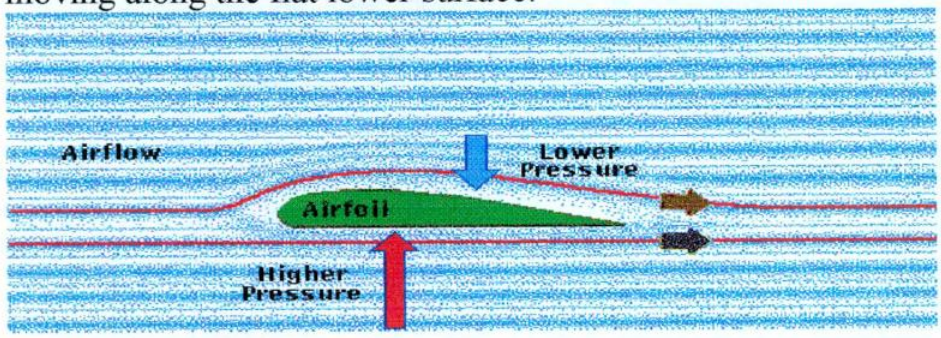
Before looking any closer at technology, we need to revisit the basics aeroplane shape to see what it is that makes an aeroplane fly.

Principles of flight (figure 28 below)

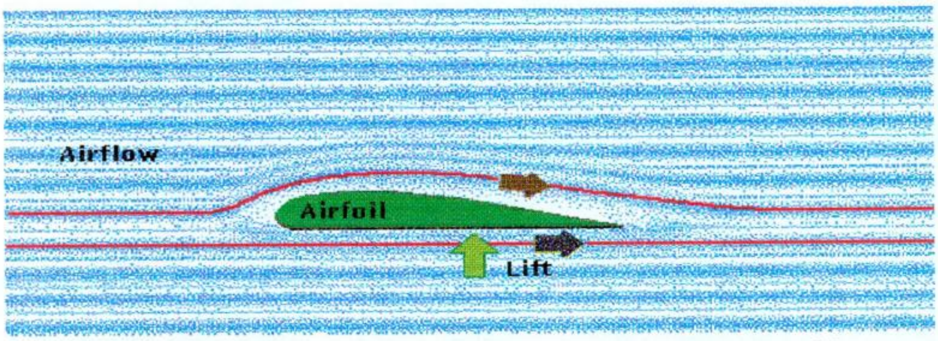
The shape of the wing causes the air streaming above and below the wing to travel at different velocities



This is because the greater distance over which the air must travel above the curved upper surface forces that air to move faster to keep pace with the air moving along the flat lower surface.



The more rapidly moving air on the top surface of the wing exerts less pressure than the slower moving air below it. This is known as Bernoulli's principle. It is this pressure differential that results in an upward pressure, or "lift". Lift is proportional to the speed of the air over the wing



Lift keeps the aeroplane in the air. As an aeroplane flies on a level course,

the lift contributed by the wing and other parts of the structure compensates for its weight.

Drag

Drag is the force that tends to retard the motion of the aeroplane through the air. Drag is a result of the resistance of air to objects moving through it. The shape of an object drastically affects the degree to which air resistance impedes the object's motion. For example, a sphere, as shown in figure *top,* and especially a square, as in figure *bottom,* both force the air to redirect itself, slowing the objects down. Vortices are formed inhibiting a smooth flow. An airfoil, as in figure *middle,* minimally disturbs the air as it travels, so the airfoil experiences little drag.

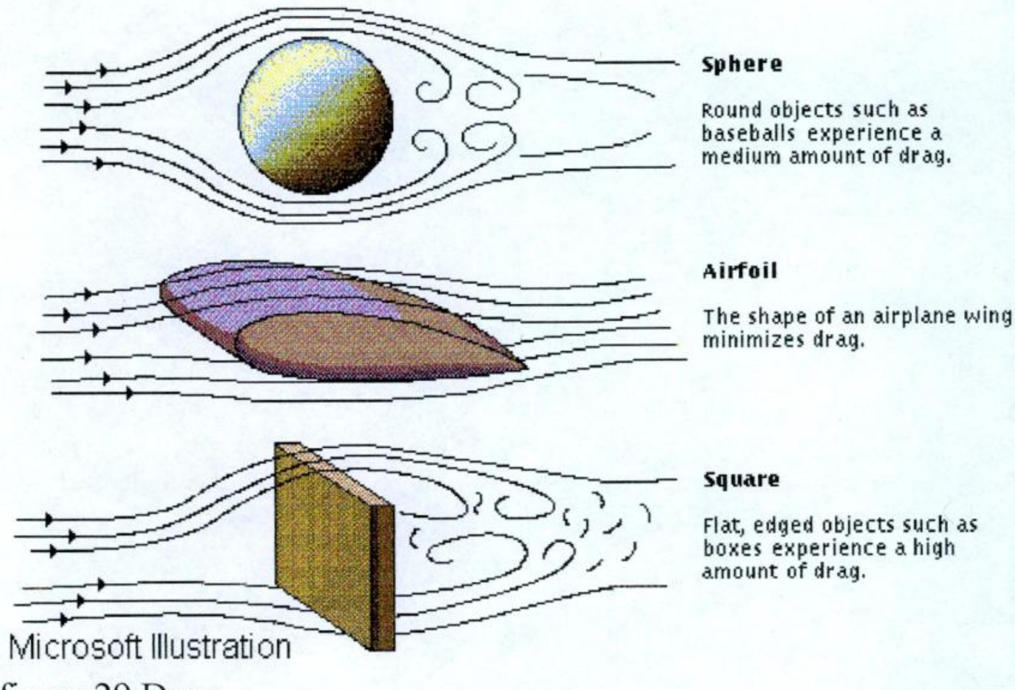


figure 29 Drag

Lines which show the direction of the flow of air at any particular moment are called streamlines, and a body so shaped to produce the least possible eddy or vortex motion is said to be a streamlined shape. It is essential that this "form" drag should be reduced to a minimum in all those parts of an aeroplane which are exposed to the air. This is achieved by 'streamlining' the aircraft.

Lift and Drag, collectively known as aerodynamics, are therefore significant determinants of the form of an aircraft.

Surface finish

Drag is also affected by surface finish. This type of drag is called skin friction. As air passes over the wing, the air is slowed up, if not actually brought to a stand still close to the surface. The layer of air near the surface retards the layers farther away owing to the friction between them. The layer of air in which the shearing action takes place is called the boundary layer. The boundary layer may be either laminar (smooth flowing) or turbulent depending on the surface finish. (figure 30)

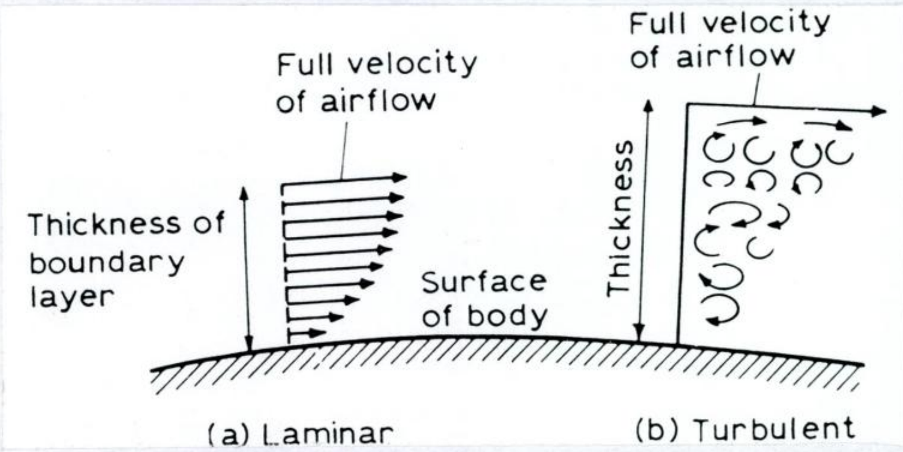


Figure 30 Skin friction

The effect of a good surface finish, and a laminar flow, on the total skin friction is of the same order as the effect of streamlining the main flow. If we could ensure a laminar boundary layer over the whole surface of a wing, the skin friction would be reduced to one tenth of its value. This is why the rivets in aluminium sheeting are today designed so as to be flush with the surface. During WW2, this measure alone is said to have increased speed in fighter aircraft by an extra 20 knots, a considerable advance in those days. Skin friction drag accounts for half the resistance that an airliner must overcome in flight. This is particularly important because it determines an aircraft's fuel efficiency.

Constraints

Given the function, there will be constraints imposed by the design parameters - weight and speed. From these, and the materials and power available, comes the design which seeks to minimise drag and maximise lift respectively. This is an iterative process where savings in one feed back into the design equations until the optimal shape is achieved.

