THE INFLUENCE OF MATERIALS ON THE DEVELOPMENT OF SAILPLANE DESIGN

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ABSTRACT

The evolution of sailplanes in the past century is a product of both the progress in aerodynamics as well as the usage of new materials including constructive and technological solutions. The focus of this contri-bution is to highlight the importance of new materials and their application in the development of sailplane design. Three periods are classified. The first begin-ning with the flights of O. Lilienthal in 1891 is char-acterized by wire braced, cloth covered willow, bam-boo and wood constructions of the wings with thin airfoils. New possibilities were discovered in 1921 with the Vampyr where by means of ply-wood a can-tilever single beam design including a D-tube leading edge of high torsion stiffness allowed a thick airfoil wing without wire braces. In this period also some important metal designs can be found. The end of this period which culminated in the HKS and KA6 con-structions was rung in with the Phoenix in 1957 which was completely designed in glass fiber rein-forced plastics (GFRP). The introduction of high strength and high modulus carbon fibers finally enabled further possibilities to increase the glider per-formance. Composite materials have been dominating the development of sailplanes now for nearly 50 years. Nevertheless, there are still problems to be solved such as the missing confidence in the very good fatigue properties of FRP. Thus, also lifetime certification and evaluation items are discussed, too.

INTRODUCTION

The evolution of sailplanes over the past 110 years is a result of various aspects of technical develop-ment. Growing aerodynamic knowledge was as well necessary as accordingly applied or developed mate-rials which were strong and stiff enough to fulfill the requirements of improvement for which one parame-ter by convention is expressed in terms of the glide ratio L/Dmax of a sailplane. Fig. 1 shows the increase of the glide ratio over more than one century[1].

The increase of gliding performance from Lilien-thal's Normal-Glide-Apparatus to sailplanes with spans of 30 m and best gliding ratios of 60 and more was a consequence of the aerodynamic improvements which, however, would not have been feasible with-out the contribution of the materials including their structural design.

SIGNIFICANCE OF THE MATERIAL FOR THE SAILPLANE DEVELOPMENT

What material properties are necessary to bring a vehicle into the air? Primarily, a load bearing struc-ture must have the highest possible strength _ (MPa) and stiffness expressed by the elastic modulus E (GPa). But also the mass (kg) has to be as low as possible, i.e. the density plays a large role.

Tab. 1 shows typical properties of strength, E-modulus and density for some materials frequently used in sailplanes and light aircraft. To decide which material suits the application better than another, one should look at the specific strength and stiffness as the relation of the absolute properties to the density.

For example, the aluminum alloy shows higher absolute values than wood but the latter is in this example even superior to aluminum in terms of the specific strength.

The properties of the composites are values meas-ured on laminates. The column "Fiber Density" is added to demonstrate the density of the pure fiber. Apart from the very first composite gliders, where unsaturated polyester matrix was used, nowadays all sailplanes are laminated with epoxy resin systems. To judge about the fiber and composite properties it must be pointed out that the values shown refer to the 0°-direction of the fibers and the laminates. Due to their anisotropic behavior they have considerably lower properties perpendicular to the 0°-direction. In slender spar beams as used in gliders, this is of advantage for the cap. When however quasi-isotropic behavior is desired, the strength and stiffness properties of the laminates are lower. Nevertheless, the advantages of FRP compared to the conventional materials, alumi-num and wood, in terms of strength and stiffness related to their density are significant.

They become more obvious still in Fig. 2. Here the specific strength is plotted versus the specific stiffness in tensile and in compression direction.

The graph shows clearly the good stiffness properties of carbon fiber reinforced plastics (CFRP). It also becomes obvious that the compression properties of aramid-laminates are very poor. Nevertheless these laminates are highly interesting as energy absorption material e.g. in the cockpit design.

In view of the relevance of the materials for the sailplane development, the three periods mentioned above are described in more detail.

THE FIRST PERIOD

The beginning of gliding can be dated to the year 1891 when O. Lilienthal flew the first time with the Derwitz-Apparatus. This glider had in its original status a span of 7.6 m, a wing area of 10 m and a mass of about 20 kg.

Structure and maneuvering are described in Reference [2]: "All Lilienthal-gliders had a strongly braced wooden frame, consisting of spars and ribs of peeled willow rods,

