The Story of Fiberglass Sailplanes

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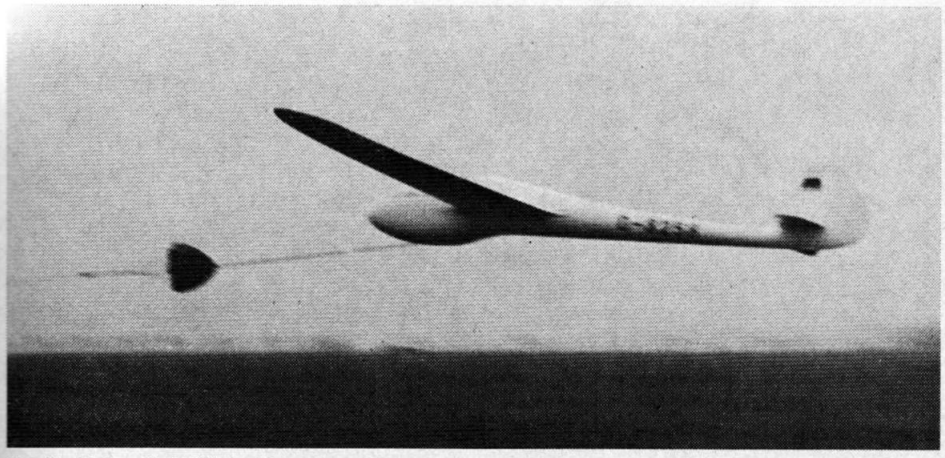
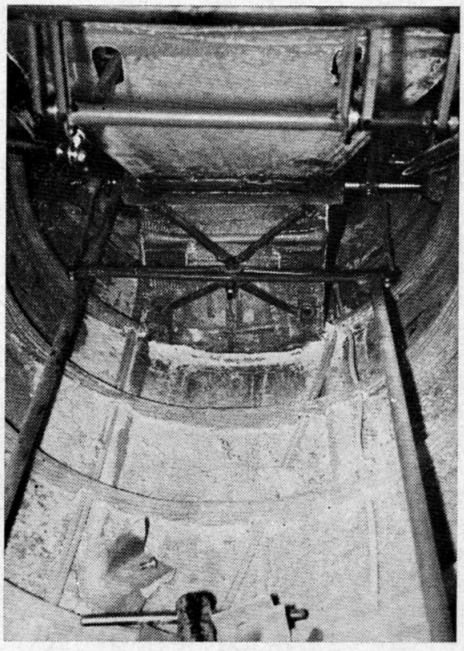
As old as aircraft building is the continuing design effort to carry all the various loads, wherever they arise, in the same shell which provides the necessary aerodynamic contours. With fiberglass we are now able to achieve this design goal in a much simpler way than with the usual materials. With fiberglass we can build aerodynamic shapes of required strengths at a minimum weight.
However there still remains the old fact that aircraft design is a continuing compromise.
Fiberglass aircraft design is governed by two considerations: the shell and the fiber.
Shell, or pure monocoque construction with all loads carried in the aerodynamic surface, is optimum. But there are certainly some necessary compromises. In the wing, for instance, where aerodynamic factors dictate a thin section of long span, the large resulting bending loads are carried by a beam. But here again the best result is obtained when the distance between compression and tension strut is as big as possible – that leads us to the integration of the struts into the skin.
Another compromise results from the requirement for easy rigging and derigging of the large span modern glider. This dictates the concentration of wing root loads at two or three detachment points, rather than flowing through the wing shell to the fuselage shell.
The first steps on the way to a shell construction began before the first world war. The fuselage of the racing Deperdussin aeroplane came very close to being fully monocoque. In the later twenties or early thirties we find this effort on the Fafnir, but still using conventional materials, and these are all of sheet form. It is quite difficult to ahieve with sheet the cambers and the smoothness required by aerodynamic shapes with their multiple curved surfaces. One has to work more or less in polygons when one has only flat sheets – except the work in sheet metal which needs on the other hand a big expense in tools or working hours.
The first attempts to fiberglass work we find in the thirties. For the first time we meet glassfiber in organized form in the electrical industry. Glass fiber bands, with an impregnation of phenol resin, were used for insulators. First tests were made to use glass laminates for phenolic pressed bakelite parts.
From this work the very high strength of the glassfibers was discovered. Apparently this high strength results from a tension built-up during the fast pulling process used in producing the glassfibers. This circumstance is the key to the whole technique of fiberglass high-loading construction.
We obtain the optimum design when the glassfibers are required to follow as nearly as possible the direction of the stresses. The main concern is to place them in the shortest possible line between the two points of load transfer and keep them in position. This usually means a straight line, and this consideration led us to working with rovings. Because the manufacturing with single glass rovings was difficult, or took a long time, it was the practice to lightly fasten these glassfiber bundles; thus producing unidirectional fabric. This gave a plywood-like solution.
When we have to carry forces which are not too high, but coming from different directions, we use glass fabric laminate. The disadvantage here is a slightly lower Young's Modulus, because in a fabric the fibers are arranged more or less in waves, chaving been twisted somewhat in preparation for the weaving.