To take an example, a sport glider needs to be light. It has no power and so must rely, paradoxically, on gravity to slip downward through the air. It is designed however, to generate a great deal of lift even at low speed[5]. This dictates the wing shape. The most efficient we know is the long, straight, narrow chord wing shown in the picture below. The objective is to achieve the best possible ratio between the distance travelled and the height lost - the glide ratio. This is better than 17:1 in modern gliders. Every effort goes into minimising weight, streamlining form and reducing surface friction. The materials of choice will therefore be wood, fabric and, increasingly today, plastics and composites.(figure 31)

The modern fighter plane, by contrast, exhibits stubby, flat wings, often in highly swept or delta form. This is because speed is the primary parameter. The designer tries to cram the most powerful engine(s) into the smallest airframe. Load carrying capacity and endurance are also important. Ability to withstand very high stress and temperature essential. It will be immediately obvious that metal construction is warranted.

The General Dynamics F 16 below has wing span which is a fraction of that of the glider above, but it packs 40,000 lb. of thrust (or push). With a speed of Mach 2+, a small wing is sufficient but a knife edge delta shape is required to minimise drag. (figure 32) Notice that this aeroplane is no less graceful, albeit in a strikingly different way, than the glider above. Its nose is needle sharp, its cockpit canopy is a single piece moulding, its power and its computer controlled control surfaces make it one of the fastest and most

manoeuvrable anywhere.

We can see therefore that function drives not only the basic shape, size and configuration, but probably also the material of choice, but as we shall now see, it is the material itself that is then the main determinant of form.

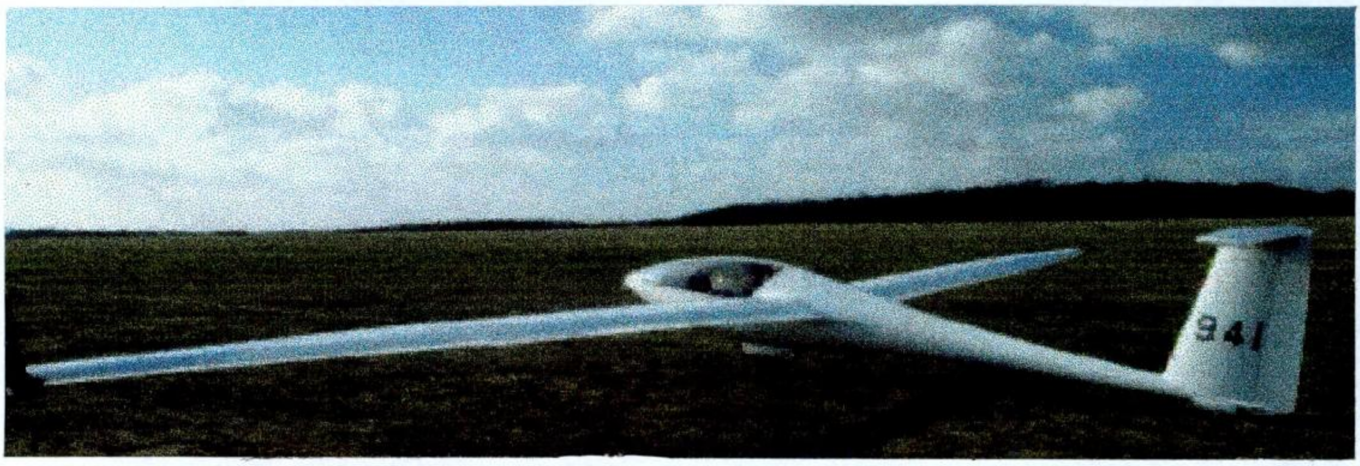


Figure 31 Glider

Figure 32 The General Dynamics F 16

Materials in aeroplane construction

The important considerations are weight, strength and formability, together with resistance to heat (e.g. at very high speeds), metal fatigue and corrosion. Safety is paramount in passenger carrying aircraft i.e. fire resistance and toxicity.

The main factors which govern the choice of material for the aeroplane designer are primarily related to function. The most important is the ratio of the load to be placed on the structure to its dimensions.

Wood

Wood was the obvious choice for pioneers like the Wright brothers just 100 years ago. Designs of the time are typically wooden framed, covered in doped fabric and strengthened with wire stays and tubular metal struts. The advantage is obvious: when loads are comparatively small in relation to the size, it is generally best to concentrate compression loads into a few compact rod like members, and to diffuse the tension loads into fabric and cord - just as in sailing ships, tents, windmills, and, of course in the modern microlight aircraft. (figure 33)

Successive generations of aircraft up to the late 1930s were largely of wood construction and had very low wing loading. With double wings, their actual dimensions were not much smaller than equivalent modern aircraft but their payload weight was less than a 10th that of modern hard skinned machines since the engine power to lift anything heavier was not available. These aeroplanes are still known as "stringbag bi-planes" (figure 34)

figure 33 Microlight

figure 34 Wooden Bi- plane

Metals

These range from high performance steels and light aluminium alloys to titanium. Aluminium, enjoys a higher strength to weight ratio than steel and is ideal for aircraft construction. However, under the same loading, Aluminium deflects 3 times as much as steel and therefore needs stiffness. Steel is used for highly stressed engine and undercarriage parts. Titanium is very expensive and difficult to use, and is used mainly where money is not an object, as with certain military aircraft. Metal construction meant that parts could be made thinner and therefore lighter. The stiffness problem demanded more a innovative design approach - the honeycomb core. (figure 35)

Metals are increasingly being replaced by composites, which we will examine next. In order to compete, the metallurgists have not been sitting by idly. They have developed new alloys such as aluminium lithiums, powder metals and super plastic forming alloys.

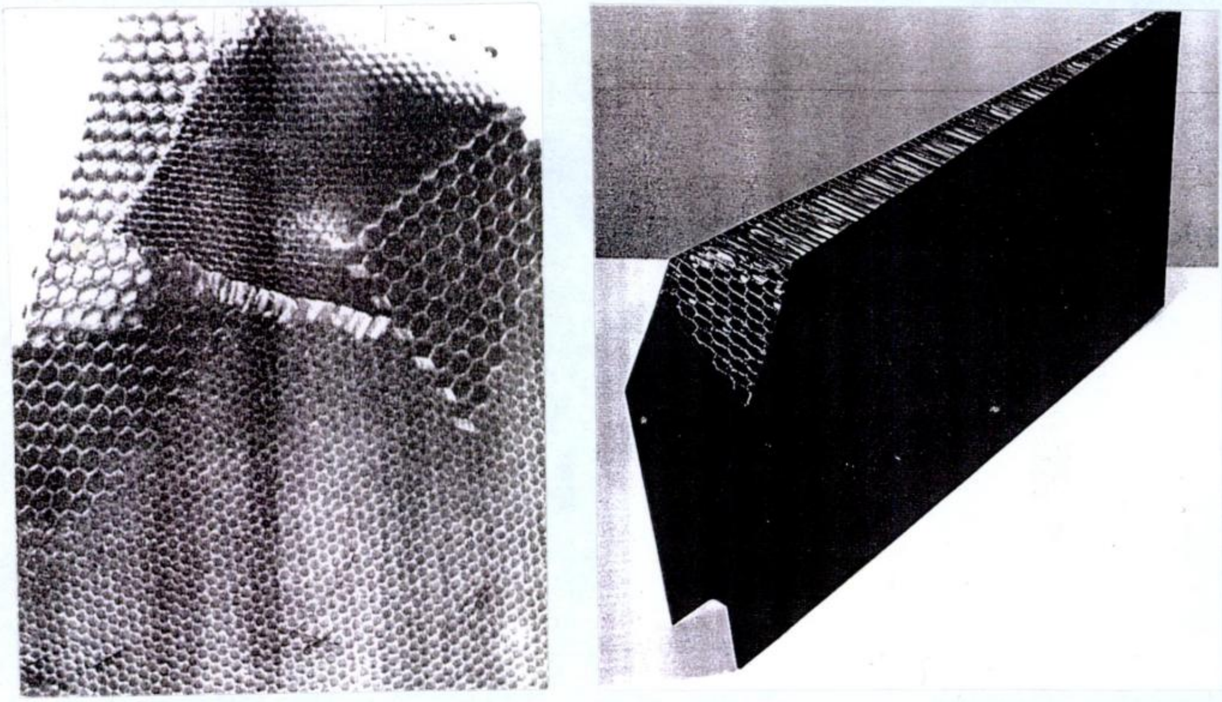


Figure 35 Aluminium honeycomb

Figure 36 Douglas DC-1

The effect of metal on form

As payloads increased with engine power, the general trend was towards monouque or hard-skinned monoplanes in which the loads were taken as far as possible in a metal skin, rather than by the internal framework. The heavier compression loads still had to be taken by spar-and-rib framework. Metal construction also enabled the introduction of cantilevered wings i.e. without extraneous support, which rely for their strength on the structural elements inside the skin. This enabled the elimination of external struts and guy wires. Stressed skin and multi-cellular wing construction allowed for the creation of streamlined shapes to capitalise on a better understanding of aerodynamics. For example, the Douglas DC-1 (figure 36) with its all - metal , multi-cellular wings was an example of the new innovative form. "The surfaces flowed into each other, creating a new standard of machine beauty." and "The entire external appearance of the transport is remarkable for its complete freedom from struts and control system parts." (Wilson, 1986, p. 129)

Today, cantilever and stressed skin construction is employed in all large aircraft, and external bracing is used only for small, light craft, usually with fabric coated wings. (figure 37)

Metals are best adapted to lattice structures with stressed skin. However, it is plastics that are best suited to continuous structures e.g. shells. We saw already how fibres in parallel were stronger and thus better suited to shells and panels than metals. Plastics also have the decisive advantage in terms of weight.