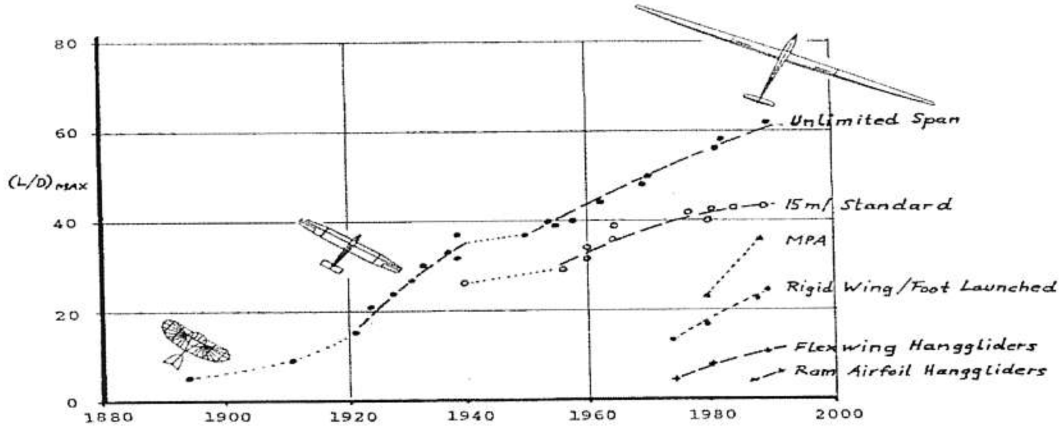

Fig. 1: Development of best glide ratio of sailplanes[1]

	Strength MPa	Modulus E GPa	Density Fiber g/cm³	Density (Laminate) g/cm³	Specific Strength / km	Specific Modulus E/ km
GFRP (E-glass)	155	51	2.52	1.835	85	2780
High Tensile-CFRP (HT)	150	124	1.76	1.455	103	8505
High Modulus-CFRP (HM)	143	252	1.85	1.5	95	16800
Aramid FRP	155	55	1.45	1.3	119	4253
Aluminum	46	79	-	2.7	17	2940
Wood	21	24	-	0.8	26	2940

Tab. 1: Typical properties of some laminates, aluminum and wood (the laminate properties are calculated with a fiber content of = 50 Vol%, the density of the epoxy matrix with 1.15 g/cm³)

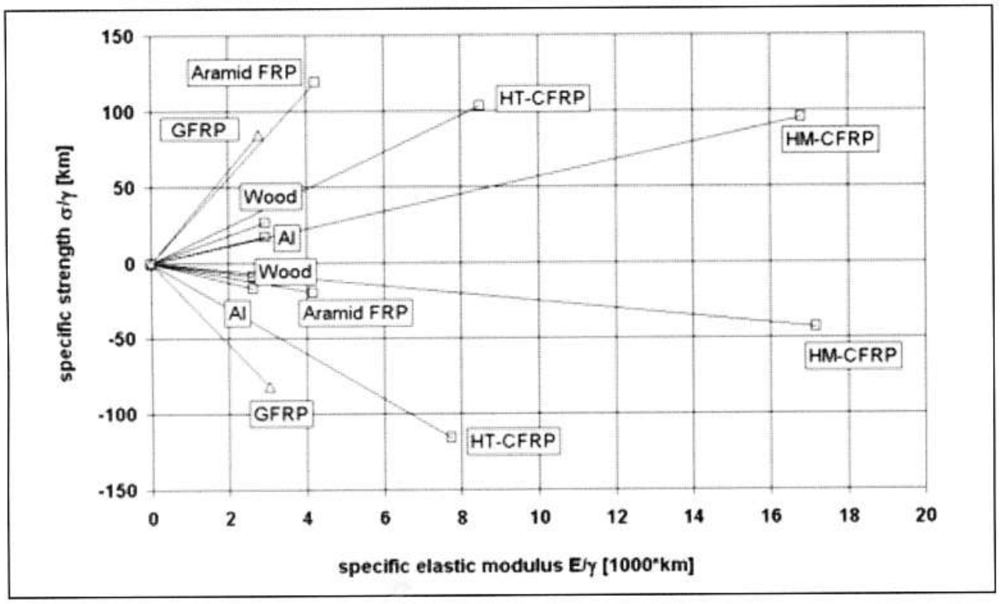

Fig. 2: Specific strength versus specific E-modulus for some laminates (0°-direction), aluminum and wood

which were covered with cotton cloth. The pilot was in a gap left free of the wing in the center of gravity. The lower arms lay on an upholstered spar cross and the hands could grasp a rod in front of that. The legs were free for takeoff and landing as well as for maneuvering control to increase or decrease the angle of attack."

Fig. 3 gives an impression of the glider structure and the pilot's position.

Fig. 3: Position of the pilot in a Lilienthal-Apparatus (Deutsches Museum, before 1945)

Flight stability and maneuvering control was a major problem in the beginning of gliding. Based on Octave Chanut's proposal to control the flight by means of moveable wings (proved not to be successful) Wilbur and Oliver Wright followed the idea to fly a curve by twisting the wings and used the torsion flexibility of the wing structure to reduce this in practice.

Fig. 4 shows W. Wright flying a controlled right hand curve in the Kill Devil Hills on 24 October 1902 enjoying the reward of a 3-year's development3.