Accurate investigations about all the different aspects of glassfibers, combined with the knowledge of the electrical industry on how to fix glassfibers in any required shape with curing resin, are the basis of operations with fiberglass material in highly stressed parts.
The first person to use this knowledge for an aircraft was Dipl.-Ing. Nägele, and he was also the first pilot of a fiberglass plane. His aim was not only an optimum method for construction, he also was searching for an optimum for reproducibility. His first try was a combination of strips of paper and casein glue, placed in a mould, to build-up a spherical shell.
At this time we in Germany had no fiberglass material; nothing at all was available for aircraft building. Our aircraft workshops and airfields look like the picture: flying was forbidden. This was the «zero» hour in our flying sport.
So, with the casen-paper method, the parts of an otherwise conventionally built aircraft took shape, and in spite of its illegal construction, the baby grew very well and was ready to fly when the sport of flying was opened again in our country.
The next step for Nägele and his fellows of the Akaflieg Stuttgart was a sailplane. In this project, the shell parts of paper mixture became load carrying parts of the plane. Based on the design of the H 30 by Dipl.-Ing. W. Hütter, which proposed a balsa sandwich between thin layers of poplar veneer or plywood, this paper flügel had a sandwich of balsa between two layers of the paper material.
In this time the young constructors had their first contact with reports concerning fiberglass. Wolf Hirth got them the first fiberglass samples, let them work in one of his workshops, and gave them many kinds of help.
Meanwhile, an assistant of Prof. Grammel, at this time quite unknown, a Mr. Eppler, took care of a further important factor in the form of a research grant from the Landesgewerbeamt Baden-Württemberg. The sum was nearly equal to today's cost of a comfortable fiberglass super sailplane but it was, in spite of this, a very courageous act because nobody could have had at that time any real idea of the development costs of a fiberglass aircraft, and nobody could estimate the distance to the goal of the work – a simple kind of aircraft production.
Assisted by the aerodynamic specialist Eppler, the design of the paper flyer was changed to fiberglass and was given the remarkable name «Phönix» (Nägele confessed: it was because we could burn up the paper flyer!). They tested hundreds and hundreds of stress samples, because the manufacturers of glass and resin were unable to provide stress data with any certainty. Finally, they decided to use a combination of fiberglass fabric and polyester resin.
The Phönix was built in the then unsual negative method. For this they needed nearly three years to manufacture the moulds and the first sailplane.
During the project Nägele had in his workshop only two helpers. A simple calculation shows the immense personal effort he had to make to gain success. By the beginning of 1957 the project was taken over by the firm of Bölkow, and Nägele's way became a little easier.
The main spar of the Phönix was still not entirely of fiberglass. It used balsawood for the caps although the balsa-fiberglass sandwich shell certainly was used as a load-carrying element.
November 23, 1957, on the airfield Schwaighofen near Ulm, the world's first fiberglass sailplane was airborne, with pilot Nägele in the cockpit. Launching was by a winch tow! The opportunities for aeroplane tow were extraordinarily rare at that time.
The first flight was short, to check the controls, after which the bird completed its first proper circuit. Then we ran to help Nägele out of the cockpit after