Figure 37 Cessna Aircraft featuring external struts

Composite materials

The search for stiffness and better formability led to the use of plastics. DuPont's composite Nomex provided the ideal core honeycomb material in kevlar skin compared to aluminium. (figure 38)

Where metal is replaced with a composite material, the savings in weight are generally of the order of 20 - 30 % . This is crucial to operating **cost.** In the Airbus A 320 passenger plane for example, a kilogram reduction of weight is accepted as worth a $35 dollar saving in operating costs each year.

Let us revisit the F-16 for a moment. Its mainly metal construction gives way to the composite materials in non-heat critical regions to eliminate the harsh angles and corners that typify other fighter forms. Such grace hides a more sinister aspect of the F16. Its radar profile (its susceptibility to being 'seen' on radar screens) is one of the lowest of any aircraft. This is due to its smooth non-metal surface, the integration of wings and fuselage at the wing roots, and its special finish.

Similarly, our glider example above is today made almost entirely of composite material. In passing, we remarked on their grace. The glider is graceful in a very natural way. It has to be so. It is required to perform the same function as a soaring bird. We are immediately reminded of the gannet, the albatross or the Andean condor, all of which can remain aloft for hours with the minimum of effort. Gliders were not always so graceful. Early attempts to mimic avian grace were severely limited by the strength and weight of the materials available. Wood and fabric had to be strutted and stayed in order to make a wing that was long enough. (figure 39)

As for birds, they have evolved; the materials that make up their bodies are ideal (and no more so) to help them to fly i.e. they are optimal. Aeroplanes, and the materials used in them, are still developing. (figure 40)

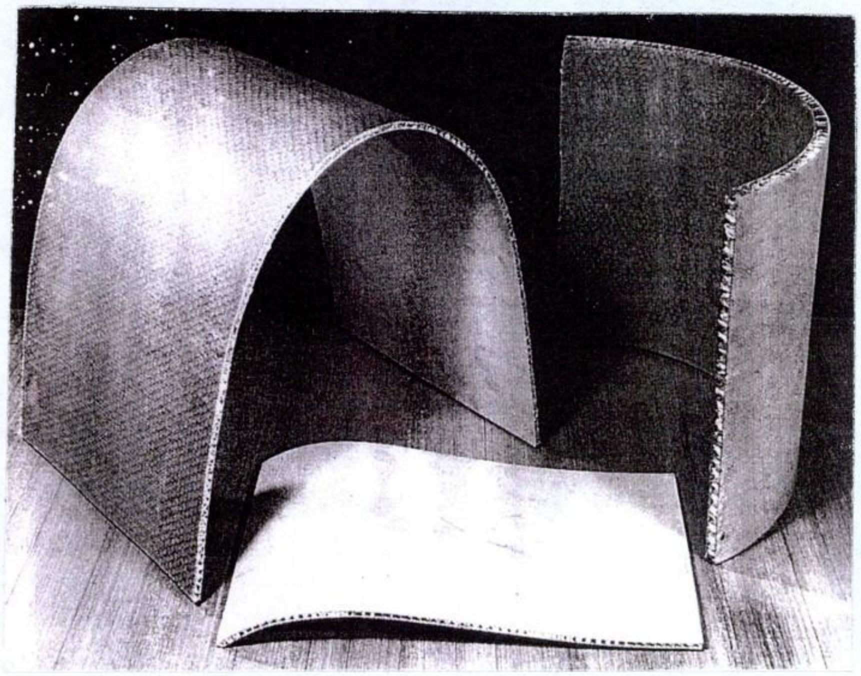


Figure 38 Nomex honeycomb, formable into curves

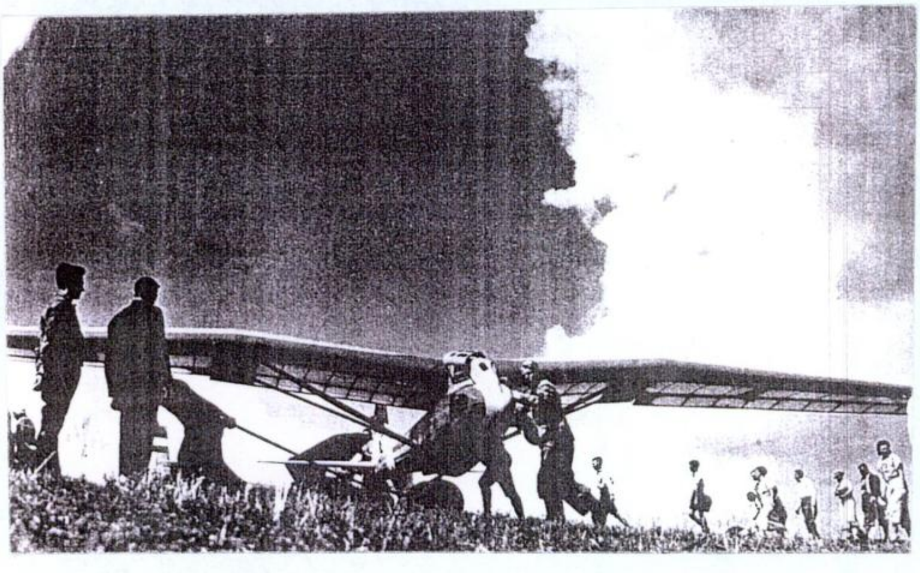


Figure 39 Early German Glider of wood and fabric construction

"The marvellous mechanical devices of human beings are only a

reflection of the mechanisms of nature." (Le Corbusier, 1935, p. 8)

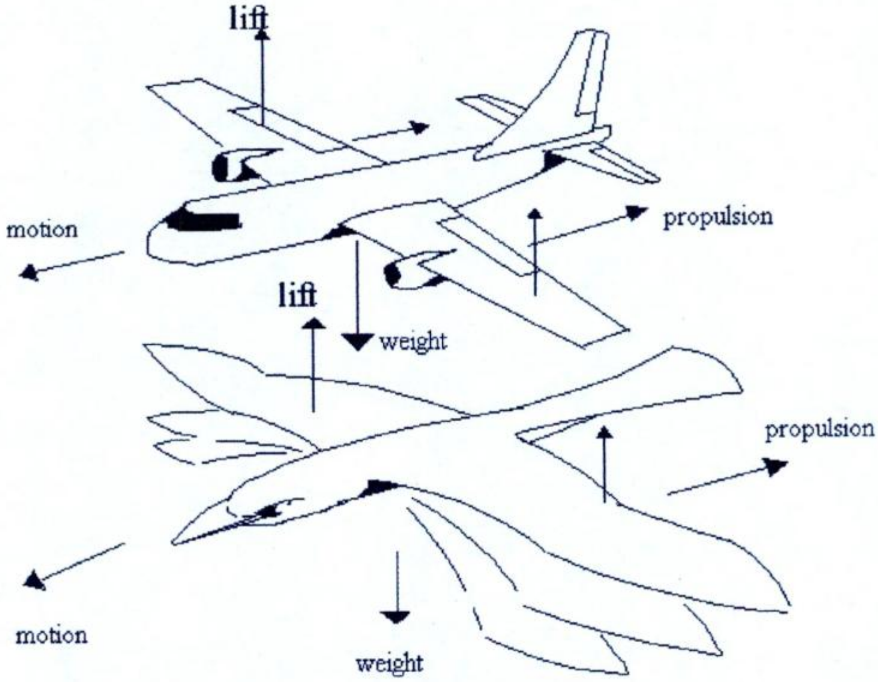


figure 40

To summarise, aircraft design is influenced by basic function which dictates aerodynamic considerations, and hence the material to be used. The important properties of these materials are strength to weight ratio, stiffness and formability. This largely determines form.

Is there a scope for aesthetics in aircraft design?