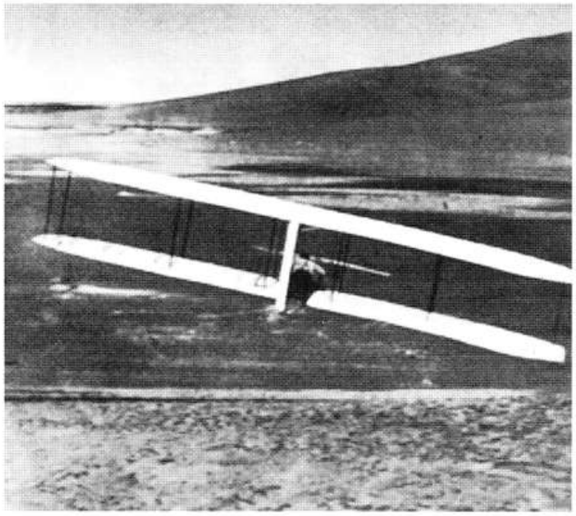

Fig. 4: W. Wright flying a controlled right hand curve in the Kill Devil Hills on 24 October 1902.

Fig. 5 shows the bracing points at the wing of the wing spars and ribs in O. Lilienthal's Normal Gliding Apparatus of 1894, rebuilt by Nitsch and Schwipps in the Wasserkuppe Museum in more detail. A widely used solution of connecting the spar and rib rods was simply to fix with a brass nail a can sheeting wound around the joint and brace it with a piano wire of the suitable thickness or strength.

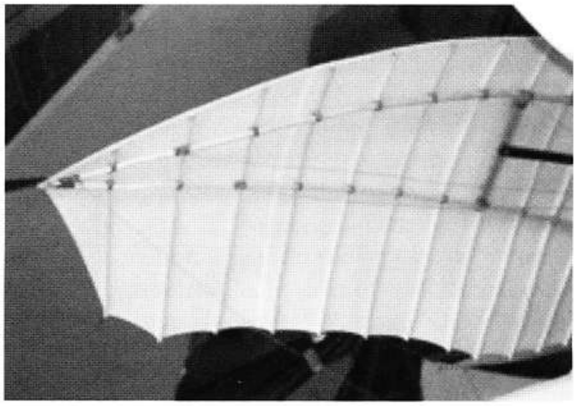

Fig. 5: Detail of braced intersection of wing spars and ribs at O. Lilienthal's *Normal Gliding Apparatus*

This first period of sailplane development is characterized by work of pioneers who designed and built their gliders themselves. No airworthiness requirements were available. The structural design and also the glide ratio was still a minor problem.

THE SECOND PERIOD (WOOD, METAL)

This changed in the following period which started after world war I with the first Rhön contest and which can be characterized mainly by the application of wooden and - after world war II - also few but nevertheless important metal constructions. This Rhön contest, to be carried out on the Wasserkuppe, was initiated in 1920 by two students of the TH Dresden Wolgang Klemperer and Erich Meyer, since they had realized a growing interest in gliding sport.

Already in 1920 Klemperer then assistant with Professor Th. Von Kármán at Aachen presented the Schwatze Düwel (black devil).

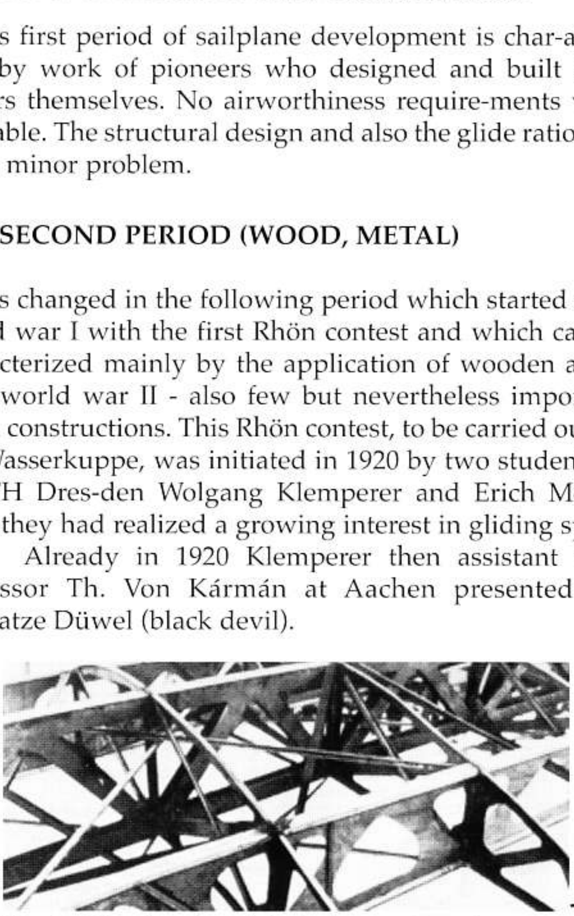

Fig. 6: Wing interior of *the Schwatze Düwel*

The basic ideas for this design came from patents from Professor Hugo Junkers. Through the availability of thick airfoils, it was possible to design a wing with a cantilever spar beam. Tape and wire bracings were still necessary inboard of the wing to prevent twist and backward deformation of the wing, see Fig. 6. The shell was in parts carton, the rest in black impregnated voile.