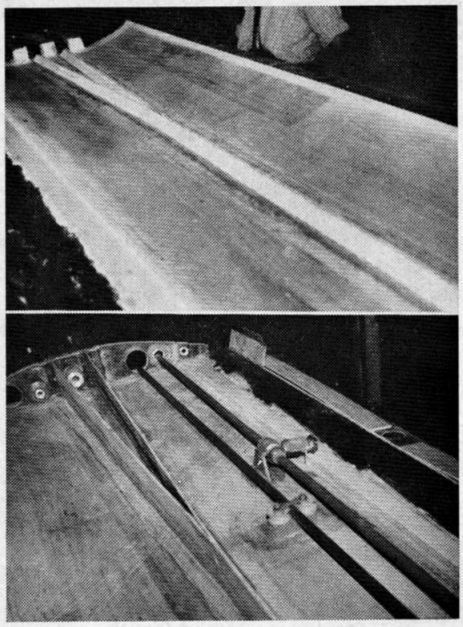


(1) First take-off of Phönix, November 1957

this first flight. We had no words for what we saw – the snap hooks of his automatic parachute (we had no other models at that time) were not fastened; should he have had to use the chute it would not have opened!
Stimulated by Nägele and Eppler, young aircraft constructors everywhere engaged in fiberglass construction. In Darmstadt, the Akaflieg started extensive experiments on samples and bigger aircraft parts in the years 1955 to 1957. The innovators were Dipl.-Ing. Puck, Wurtinger, and later Lemke, Waibel, Holihaus and Friess. Sometime later, Puck and Wurtinger became the leading engineers of the new German Plastic Institute. All of the others are still working in fiberglass; Friess as the well-qualified Airworthiness man at the Luftfahrt-Bundesamt.
Following the construction of the three sailplanes D 34, a to c, which all had the same wing design (a full foam wing core covered with a skin of plywood) the D 34 d used a core of paper honeycomb and a skin of fiberglass. It was flying in 1961.
But the great time of fiberglass was coming for the Akaflieg Darmstadt with the D 36, which already had the signs of its time: a shell of balsafilled fiberglass and a roving main spar. It was airborne in 1964.
In Braunschweig, the Akaflieg began to make parts of the SB 5 in 1957. The SB 6 had a load carrying shell but only one side covered with fiberglass. From this type, Dipl.-Ing. Björn Stender derived the famous BS 1. This sailplane was the first which could reach about 300 km/h at a reasonable gliding angle. So it was the important forerunner of the present line of sailplanes. It was unfortunate that the BS 1 production was started under very limited financial circumstances, and the relation between manufacturer and customers was so unbalanced, that I feel this was the deeper reason for its failure.
The BS 1 would, in a later version, be produced by pouring foam into the fiberglass cover skin inside of a mould. We have to wait and see if this production method will further advance aircraft building. The method with precut sheets of foam material used in prototype No. 2, was only an intermediate solution.
Stender is also credited with the simplification of the double-fork wing joint of the H 30 to the now universally used tongue-fork joint. The first fundamental fiberglass report published in Germany in the «Kunststoffe»-journal of 1954 was the time of starting for many of us, so also including ourselves – the Hänles. Looking for a way to construct two 17 meter long blades for a wind-power generator, Prof. Hütter and his then assistant, Hänle, risked the jump into the unknown – to fiberglass. They found the same difficulties as Nägele and Eppler: the data from the material manufacturers were insufficient. We had to do the same endless tests as Nägele, but direction was given by the long, slim shape of the blades which became the direction for using rovings.
First, we tried to imbed some hardened roving rods in fresh fiberglass material. This experiment disclosed a basic problem: the very high loads that could be carried in the roving material could not be transmitted i into the attachment fitting in this manner.
For this we tried to put in moulds still soft strips of rovings. We found that a group of resin-wetted glass rovings, pulled through a tube without time to harden therein, would become not a broom, but a fine, formable clothesline, the ideal basic material for the work up to the present day. On this basic discovery is built the work of many manufacturers of aircraft fiberglass parts.
In checking the strength of the new material we had difficulties. The jaw of the stress machine would repeatedly slide off the specimen. How were we to measure the breaking point? By chance Prof. Hütter, in handling a freshly wetted roving line, bent it around his finger – and the loop was born, the method of high stress transfers for all Glasflügels up to this time.
Finally we obtained exact results in our tests: up to 8,000 kg per square cm tensile strength, and if the loop was designed correctly there was imperceptible reduction of strength in the connection. So was born the HH-Hütter-Hänle-method, as an optimal solution for design of fiberglas girders.
The firm of Bölkow was so interested in the new method they asked Hänle for a series production of rotor blades needed for wind tunnel tests and for the ground trainer. Based on this patented method Bölkow is producing its rotor blades today.
This order was the start of Hänle's own firm in 1957 which was named a little later Glasflügel.
It as a short step to transfer this fiberglass experience to the construction of a little sailplane, based on the design of the wooden H 30. First, it was only a hobby, an aircraft to fly ourselves. But this design was the first with a main spar entirely of fiberglass. The spar was part of the shell and had a loop connection – in other words, with all the pricipal design features of later sailplanes. It was also the first that was made using the now normal epoxy resin type.
This H 30 GFK, which still circles above the Teck mountains, was the mother of the Libelle; its father was the famous turbo plane H 30 TS.
In recognition of the very great capacity of this new material to absorb energy, the fuselage of the Libelle was designed as a springlike, all-fiberglass element – rigid enough to resist the usual loads in flight and on the ground, but highly elastic when abnormal forces were attacking. This element is able to absorb a big portion of the destructive energy of an accident. This property is also used in working spring