Given the scope of the new composite materials for weight savings, strength and reduced drag, why should aircraft designers not be able to conceive in terms of form and apply composites to produce what they want ? Freed from the limits of the old materials, could aircraft designers not indulge their art for its own sake with the same passion that was there since the beginning ?

Designers and architects over the years have celebrated the functional beauty of an aeroplane.

> The aluminium framework of an aeroplane - search for economy of material, for lightness, always the fundamental, the essential law of nature. Similarly in the marrow of our bones , the same fibres of equal resistance exist Clearness of function."(Le Corbusier, 1935, p.24)

As we have seen, organic forms had been evident in aviation's streamlined shapes, when it was nowhere else. This is because such forms were directly related to their function.

> The schools of the 19th century destroyed he human scale and destroyed respect for material. The aeroplane on the other hand, embodies the purest expression of the human scale and a miraculous exploitation of materials (Le Corbusier, 1935, p. 61)

For those who need to sell them, aircraft must look, as well as be, 'fast'. Style says a lot about performance, not always truthfully, of course. Trains are a case in point. Seymour and Powell designers of the Intercity '250 Mark V' for British Rail, are keen to stress that they made consumers their starting point rather than bogeys and traction.

Repudiating the 'form follows function' dictum, they say "There is a tendency to run down the technical route and allow styling to evolve from it. But you can't allow form just to happen somehow as a consequence of an engineering function. We have a saying here that form follows function . The form they have proposed is designed to look fast as well as be fast, It's not just a mindless piece of aerodynamics." (Hancock, 1991, p.41)

Although an airline passenger doesn't chose the aeroplane he flies in, aesthetics are a selling point to the airlines who buy the aircraft. Private aeroplanes, pleasure, and corporate need to be designed with even more appeal in mind as they appeal directly to the consumer and must satisfy some aspiration of that consumer.

Chapter 4

COMPOSITES IN AVIATION

In 1983, at Yorkshire, England, the world's first all composite aeroplane took to the sky. It was the T57B Firefly military trainer. It had a smoother than usual profile. Those taking a close look might have noticed that something was missing - it had no rivets. The low drag profile of its glass reinforced polyester material was just one advantage of its construction. It represented something of a technical breakthrough for the use of composites in aviation. (figure 41)

This chapter will look at the application of composites in aviation, we will see that the light or leisure aircraft has been most amenable to composites and it is to this area where the greatest impact in form is to be seen. We just saw how in metal construction, small aircraft are still externally strutted. We also saw how aesthetics are important here too. We will see if there really is more to the composite aesthetic than form simply following function. The designs of Burt Rutan provide an insight into the possibilities in terms of function, form, and innovation.

History of composites in aviation

Aircraft designers have, in fact, been using composites selectively for years. Fibre Composites first appeared in aircraft bodies in the 1950's. it will be remembered that fibreglass was developed for aircraft radomes. In the military area, since 1970 ,all new US fighter aircraft have been fitted with composite stabilisers.

Initially, composites comprised less than 1% of aircraft by weight and were restricted to secondary structures such as wing tips. This figure has steadily increased and composites have encroached upon the primary structural areas like wings, so much so that small business planes (Beechcraft Starship, Lear Fan) and gliders have now been built whose structures are virtually 100% composite. Today almost all gliders are made of composites. In the demanding military field, the figure has reached 26% (for example in the

AV-8B, the U.S. version of the British Harrier Jump-jet). Weight savings over comparable metal parts have been as high as 30% and typical cost savings have been around 20%.

However, the Airline industry has not proved so enthusiastic as yet. Could there be public distrust of new materials ? Composite aircraft are lighter and have a more aerodynamic look, so one might expect them to give the impression that they can fly better. There is, however a lingering trust in the power of metal, and the common impression of composite materials is that they are merely an exotic form of plastic. The airlines may have their own view. Peter Burgeff in his article on aircraft design suggests the reason to be one of repair cost. Composite repairs require still more labour. "No air plane is so expensive as a grounded aeroplane." (Burgeff, 1996, p.38) Also low fuel cost has out-weighed the advantage of composites.

Private, corporate or leisure aircraft on the other hand need to appeal in terms of performance <u>and</u> appearance. Those who buy them intend to fly them after all. Manufacturers of corporate or executive aircraft have adopted composites not just for performance but notably the image it portrays. A high-tech look for a go-ahead company engaged in advanced technology. (figure 42) The leisure industry in particular is liberal in adopting new technology which it can sell as offering a competitive edge. This is entirely congruent with a sleek and futuristic image. It has thus primarily been the smaller, lighter aircraft that have spurred composite construction in aviation.

> New technology based on composite sandwich structure has revolutionised the world of aviation, particularly in the construction of small light aircraft. In many cases kit built aeroplanes have led the way in the application of these materials. The 'lancair 320' is <u>sleek</u>, <u>elegant</u> and according to experts among the best in the field.
> (Antonelli, 1995, p.61)

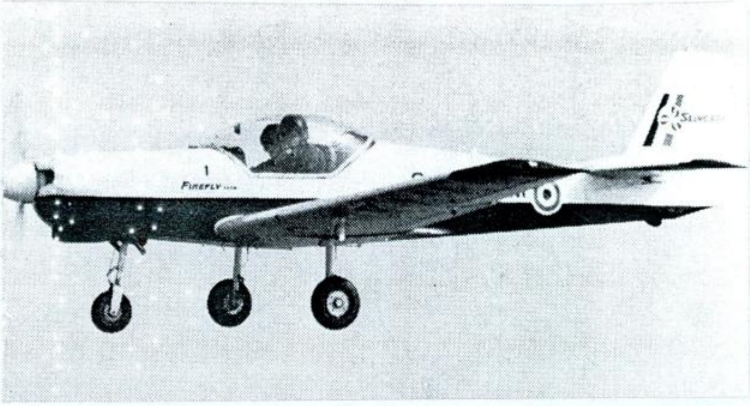


Figure 41 Slingsby T57B Firefly 1st (all-composite aircraft)

Figure 32 Corporate Aircraft(the Aerodynamics Jet Cruzer)

Figure 43 'Lancair 320'

Leisure Aircraft-the kit plane

The Lancair, (figure 43) above, is indeed sleek and sporty. The absence of the external struts normally found in such craft confers a sense of freedom. The fabrication of the composite materials facilitates home construction. Kit construction is now a growing sector of the leisure aircraft industry. "The growing Kit plane industry is a market segment that now outsells the production market fleet by 3 to 1." (Lancair@ Lancair.com.)

How composites compare

Fatigue Composites have better resistance to fatigue because the cracks or surface imperfections are prevented from propagating[6]. Metal is particularly subject to fatigue (indeed, it has a definite and a finite fatigue life) and there have been many well documented air accidents attributed to it[7]. Fatigue resistance of wood is, however, excellent.

Corrosion The problem with steel is rust, although aluminium is relatively corrosion free when properly anodised. Wood is simply susceptibility to rot. Properly protected and stored, a wooden airframe will last decades, but if not, it will decay in a few short years. Composites do not corrode or rot but there are concerns about the longevity of the material. Most resinous surfaces must be painted white to prevent excessive heat build up in sunshine. This is because epoxies and vinyl esters (resins in which fibres are embedded) soften significantly with increased temperature.

Malleability Metal is relatively simple to work with, and it is inexpensive. Composites, however, require even less skill than that for conventional sheet metal fabrication, and start up costs are relatively low. Labour time (in finishing, for example) can be higher than with metal. Wood tends to be expensive and the supply is erratic although woodworking skills are relatively ubiquitous.

Strength The main advantage of composite materials to the aircraft designer is their very good strength to weight ratio being better than either wood or metal as we saw in chapter 2. It is interesting to note that wood is, in fact, a natural composite of lignin reinforced with cellulose fibre. Composites initially lacked stiffness, but the development of carbon fibre has solved this problem as has the development of honeycomb or foam cores. Where strength requires the use of metal or wood components, these can be bonded to the composite components to form an exceptionally strong joint.

Weight as cost factor

Weight saving has probably been the greatest innovation composites has brought to aviation. Composite aircraft need less fuel, but can carry more of it. They can therefore can fly greater distances. In 1986 a composite aeroplane named 'Voyager' (see figure 44) performed an astonishing round the world non-stop flight. It remains the only plane to have done so. We shall meet its designer shortly.