The breakthrough came in 1921 with the Vampyr built by the Akaflieg Hannover and successfully flown by Arthur Martens during the second Rhön contest. The structural as well as the aerodynamic design was from Dr. Georg Madelung. The main features were the free flow along the fuselage, and besides the cantilever wing, also control possibility by ailerons4. The innovation was the design of the wing. Whilst all predecessors were either biplanes or mono-planes with several spar beams, the Vampyr-wing realized a cantilever monospar design for the first time. This was enabled by integrating the nose shell into the structural design by covering the ribs with plywood to the I-spar beam, which was positioned at the highest point of the airfoil. Thus, maximum possi-ble torsion stiffness could be achieved. The spar beam had merely to carry the bending loads. This construc-tive concept has been used since then in all sailplanes. It is demonstrated in Fig. 7 with a view into the root-nose section of a rebuilt Vampyr-wing.

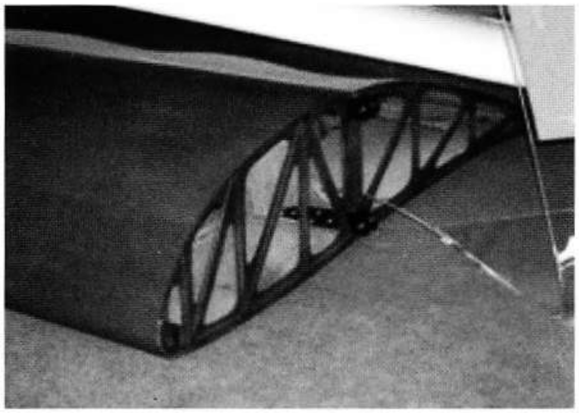

Fig. 7: Root-nose section of a *Vampyr* wing (Rebuild in Wasserkuppe-Museum)

Based on the aerodynamic and structural experi-ence gained with the Vampyr (span 12.6 m, glide ratio about 16), in 1923 the Akaflieg Darmstadt designed and built the Konsul with many improvements. In a study, Hoppe-Spies invented the airspeed polar and found the necessity of not only a low sinking speed but also a high glide ratio and, thus, a high aspect ratio. With the span of finally 18.2 m and an aspect ratio of 15.8 (the Vampyr had 10), this glider achieved a glide ratio of about 21.4. For the first time, a differ-ential was applied for the ailerons which improved the maneuverability significantly. Due to all the new features and, thus, being a prime example, the Konsul was named the "father" of all future high performance sailplanes.

The high effort in structural proof testing of strength and stiffness of spar beams, torsion nose and fuselage shells was also a new important step in sail-plane development as a guaranty for a maximum of safety with respect to the large wing5. This must be emphasized since, at this early stage of real sailplane design, no airworthiness requirements were available. In the Rhön contests, it was the "Technical Commis-sion" which judged about the flight and structural safety of the individual sailplanes.

Merely ten years after the Konsul, the first DFS airworthiness requirements9 gave examples for neces-sary design allowables for wood and how the speci-men specification had to look like.

Nevertheless, numerous new and famous high performance gliders made in wood construction suc-ceeded in the following years before the second war like e.g. Fafnir, Austria, Reiher, to mention only a few. Looking back to the wood properties in Fig. 2 it is amazing what high performance gliders have been designed already before the composites conquered the market. The increase in glide ratio, however, can be referred less to increased properties in the wooden material than in a better design efficiency and aerody-namic improvements. Limits were particularly dem-onstrated with the Austria which had a span of 30 m. Due to the high deflection of the wooden wings by their own mass, their fuselage attachment point had to be in a position very high above the cockpit, in order that the wing tips did not touch the ground. Also the maneuverability was very difficult.

A new impetus was then given by the increasing knowledge about the aerodynamic advantages of laminar airfoils. The first sailplane to use it was the tailless sailplane Horten IVb designed in 1940 which copied the Mustang-airfoil. Also Pfenninger designed with the Elfe II a laminar wing. Both gliders again were wooden constructions. In the first world gliding championships after the war, it was the metallic glider (1952) RJ-5 from Ross-Johnson which surprised. Under support of Dr. August Raspet, many aerodynamic improvements were carried out on this sail-plane. It demonstrated that the glide ratio could in-crease from less than 31, in the original state, to more than 40 by systematically excluding negative effects like wavy surface, airflow through slots of canopy and flaps, obstacles etc.

This design gave the input for the development of the HKS series6 which - apart from the standard glider Ka 6 - can be signified as a culmination in the devel-opment of wooden sailplanes. The double-seated HKS 1 had its first flights already in 1953. Fig. 8 shows it in flight.

Fig. 8: *HKS 1* in flight

The HKS 3 won the world gliding championship in Leszno in 1958, and Rudolf Kaiser received the OS-TIV-prize for the Ka 6 as the best standard glider (Ka 6) at the same time.