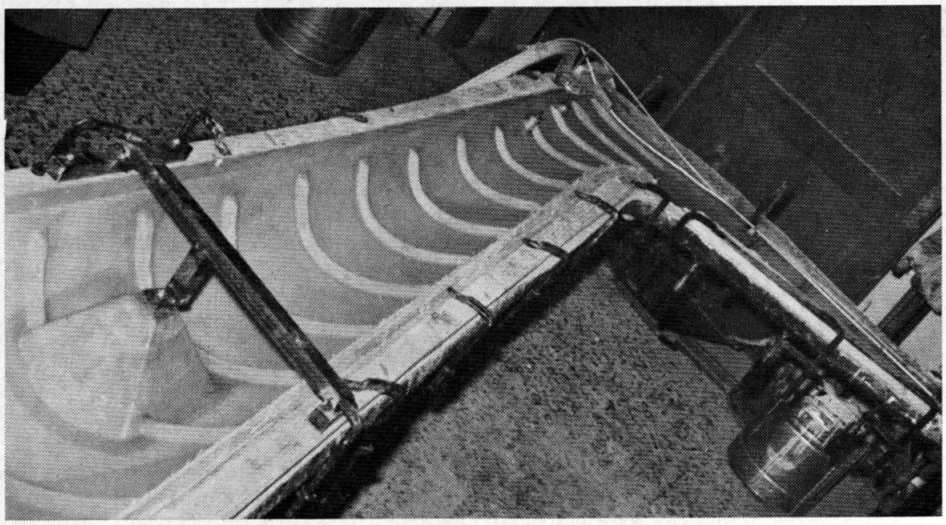
(2) Interior of BS 1 Fuselage



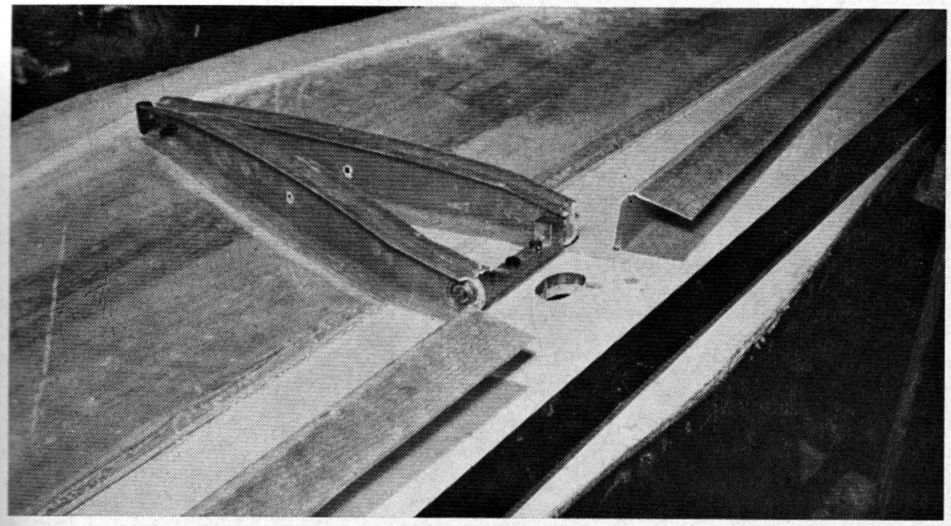


(3) Interior of Libelle Wing

elements as in the fibercone spring in the landing gear, and the skid, later also in landing gears for aircraft.
The Libelle was the first fiberglass sailplane produced in larger quantities and available to the general public. It was the object of critical study to fulfil the requirement for airworthiness certification both in Germany and in the United States. This effort brought problems bigger than those of the construction of the sailplane itself. For the first time, in the case of sailplanes, breaking load and fatique tests on whole aircraft parts were required because it was impossible to obtain design standards for the certification in any other way. The method of the 45,000-hours test was used on the Libelle wing the first time. For the manufacturer this was an immense burden with not too much help from government or officials.
During the working ont of these problems, the method for determining the limitation of sailplanes were put on a much changed basis. For instance: at the time it was usual to state first how fast the sailplane should fly, and to layout the strength analysis to that value. With fiberglass you have first to check how fast the plane is able to fly depending on its aerodynamic quality and desired wing-loading, and then to bring the strength analysis to the value so obtained.
There were found facts which nobody was speaking about in former acceptance procedures for wooden or metal planes. The result was not only the modern airworthiness requirements for fiberglass planes, but a general progress for airworthiness rules of modern planes.
For this progress, gained by manufacturers and examiners together, we had to pay a high price, and this was, really, the reason for all the efforts: the loss of one of the most qualified young designers of fiberglass sailplanes during a test flight in his BS 1. By this accident, everybody for his part was taught that the new possibilities required new dimensions.
With fiberglass we are able to build fuselages capable of absorbing the energy of crashes and remaining intact in a way never known before. How difficult it was to convince the officials that such a fuselage has to be elastic! Such examples typify the requirement for all participants in this work to re-educate themselves.
With fiberglass we could now design sailplanes with aerodynamic qualities unknown in the past, with diving velocities never dreamed of before, but also with new problems, because this velocity can be reached very fast in some cases. With fiberglass the way was open to the employment of large wing spans with thin sections nearly impossible with conventional materials.