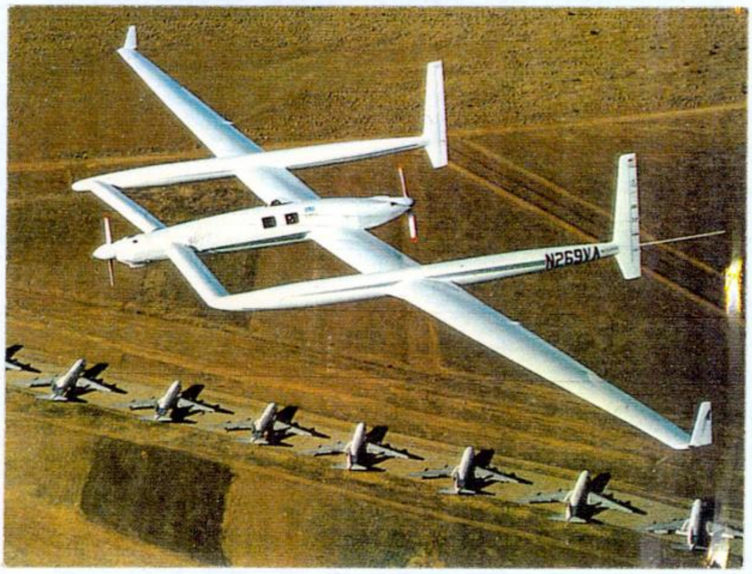


Figure 44 Rutan's Voyager (1986)

The aerospace industry is willing to pay a thousand dollars a kilogram of

reduced weight. to lighten a satellite. This reverse bargaining where one pays to have less takes place elsewhere: 215 dollars for a kilogram less of a helicopter, 140 for commercial airlines, from 7-70 dollars for sports equipment.

Weight as a Performance factor

Another remarkable aircraft is the Gossamer Condor (figure 45), which in 1977, became the first successful human powered aeroplane. It is:

> ".. an object with one of the highest performance to weight ratio ever achieved. With a wingspan of close to 30 meters - weighs only 34 kilograms , due to the use of an extremely light carbon and aramid fibres."(Manzini, 1989, p. 98)

The point here being that the absolute limit imposed by the human power output would never have been enough to propel a craft constructed of any other (heavier) material.

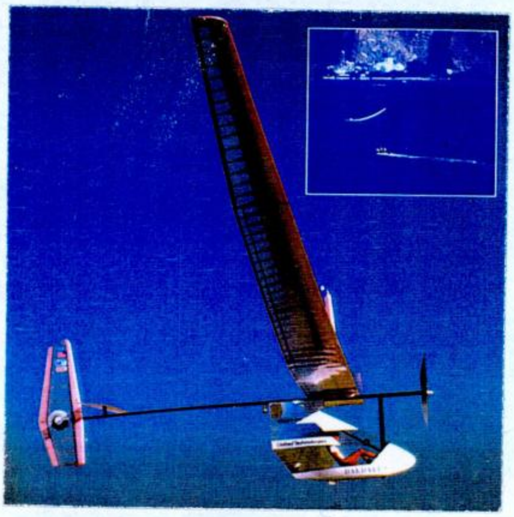


Figure 45 Gossamer Condor, (1977)

Properties contributing to form

We have learnt of the ability of composites to take on single piece complex forms. Observe the engine cowls below. (figures 46, 47) The first is fabricated from several metal pieces, riveted together. The second is a single piece composite moulding. The composite cowl is by far the more aesthetically pleasing.

Figure 46 Metal engine cowl

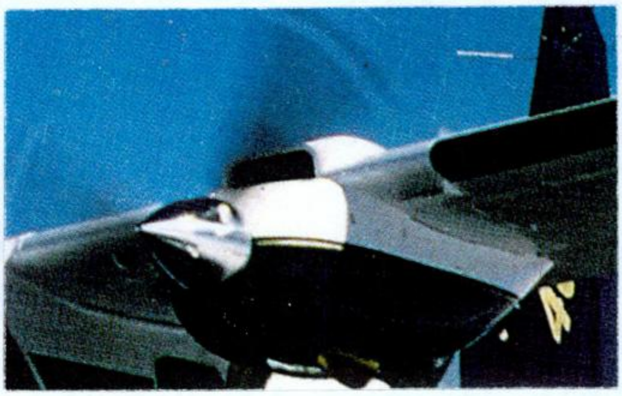


Figure 47 Composite engine cowl

We saw in chapter 2 how composites naturally result in organic and streamlined forms. We also saw how they have a very good surface finish. Chapter 3 determined that both these properties were desirable in aircraft design because they minimise drag. (see figure in later section on Rutan)

Uniformity, integration

We also saw how the formability of composites results in an integration of parts. Peter Burgeff asks us to scan, with the eye of a designer, what he called the uniformity of modern commercial aircraft for something exciting. He then invites us to notice the Piaggio Avanti (1988), He says: "The plane exhibits immaculate aerodynamics and design down to the smallest, usually neglected transitions". (Burgeff, 1996, p.33) This aircraft does actually stand out in terms of form. He points to its fully flush cockpit, integrated with fuselage streamlines. Not surprisingly, it is built predominantly of composite materials. (figure 48, below)

Figure 48 Piaggio Avanti.(1988)

Burt Rutan

Largely because of designs like Piaggio's, composite materials have caught the eyes of private and commercial builders alike. But no one can claim more credit for eye-catching forms than American designer Burt Rutan. He has skilfully exploited their strength and cost advantages. His aeroplanes have remarkable shapes exhibiting low drag and beautiful finishes.

After receiving a BA. in Aeronautical Engineering, Rutan went to work as a flight test engineer for several years mostly at the Edward Air Base in California. In 1974 he branched out on his own and formed the Rutan Aircraft factory, where he designed and marketed plans for some of the most popular aircraft ever built including the Long-eze and Vari-eze. The Long-eze is examined in detail below. Rutan's designs are noted for their unconventional appearance and aerodynamic performance; yet they are simple and east to build.

In 1982 Rutan founded Scaled Composites Inc. To date, the 85 person company has completed over 20 major designs for high profile customers like Beech Aircraft, Mc Donnell Douglas and others. One such aircraft - the Beech Starship, is examined later. Outside the tightly knit world of aircraft design, Burt Rutan is justly famous for designing the record breaking Voyager which we met above. Built to focus attention on the strength, safety,

and performance of all composite aircraft construction, Voyager succeeded beyond all expectations. It had a wingspan longer than a Boeing 272 passenger jet's, yet it was lighter than a small car. This enabled the craft to carry more than 5 times its own weight in fuel. It was this attribute that was exploited to such effect in the non-stop flight.

Tom Poberezny, chairman of EAA (the Experimental Aircraft Association) says:

Burt Rutan has made significant contributions to all spectrums of aviation over the past three decades. His ability to go beyond conventional thinking and emerge with ideas both technologically brilliant, yet functional have led some to say that he literally reinvented the aeroplane. (Poberezny, 1996, p.1)

We mentioned the Rutan's revolutionary 'Sculpting' technique of fabricating composites in chapter 2. Although Rutan did not invent materials like fibreglass and foam, his construction methods incorporating these materials have changed the way home builts are made. "His distinctive style moved home-built aircraft into a new realm of design and construction" (Poberezny, 1996, p.1)

Rutan Long-Eze

One of the world's most popular home built aircraft today, Burt Rutan's Long-Eze has succeeded because it is easy to build, is a good performer, and is attractively futuristic (figure 49) Built of composites, the Long-Eze can be assembled by modestly skilled enthusiasts with little aircraft building experience. Considerably less expensive than a factory-built aircraft, yet offering far superior performance, the Long-Eze has succeeded in setting a new standard for light, high-performance privately owned aircraft.

We have already established the styling possibilities of composites, which are: compound curves, one piece moulding etc. We saw that what this meant for the overall shape, was a more organic form. Notice the biomorphic forms of Rutan's Long-eze. (figure 50), Observe the smooth

integration of the various components into a uniform whole. There is a natural minimal aesthetic, characterised by sleek surfaces, and organic curves. (figures 49) This is the very essence of what we, as humans, imagine was meant to fly.

<u>figures 49</u>
Rutan Long-Eze

Figures 50
Biomorphic forms

Function and form

Full use can be made of the ability of composites to take up complex curves to provide both function and a pleasing aesthetic. The detail of the wing-tip in figure .. may look ostentatiously pleasing, but it is seriously functional. The upward curve is designed to minimise "wash-out" or, loss of lift over the wing tip. (figure 51)

The aesthetic is not just a function of the form however, but also the high surface finish which enhances the form. (figure 52).According to Vignelli Associates, New York:
"All materials reflect or absorb light according to their surface finishes. Light is the master of form. It shaped the contours of an object." (Ozborne, 1990, p. 149)

The gelcoat, the first contact layer with the surface of the mould (clear or coloured) , results in a clean line surface finish Any machining or finishing is unnecessary and thus the final form is uniform, and undisturbed.