In the development of the HKS-gliders all concen-trated knowledge about aerodynamic and structural design applied was reported in various publica-tions4,5,6. High

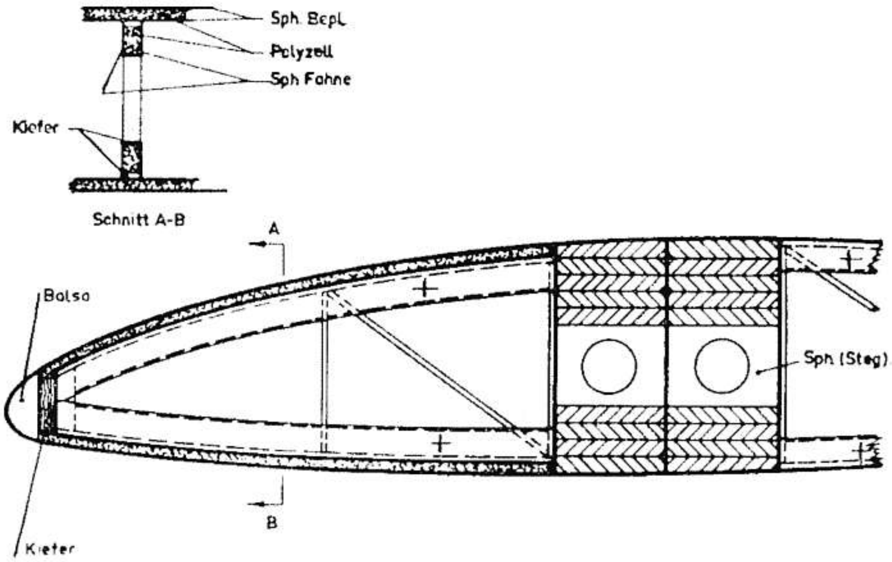

Fig. 9: Cross section of nose and spar of the *HKS 1*-wing

effort was devoted e.g. to the optimum surface of the wing to get an as long as possible lami-nar air flow. All means for improvement yielded in a glide ratio of about 40, but there was also a limitation by the application of a wooden spar, see Fig. 9.

To achieve the necessary high strength and stiff-ness of the wing, the spar caps had to be built very thick - a reason for the high wing mass leading to a relatively high wing loading. Additional factors for this disadvantage were the substructures for achieving a stiff high performance surface and the mechanism for the flexible flaps.

From this view it becomes clear that in spite of the relatively high glide ratios already achieved with the laminar airfoil generation gliders made of wood and metal, only a stronger and stiffer material would be able to lead to further performance improvements.

THE THIRD PERIOD (FIBER REINFORCED PLASTICS, FRP)

The takeoff of this new age was the year 1957 with the Phoenix (fs24) which was a development of R. Eppler, H. Nägele and R. Lindner. They applied glass fiber reinforced plastics (GFRP) for the first time. It took a long time effort to find this material. As early as in 1950 H. Nägele tried to replace plywood by casein glued paper. Designing the H30 (still before 1950) it was an idea of Wolfgang Hütter to make a sandwich with balsa wood as the core and plywood as the cover material. The impulse to use glass fibers came in 1954 through an article of the Reichhold Company on the application possibilities of unsatu-rated polyester7. In three years preparation countless proof tests were conducted with specimens of the new material to determine the various tensile, compression and shear properties. At the same time, Ulrich Hütter (brother of Wolfgang) later Professor at the Univer-sity of Stuttgart and first Director of the DLR Institute of Structures and Design, started successfully to use GFRP for the design of wind turbine rotor blades - together with E. Hänle who later became responsible for the Libelle and Kestrel designs.

Fig. 10: Phoenix (fs24), first GFRP sailplane

In parallel, calculation methods were developed for the anisotropic material by U. Hütter and R. Eppler as well as by Puck and Wurtinger from the University of Darmstadt. This was also basis for the new develop-ments of the Akaflieg Darmstadt. W. Lemke, G. Waibel, K. Holighaus and H. Friess set a new scale in the development of FRP gliders with the D36. The first three later became the leading engineers in the series production of sailplanes starting with the ASW12 (G. Waibel), Cirrus (K. Holighaus) and LS1 (W. Lemke). H. Friess became responsible for the certification of the gliders with the new and still a bit exotic material in the LBA, the German certification body, and could, by his knowledge and also patience, smooth the long path of certification procedure. Other predecessors of the later starting series production were the constructions Hidalgo (fs23) and Cuervo (fs25) from the Akaflieg Stuttgart, BS1 from Björn Stender, the SB-sailplanes of the Akaflieg Braunschweig and also W. Hütter's H30-TS the prime example for the Libelle-gliders.

The FRP application in the new developments showed relatively early that glide ratios of 40 and more could be achieved with much less effort than in the wooden class. Besides the great leap in the devel-opment due to the better material properties, the manufacturing technology differs totally from the conventional one where the procedure begins with the main spar beam which is then connected with ribs and later the shell which is coated with paint afterwards. Much effort has then to be taken to give the profile an optimal surface. In the FRP-technology, at first a gel coat is rolled into the negative mould prepared with any reproducible shape and surface roughness at all, then the sandwich shell is laminated and the spar beam and the other necessary structural parts and control rods and mechanisms are built in. Finally the open mould will be closed with the counterpart to bond the two halves to the final structural design