With this new geometry, higher speeds, and this highly elastic material, flutter problems arose. There was a need to find out simple methods of analysis for predicting the flutter modes of the new slim wing design and to find out divergent modes by proper distribution of the structural material or by mass balancing. I think all designers of fiberglass sailplanes feel well in the hands of Ing. W. Stender, the father of Björn, with his wide experience.
Finally, we have the material itself: do we know all about this fiberglass? The problem in relation to airworthiness requirements is, simply stated, to safety regulate such aircraft design and construction on the one hand without, on the other hand, stopping development. The officials who were pulled into the swirl of the development had hardly returned to the quiet reached by the new improved rules when they were confronted with new developments and theories. Perhaps we are at the same point with fiberglass as count Zeppelin in the beginning of this century when, for the first time, duralumin was used in his rigid airship.
The motto is: re-think, discard, simplify. The material and its technique is still just too young for us to think that the end has been reached. A part, whose design is an optimum for conventional material will look completely different in fiberglass to be still same optimum in that material. A simple transfer by scale may only result in a bad copy, if not a complete failure. A fitting which was in the previously normal fashion volted on to the fiberglass part will tomorrow be reduced in its dimensions and imbedded into the fiberglass structure. The dax after tomorrow, it is perhaps completely absent, because it is reduced to a little connection eye, fully integrated into the part. In wood or metal one has no other possibility for making a connection except with bolts. The required bored holes certainly reduce the load carrying part of the material. Only the fiber is able to embrace the bolt and run through the whole aircraft part without interruption.
In fiberglass one is able to vary the quantity or quality of the material in conformity with stresses flowing and thereby produce the most efficient structure.
Re-thinking is the motto, especially for the workshop man. The time when aircraft are baked like bread is still very far off, and it must he said that we still are waiting for the really big series production method. In addition to the compromise of the aircraft design itself are the compromises entailed in its manufacture.
For instance, use of laminar airfoils is only logical if we are able to use this airfoil throughout the whole wing span with a minimum change in the profile during use. In wood or metal we would have some difficulties, especially with



(4) Libelle-fuselage inside



(5) Interior of Tailplane

temperature changes. The achievements of BS 1 and D 36 were accomplished largely because the laminar airfoil was made practical over a large span.