Once again, the same properties that contribute to function also result in an appealing form. The surface finish helps prevent turbulent airflow, but also helps define the form. Similarly, the white paint, applied to reflect heat from the sun which would otherwise soften the resin, contributed to the overall aesthetic. In the words of Richard Meier & partners, New York;

> "White is in fact the colour which intensifies the perception of all the other hues that exist in natural light and in nature. It is against a white surface that one best appreciates the ploy of light and shadow, solids and voids. Traditionally white has been taken as a symbol of clarity - of perfection" (Ozborne, 1990, p. 146)

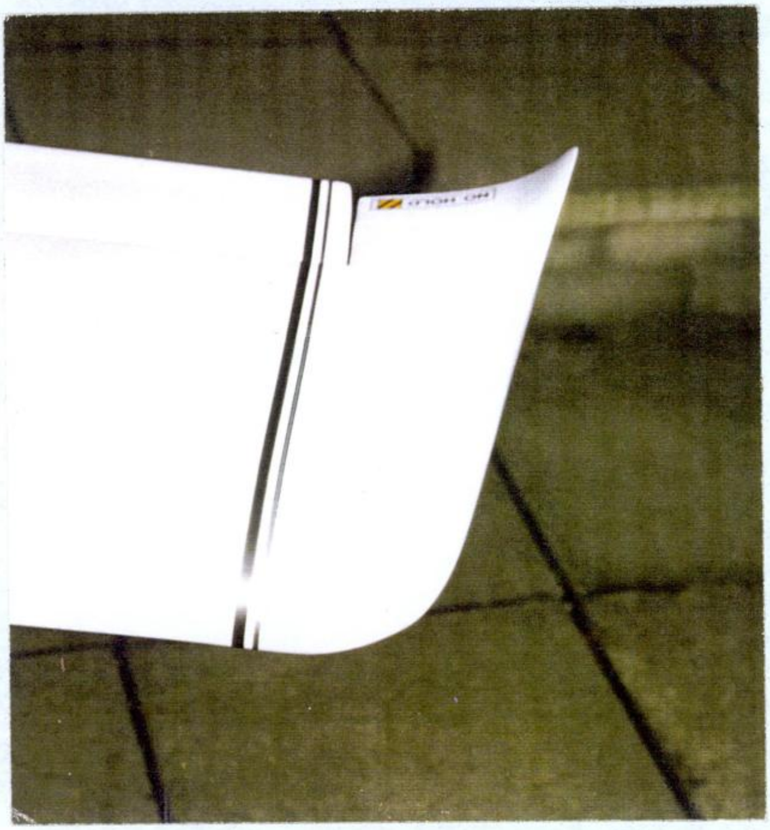


Figure 51
Wing tip featuring curve

Figure 52
High surface finish

There is something more to form however, than the aesthetic derived purely from function. In August of 1996, Rutan arrived at the Experimental Aircraft Association's annual show in Oshkosh, Wisconsin, flying what was described as "the weirdest looking aircraft" ever seen there. It was an Asymmetric twin engined craft named the 'Boomerang' featuring one engine mounted in the nose of the fusilage and another in a long parallel boom on the port side. This an example of how Rutan's aircraft demonstrate the freedom to play with the basic shape that composites offer. (figure 53)

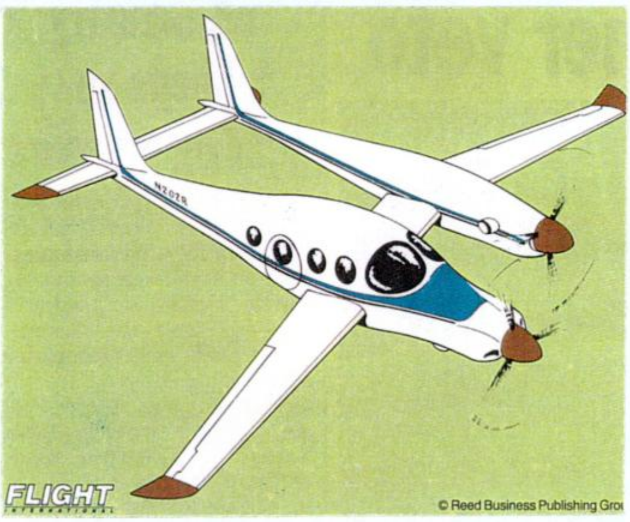


Figure 53
Rutan's 'Boomerang' (1996).

When I asked various airframe builders why they chose composites, the

main reason quoted was to save weight. All acknowledged, however, that the aesthetics of the form afforded by the use of composites are unique :

Richard Wong, senior engineer at Beechcraft says of the Starship:
(figure 54) "The unconventional profile makes for a very attractive appearance, mainly due to the all-composite airframe which enables the moulding of large, smooth seamless aerodynamic surfaces".(Wong, 1991,p.)

This suggests that there was initially an absence of bold styling but that the material and subsequent manufacturing process lent its own aesthetic. The Firefly, although revolutionary as the first all-composite aircraft, did not exhibit any expression of its material "truth".

> The term 'Black aluminium' is used in a derogatory sense to imply that the composite design is a copy of a metal design and is not utilising the unique properties of composites. Structural shapes have been developed over many years to give the most efficient structure. Changing materials has a significant effect on the optimum shape (Jackson, 1987, p.3)

Now, after composites have been proven to out-perform other materials in aeronautical engineering terms, and given Rutan's innovative and exciting forms, designers are no longer afraid to show off the expressive soul of composite material. This mimics the imitative transition of plastics to acceptance. Today, Lancair's goal "is to continue to play an important part in shaping the future of modern aviation through innovation, technical advancements, design purpose, and <u>aesthetics</u>" (Lancair@Lancair.com)

"The state of the art has developed to the point where it is often hard to tell whether components are made from reinforced plastics or from metal"
(Mayor, 1993, p.182). To the casual observer this may well be true. I tend to the view, however, that the observant person will know, firstly, that certain organic forms are simply atypical of metal construction, and, secondly, that such a unique aesthetic, accompanied by light weight, is indicative of reinforced plastics.

Figure 54 Beechcraft 'Starship', (1982) designed by Rutan.

The future for Composites in aviation

Further possibilities now being explored include unmanned high altitude reconnaissance aircraft, as well as successful solar powered aircraft. The first truly successful man-powered aircraft was of carbon fibre construction. Composites are also leading the way in other industries. For example, solar powered vehicles are now in prospect with the weight saving characteristic of composites.

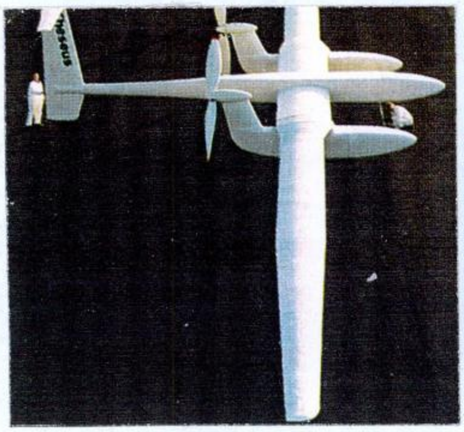


Figure 55 Theseus high altitude demonstrator

Figure 56 Solar Powered aircraft

Ezio Manzini says of plastics that they have "exploited their formable qualities not so much in the direction of fulfilling technical and constructional needs, as in the expression of different images". (Manzini, 1989, p. 34) We can now say of composites however, that the equivalent formable qualities have been exploited to provide both constructional and image benefits.

Accordingly, we can now see that composites have been innovative in terms of form, performance, encouraging further innovation and also in offering a whole new approach to home construction and, indeed, designing one's own aircraft.

It would appear that the use of composites will benefit conventional aircraft design by supplementing it in the case of appropriate parts, but especially by their use for new innovative all-composite designs.

Conclusion

Innate aesthetic is not just a result of the aerodynamic functions, but also of the freedom from constraints imposed by previous materials.
Composites can be moulded to any conceivable shape resulting in fluid organic forms.