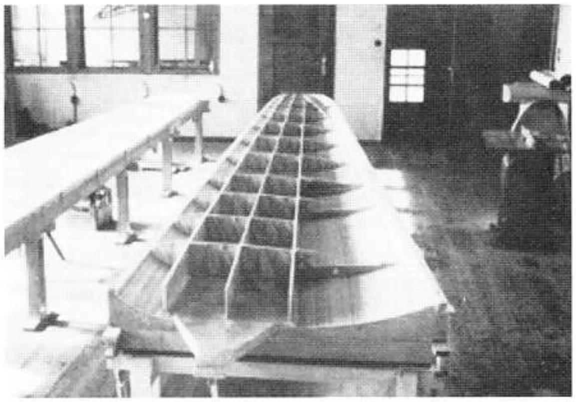

Fig. 11: Phoenix shell in negative mould

This technology has the advantage to be suitable for cost effective series production. The large effort to produce a high performance surface must be applied only once in the production of the moulds. The repro-ducibility minimizes the effort for a good finish. Beyond that, the time consuming manufacture of the ribs, which give the wooden or metal designs the necessary stiffness, can be omitted in the FRP wings due to the high stiffness of the sandwich constructions of the shells.

The time gap of about ten years from the beginning of FRP application to series production was relatively long, but it can be explained with the fact that the confidence into this material had to grow. The exist-ing industry also hesitated to change the production means for wooden sailplanes to the totally different and expensive ones for FRP gliders.

Concerning structural details, the spar beam of the Phoenix (and similarly those of the Hidalgo and the Cuervo) was a special lightweight design with very broad flat spar caps laminated with unidirectional oriented glass cloth, see Fig. 12. The shear forces were taken by three webs which were also necessary against buckling of the thin caps. Additionally, sev-eral equidistant ribs against buckling or wrinkling were bonded between the webs. The sandwich core of the shell was balsa wood, similar to the previous designs in the first 10 years of GFRP application.

Fig. 12: Cross section of "Hidalgo" test wing

This spar design philosophy resulted in a very low mass of the wings. As an example, the empty mass of the Hidalgo was only 104 kg, although it was de-signed according to the existing airworthiness re-quirements for sailplanes. Fig. 13 shows R. Gailing with the Hildago on is shoulder, who, in the German Gliding Championships in Roth, 1966, competed very well with the tiny 13 m glider against open class sail-planes.

Fig. 13: R. Gailing with *Hidalgo* on his shoulders

The conventional spar beam designs then became a box beam or I beam, respectively. Balsa was replaced as sandwich core material by foam. Fig. 14 shows a typical Schempp-Hirth wing structure with GFRP or CFRP spar caps and shear webs. The spar caps are relatively thin compared to those of the HKS in Fig. 9 demonstrating the superiority of FRP to wood appli-cation in such an ambitious design.

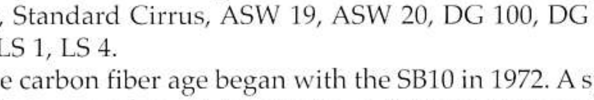

Fig. 14: Drawing of typical wing structure with GFRP or CFRP spar caps and shear webs

Samples of famous and successful GFRP sailplanes of series production are e.g. the Nimbus 2, ASW17 in the open class, Standard Cirrus, ASW 19, ASW 20, DG 100, DG 200 and LS 1, LS 4.

The carbon fiber age began with the SB10 in 1972. A span of 29 m was achieved by placing a CFRP middle section between the SB9 wings. The introduc-tion of CFRP was continued in 1975 with the tele-scopic wing design fs29 of the Akaflieg Stuttgart, see Fig. 15. Due to the higher stiffness of the carbon fibers compared to GFRP, it was possible to design a 3 m hollow shell with a maximum thickness of 3 mm.

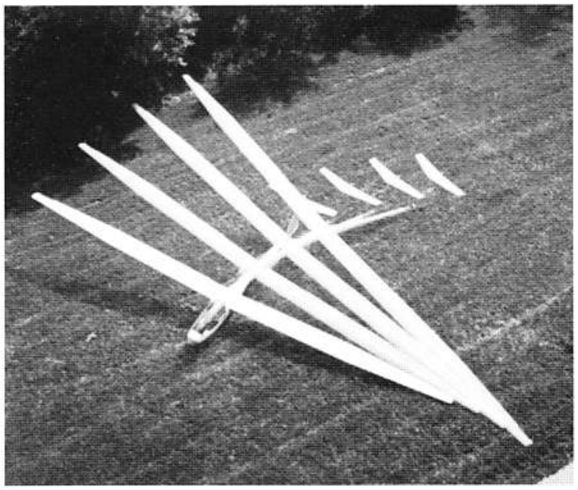

Fig. 15: Phantom photo of the telescopic wing design *fs 29* of Akaflieg Stuttgart

The principle of the mechanism and the support of the outer wing at the spar beam are demonstrated in a patent drawing in Fig. 16.