In the negative mould method used in today's serial fiberglass manufacturing, the quality of the surface depends on the quality of the mould. The better the mould, the better the part, and the lower the rate of lost time work. Here we are captive between the conflicting factors of an expensive mould and the relatively small number of parts required in sailplane manufacture. And the more complex the part, the more expensive the mould. The demand for reducing handwork, in view of its cost, is another big part of the problem. Many production methods which look very progressive at first may be eliminated in the future because the number of manufacturing steps, and their costs, were not fully recognized.

The improvement of the fiberglass material itself seems not yet finished. Studying the flight manual, one will still find this limit of full strength at 54 °C, dictated by the most usual resin mixture of today. Certainly, any pilot who has sat in a sailplane at only 40 °C ambient temperature will confirm that this temperature criterion is amply high. In spite of this we would be glad to have a resin mixture with all the advantages of our present resin yet having a higher temperature limit, because we could then build coloured sailplanes which could be very desirable now and in future high density air traffic.

What is the present resin really like? Why has it taken its place in all our workshops? It is nearly liquid and is able to moisten the glassfibers easily and rapidly. It can cure at room temperature to such grades of strength as needed. When cured it is satisfactory in extreme climate conditions. It contains no solvent and, therefore, does not shrink in curing. It has one of the longest open times we know. It does not smell bad, and for the most people it is not aggressive. In brief, it is the most favorable compromise we know today. Fundamentally, resin and glass are not capable of chemical combination. The glass has no free valances, besides, it is coated during manufacture with a smooth substance. Because the glass has a different tensile coefficient from the hardened resin, we get white spots when we apply a load on the fiberglass. These spots are the signs of loosening of the resin from glass at which point there is no more a support for the glass fibers. An effort was made to obtain a bond between glass and resin by a substance which is chemically kindred to both. But it seems this method it not well developed at this time. Research work of F. I. Kossira and others has shown that we will always get the best result by using non-impregnated fibers. But this is not practicable because the glass fibers alone are too brittle. Perhaps the problem is distorted by the fact that these contact substances are sprayed on the fibers only imperfectly: here a spot, there a sprinkle. The microphotos let us see this circumstance very clearly.

While we are still struggling with the optimal utilization of the glass fiber we must not overlook the possibilities of new materials — the generation of the carbon, boron, silicon fibers. Also, tests were made with asbestos fibers, but they were unsuitable for us because of their shortness. It seems that carbon fibers could be used in the same manufacturing methods as glass fibers; on the contrary, the boron fibers would be too brittle for us to form a loop, for instance.

All these fibers have a much higher tensile strength than glass fibers and a manifold value of Young's modulus. It would be possible to build with them a wing of greater stiffness or with a thinner airfoil but same stiffness as fiberglass wings. These wings, in many cases, could also be lighter than fiberglass wings with the same loading. But the task seems to be: to avoid the loss of the biggest fiberglass advantage — the high absorption of energy, and to earn at the same time the strength properties of these new fiber material. Would this be possible?

It is better to have more safety for the pilot and ship than less. Nevertheless we meet here a limitation. These modern planes have excellent aerodynamic qualities and a higher wing loading than in former times of soaring. Following this line of thinking: what is the part to be played by all these fibers toward the problem of increasing velocity difference — higher interesting cruising speed and at the same time a lower landing speed? In Germany the first carbon fiber wing part is under construction now by the Akaflieg Braunschweig (centre section of SB 10). Many others are looking to the reduction of buckling in thin shells from the higher stiffness of the carbon fiber.

The more questions we put, the bigger grows the circle they encompass! For a long time we have known that soaring and sailplanes are not silent islands in the ocean. We know countless examples of transfer of aircraft design to other design work. Nobody is able to prophesy the measure of influence on general aircraft design of the present methods of glider construction. And nobody can predict the direction and length of the way. Is the fiber method really the ne plus ultra? Also when power units are working in such a body? Will we get new tasks, perhaps in high altitude soaring? Which way will we go with span and shape of a wing? Has the sailplane, has the aircraft generally, its final shape?

The most facinating point in soaring is its intellectual span. Soaring will be tomorrow the same as today: not only the best part of life, but the compost in the land.