> Matter, which has always been the solid, stable, and inert counterpart of ideas, has become ductile and malleable into every conceivable shape. We are no longer confronted with a given taxonomy of materials and manufacturing techniques, but with a continuum of possibilities. A synthetic way of expressing this transformation could be described in terms of a 'fluidification of matter' and an acceleration of time.(Manzini, 1989, p. 53)

The innate aesthetic of composites is such that some applications exploit this aspect only. In fact this unique aesthetic has been imitated. Children's bicycles, for example do not justify the cost of composite material. Yet the composite form is exciting and appeals to children. Manufacturers have thus adopted this aesthetic and encased the conventional steel frame inside two large plastic shells to create a three- dimensional, organic look, "a kind of swollen mutant composite look". (Evamy, 1993, p.23) (figure 57)

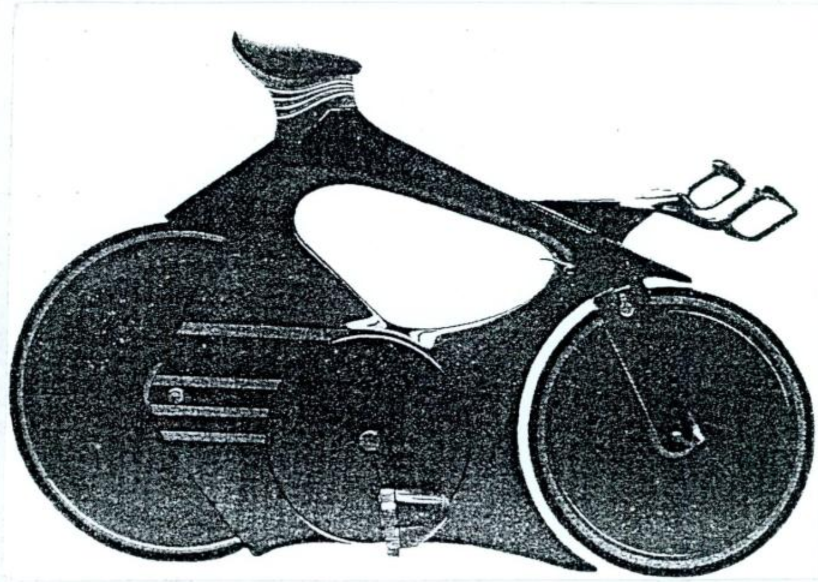


Figure 57 Composite bicycles

Figure 58 Children's bicycle.

We have discovered that there is indeed something that might be termed the unique aesthetic of composites - its great versatility of form without compromise on strength.

Once market acceptance established, designers felt free to innovate. So it is such with composites. Having more than proved themselves functionally designees are now free to exploit their innate aesthetic.

So what do composites hold for the future of Design? It would seem that we have not fully exploited the strength to weight properties of the common glass fibre materials. Their formability is almost limitless. This is without prejudice to the properties of the even more exotic materials and processes now emerging. The future seems bright and it is all about new form and ideas.

Where weight saving accompanied by high strength is required, as in sports goods composites have been welcomed. Indeed they have innovated in this area too. They have offered the professional sportsman a competitive edge.

An important aspect of industrial design is that of ergonomics, the human factor. Composites can be moulded to fit the contours of the human body. The natural biomorphic forms possible with composites are friendlier than the sharp edges of metals. In terms of tactility, the warmth of plastics/composites compare very favourably with metal, for example in handles etc. The Finnish Design Company, Fiskars who produce garden tools and the like, use composites for a combination of this property as well as their strength to weight ratio.

It is now possible to say that the main thesis can be substantiated. The use of composites in aircraft design has led to a radical departure facilitating new and attractive forms as well as improvement in performance and, as a result, their use in other areas has received a major boost.

If the last quarter century in aviation can be characterised by images of size, power and majesty, typified by the jumbo jet and the space shuttle, then it may be that the next century will see a victory over function and a return to the grace, form and beauty typified by the biomorphic shapes we so admire in the birds of the air.

> New materials neither bombard nor overwhelm the onlooker with superfluous detail - they pacify. The aesthetic of the 90's will concern sensitivity. Our hope is to employ material that will enhance. Clarity, beauty, proportion. It is these ideals we strive to interpret our space.
> (Ozborne, 1990, P. 148)

1 The Mach number is speed measured in multiples of the speed of sound in air e.g. Mach 2 is twice the speed of sound, or about 1,500 mph.

2 The TU-144 crashed spectacularly at the Paris air show of 19.. It was withdrawn from commercial service shortly afterwards.

3 e.g. Jane's All the World's Aircraft, which is the definitive guide.

4 A pressure vessel is optimised in circular cross section, e.g. a gas cylinder.

5 A glider's wing is said to have a very high aspect ratio i.e. wing length proportional to wing chord or width.

6 See chapter .. above

7 The best known is that of the loss of the first commercial jetliner, the DeHaviland Comet in the Mediterranean in 1956.j

Appendix I

GLOSSARY

Composite	A generic term used to describe the mixture of a fibrous reinforcement and resin
CRP	Carbon Fibre Reinforced plastic
Fibre	A material in filamentary form having a small diameter compared with its length
Fibre content	The amount of fibre present in a composite, usually expressed as a volume percentage or weight fraction
Foam Cores	A foamed resin created by using a foaming agent-rigid foams are useful as core material in sandwich panels in between stiffer outer layers
FRP:	Fibre reinforced plastic
Gel Coat	The surface layer of a moulding used to improve surface appearance or preppies- applied using a quick setting resin
GRP:	Glass reinforced plastic / polyester
Hybrid:	A composite containing two or more types of reinforcement

Impregnation	The process of introducing resin into filament bundles or fabric laid up in a mould
Mat:	A material consisting of randomly oriented fibre bundles , which may be chopped or continuous, loosely held together with a binder or needling
Matrix:	The resin in which the fibrous reinforcement is embedded
Monoque:	single shell
Mould:	The tooling in which the composite is placed to give the correct shape to the article once the resin has been cured
Moulding:	An article manufactured in a mould
Prepreg:	pre impregnated with resin, ready for manufacture into a component - either in the form of a sheet or tape
Pultrusion:	A process in which filaments and / or fabric coated with resin are pulled through a heated die and rapidly cured to retain that die shape.
Reinforcements:	Fibres which have desirable properties to increase the properties of the host matrix
Resin:	The polymeric material into which the fibrous reinforcement is embedded. This is where the term reinforced plastic comes from- the resin, or polymeric material being the plastic.

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Appendix III

MANUFACTURING PROCESSES

Press Mouldings- hot press (RPM)

This process involves a press (cold or heated) which s used to form an article from a compound comprising a mixture of fibres and resin. Applications include car body panels, Aircraft skins.

Resin Transfer moulding (RTM)

A process in which the catalyst resin is transferred into a mould into which the reinforcement has already been laid. Applications include propeller blades, panels, car doors

Centrifugal Moulding

The chopped fibres, impregnated with resin are sprayed in to the inside of a mould which is rotated to prevent consolidation of the mixture. Used for the production of cylindrical parts.

Filament Winding

The automatic winding of resin impregnated reinforcements around a mandrel which is removed when composite is cured. Used to produce such items as pressure vessels, pipes etc.

Pultrusion

An automated process in which filaments and / or fabric coated with resin are pulled through a heated die and rapidly cured to retain that die shape. The idea is similar to extrusion for metals. Applications are skis, aerofoils, and structural sections for bridges.

Injection Moulding.

Molten thermoplastic resin and chopped fibres are injected into a mould where the composite is formed and allowed to cure. Used to produce small intricate parts.

Prepreg Moulding

A process where Prepreg material is moulded wither by autoclave , or vacuum bagging.(se below)

Vacuum Bagging- An advanced moulding technique where weight is reduced by eliminating excess resin by placing the part in an environment where vacuum pressure can be applied.

Foam Cores

Stiffness can be substantially increased in thin sections by using a low density foam or honeycomb core between the laminate skins. These are called sandwich laminates.

Appendix IV

QUESTIONNAIRE

1 Please list the main All-composite or part composite aircraft designed / manufactured by your company?

2 For each of the above aircraft, specify as to type
e.g.: Glider
Pleasure craft
Corporate aircraft

3 In the case of each aircraft what were the main composites used?

In each case what percentage of total material used was composite

Which of the main components are composite construction?

4 What were the main reasons for designing with composites:
Weight reductions........leading to increased speed
...............leading to increased payload
Greater scope for aesthetics (innovative forms)
Cost
Other
(If there is a number of reasons, please list in order of importance)

5 How would you compare performance to that of non- composite aircraft?

6 To what extent do you contribute the success of your aircraft to the use of composite materials?

7 What do you see as the future for composites in aviation?

8 Can you sight any articles / magazines dealing with your company that might be of relevance to the above questions.

Appendix V

APPLICATIONS (PROMOTIONAL LITERATURE)

The ADVANCED COMPOSITES GROUP

Composites applications in the Aerospace Industries

The Advanced Composites Group is ideally placed to offer a unique service to the Aerospace Industry.

With a wealth of experience stemming from a solid foundation of materials and structures knowledge, ACG is able to solve the most complex of composites optimisation challenges.

Advanced Composite Materials Ltd is established as a supplier of our unique LTM range of materials. These offer a wide scope of opportunity, from top quality tooling to low temperature curing high performance component prepreg systems. Coupled with tooling blocks, adhesives, finishing systems etc, composite structures for aircraft can be tooled correctly first time.

The Advanced Composites Group, Inc. offers a similar service to ACM within the USA. The full range of prepreg and tooling manufacture is available through this subsidiary.

Advanced Composite Components Ltd offers a full service for composite component manufacture ranging from interiors, secondary and primary structure, and all associated tooling. We offer the additional benefit of design support for tooling and components.