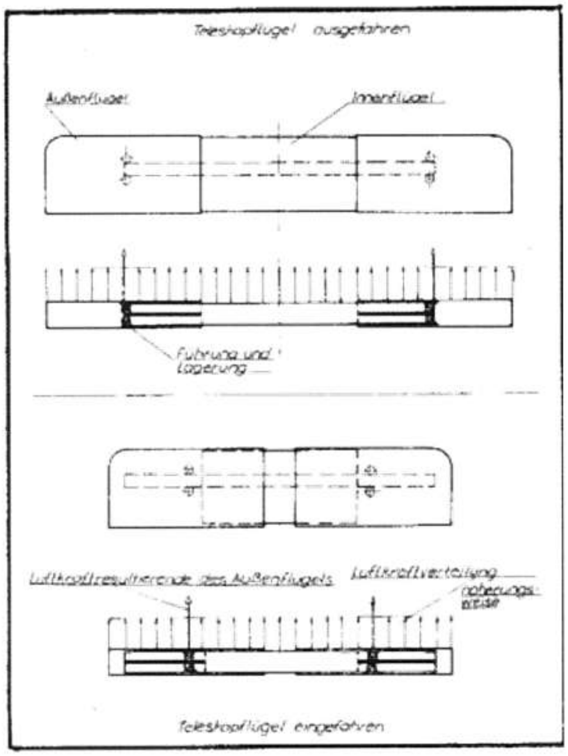

Fig. 16: Patent drawing with principle of the support of the outer wing at the spar beam of the *fs29*

Carbon fibers had a price of about 1.500,-$/kg at that time - impossible for an Akaflieg to purchase. The students managed to get the material as a gift from the Toray Company. But it was an excellent advertising argument for Toray and was the beginning of a big market. Today the same material has a price of about 20,-$/kg and nearly all high performance sailplanes apply carbon rovings in the wings. The application seems to be affordable for the costumers.

By the application of FRP (and especially CFRP) and their high specific strength and stiffness, impor-tant improvements in glider design were enabled such as

- thinner airfoils,
- larger span,
- higher aspect ratios,
- higher torsion stiffness,
- improvement of aeroelastic problems, increase of flutter speed,
- passive safety by design of crashworthy cockpits,
- better handling and maneuverability,
- high lifetime due to excellent fatigue properties.

With the certification of the CFRP again a great leap of performance increase can be observed. In spite of the relatively high material price for CFRP and thus for the sailplanes, the market accepted this due to the higher performance. This seems to prove that the design driver for sailplane development is the maxi-mum gliding ratio on the one side but also the comfort and safety issues which are offered to the customer due to material inherent possibilities. The designer must balance the relationship between the aerody-namic and aeroelasticity challenges, the material including its mass on the other side, and the costs of the product.

Now glide ratios of more than 40 became possible for the standard class sailplanes. Open class gliders like the ASW 22, ASH 25, Nimbus 4 and Nimbus 4D achieve even 60. The highlight and final point of sailplane development at the moment is the Eta. This sailplane with a wing span of 30.9 m is an extreme design which is only possible by the application of high modulus carbon fibers, in this case Torayca M40J. It had the ambitious goal to significantly im-prove the performance of the existing open class gliders. Although no glide ratio is known yet it is supposed to be far beyond 60. Fig. 17 shows the Eta together with another high performance glider to demonstrate the huge span.

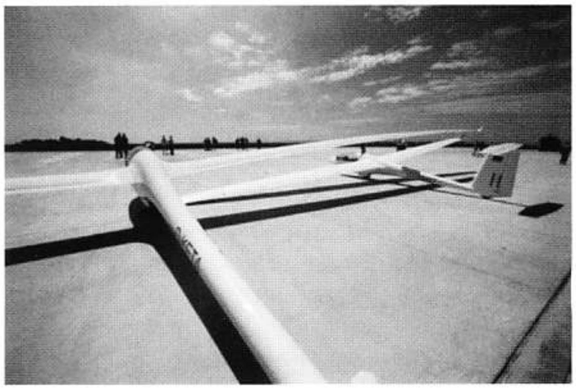

Fig. 17: "Eta" together with another high performance sailplane

The prototype wing was manufactured by Streifeneder in a vacuum injection method which had been studied in model tests at the DLR Institute of Structures and Design. Using this technology, a per-fect fiber matrix compound is achieved without the disadvantage of air voids. The dry fiber material is applied at first, and then the mould is covered and closed with an air bag. Finally the air is evacuated along the forward and rearward lines of the moulds and, thus, the resin is drawn along the spar just in a time that the matrix cannot yet react. With this method, only a few people are necessary to laminate the wing shell.

There are still other qualities in the FRP which lead to applications quite different from high glide ratios. A big concern is the passive safety of the pilot in a crash landing. Protection possibilities are here espe-cially in a hybridization of composites, i.e. in the combination of the high energy absorbing materials like e.g. aramid or poly-ethylene and the stiff but brittle carbon fibers. Fig. 18 shows the result of a systematic investigation on the fracture toughness for hybrid lay-ups of CFRP and SFRP (aramid fiber rein-forced plastics) with respect to the nature of the lay-up11.