CAD simulation of **Israviation ST 50 project**

Main Picture: Mcdonnell Douglas F-15

The Advanced Composites Group

Composites solutions for the automotive Industries

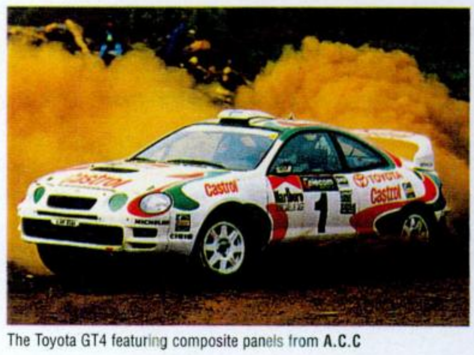
The Advanced Composite Group boasts the world's most impressive "track record" of automotive and motor racing achievements of any composite manufacture.

The Group started in a garage in Rochdale in 1975 producing aerofoils and endplates for F1 and World Sportscar Championship cars, and by 1978 had moved on to chassis panels and full chassis tops. Its first complete F1 chassis was built for Alfa Romeo in 1981. The Group has now produced over 650 chassis. These range from Formula 1 and Group C to Formula Atlantic, GTP and Indy.

ACG has also been involved with high performance road cars for Oldsmobile, TWR/Jaguar and Schuppan.

Since its inception ACG has been in a unique position to support the automotive/racing industry with a comprehensive range of composite materials and manufacturing experience.

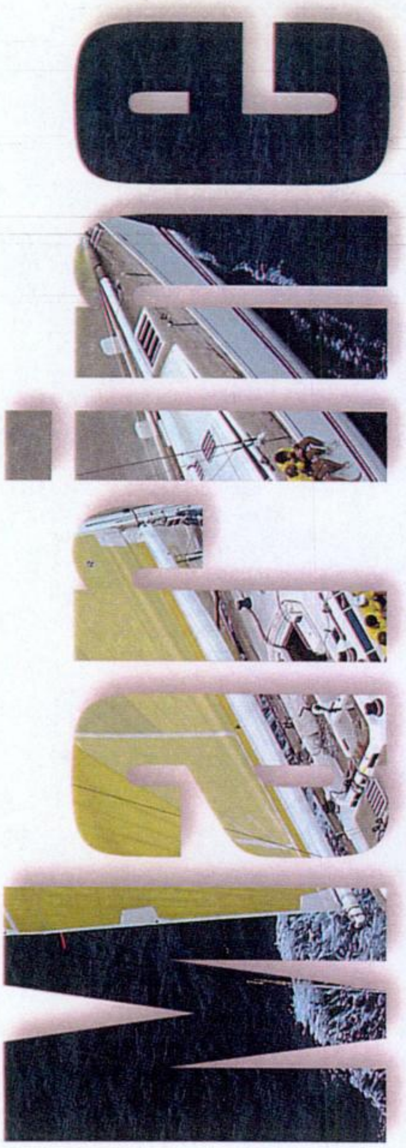
Through its materials production division, ACM, the group can offer tooling materials ranging from a room-temperature curing, gel-coat surfaced precom to low temperature autoclave cure prepregs. For components there are low temperature, curing toughened epoxies that are suitable for vacuum or autoclave-assisted processing.



The Toyota GT4 featuring composite panels from **A.C.C**

Main Picture: The Pacific PR02 F1 car

The ADVANCED COMPOSITES GROUP



Race winning composite formulae for the the marine industries

From racing shells and kayaks to power boats, and from oars to masts and booms, Marinepreg® continues to demonstrate the convenience of low temperature cure epoxy prepreg to achieve consistent product by cost efficient processing routes.

The ability to save weight and win races with Marinepreg has already been demonstrated in boats made for the Centomiglia Regattas in Italy. For USA the Hobie Cat has Marinepreg carbon fibre masts. Several other mast and boom projects are ongoing.

Designed by Ed Dubois of Lymmington, Holland Composites have just completed moulding a 55 ft power boat in Marinepreg for Vitters. Here the ability to use high performance epoxy / fibre composites cured in simple ovens at low temperature achieves significant benefits for optimising structural design and achieving the desired performance objectives.


Low cost processing of **Marinepreg**®

Main Picture: ITA '93 winner of "Centomiglia' on Lake Garda, Italy.

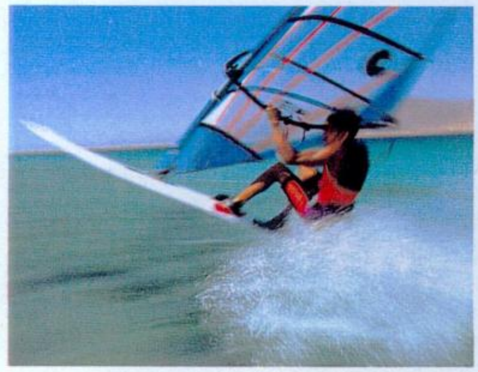

32m carbon mast for Francespar

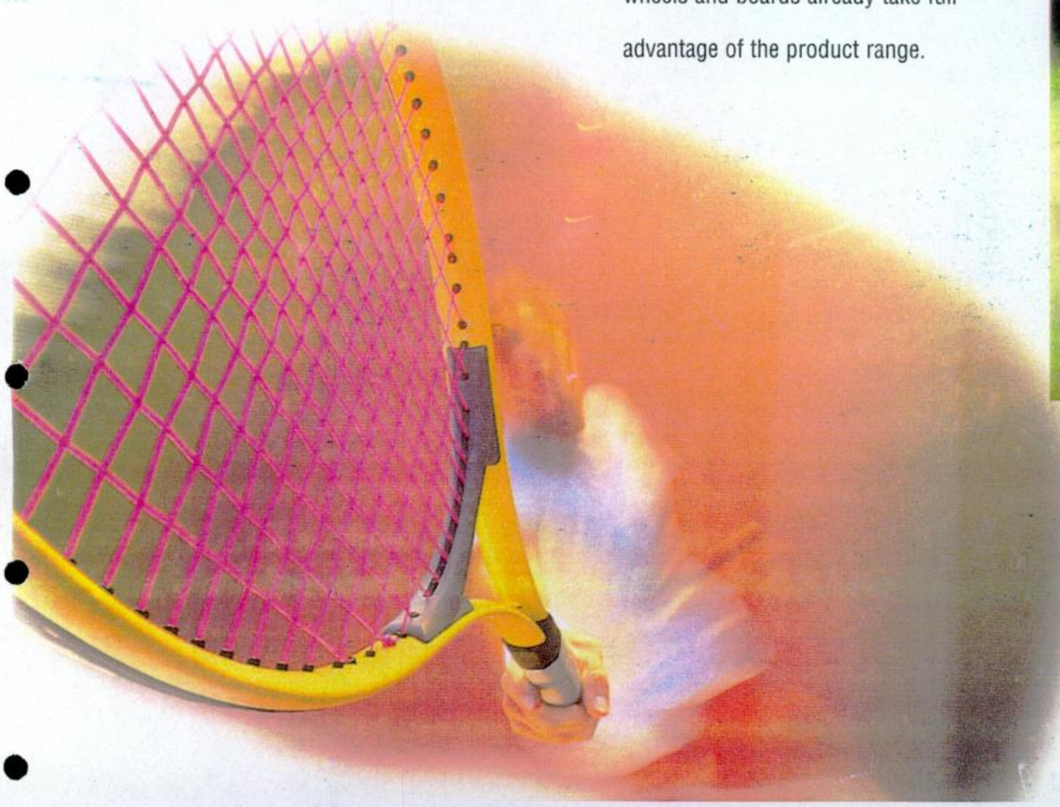
The ADVANCED COMPOSITES GROUP

Applying the winning formula to sports equipment

We all like to win - and that is what all sporting goods manufacturers try to give their customers. Equipment is being designed to give an edge and by using composite materials, particularly with carbon fibre reinforcement, producers are gaining the optimum stiffness and strength to weight ratio in their design.

Materials available from ACG give designers free rein to achieve their goals. Unidirectional and multidirectional reinforcements in a wide range of areal weights support a selection of over fifty thermosetting matrices. Racquets, rods, shafts, wheels and boards already take full advantage of the product range.





The ADVANCED COMPOSITES GROUP

Skis & Snowboards: Maximum performance, control and cost effectiveness.

Snowboards: Whether you're grinding, railing or thrashing you want a light, strong and fast board to stand up to the repeated beatings you give it. The best way to give you the performance is with new composite materials from ACG.

Skis: Established manufacturers understand the need to continually improve their designs in a highly competitive market. High stability turning with a minimum of energy and excellent hold are essential drivers for new designs. No tops, no sidewalls, just a one piece cap is the manufacturer's requirement. Low temperature cure, fast processing, dedicated prepregs that can be wrapped or formed into the cap are the name of the game from ACG.