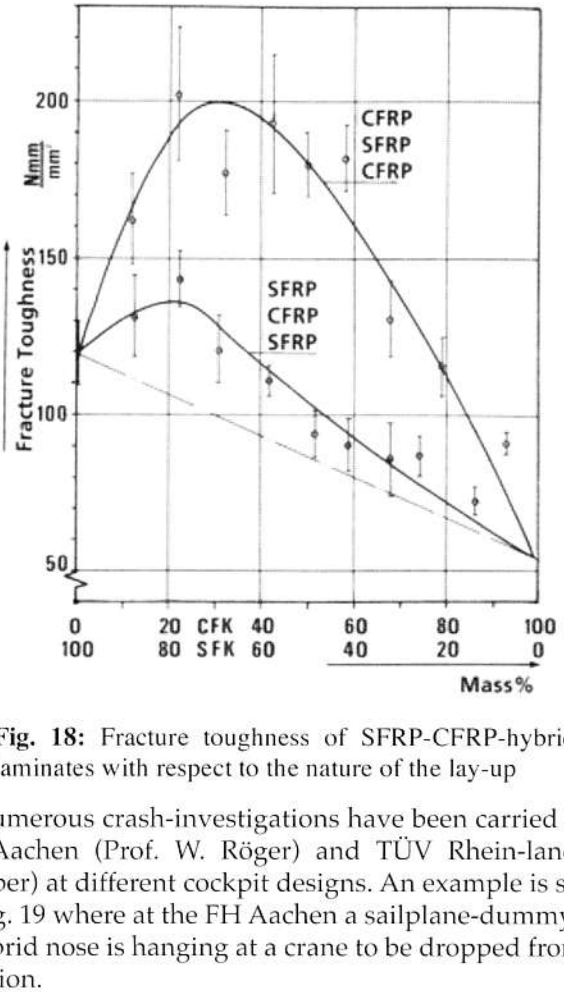

Fig. 18: Fracture toughness of SFRP-CFRP-hybrid laminates with respect to the nature of the lay-up

Numerous crash-investigations have been carried out at FH Aachen (Prof. W. Röger) and TÜV Rhein-land (M. Sperber) at different cockpit designs. An example is shown in Fig. 19 where at the FH Aachen a sailplane-dummy with a hybrid nose is hanging at a crane to be dropped from this position.

Evaluations of those measurements are being trans-formed into practice immediately by the designers and are being discussed in certification panels for further developments.

CERTIFICATION OF MATERIALS AND LIFE-TIME WITH RESPECT TO THE AIRWOR-THINESS REQUIREMENTS

Historically it is interesting to note that for a long time no written airworthiness requirements were known in the 1st period and also in the "wood" period until 1927. It was the "Technical Commission" which judged whether a glider was admitted to fly at the Rhön contest or not. First guidelines for the design of gliders and sailplanes were established by the "Rhön-Rossitten-Gesellschaft"8 in 1927, followed in 1934 by the first DFS airworthiness requirements for gliders and sailplanes9. The further developments of these rules culminated in the JAR22 and the OSTIVAS the present certification bases for the sailplane designers.

Fig. 19: Crash test at FH Aachen on a sailplane dummy with hybrid nose of the cockpit (photo by courtesy of W. Röger)

In Germany some amendments were developed for type certification and for service life questions. Addi-tionally FRP-material aspects are discussed in the ANF which is a panel of designers, researchers and the authority. This panel was founded under the um-brella of DLR in 1977 by

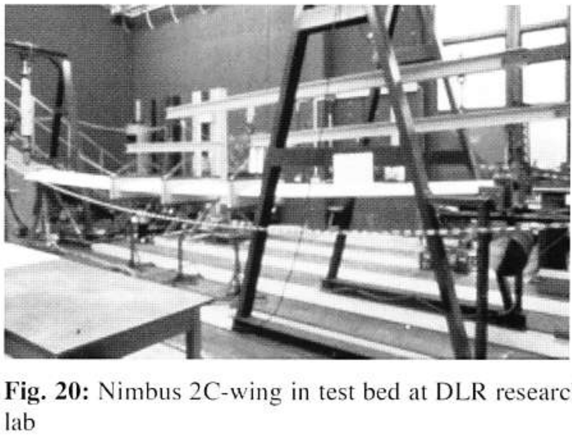

Fig. 20: Nimbus 2C-wing in test bed at DLR research lab

initiation of Professor Fred Thomas, since the industry needed input for the certi-fication of CFRP. Documentation of the research results can be found e.g. in Reference [10]. One of the first investigations was the service life test on a CFRP-wing of the Nimbus 2 model. Fig. 20 shows the wing in a test bed at DLR.

Questions of lifetime certification are a main object at the moment, since the first FRP gliders will reach the certified 12.000 flight hour limit in due time. A new attempt is just being started to prolong the life-time information and, thus, also the certified flight hours of sailplanes applying a new method which is described in more detail in Reference [11]. It is based on s-n curves of the relevant materials in a primary structure like a spar beam, its FEM-analysis and com-bined with sinusoidal fatigue tests on spar beams. The results shall give input for future certification rules.

CONCLUSIONS AND OUTLOOK

It could be demonstrated that in the first phase of glider development (before the first war), the material itself was not yet a limiting problem, since the pilots still had to learn the aerodynamic basics and the con-trol of their gliders in flight. In the second phase start-ing with 1920 and ending about 40 years later, the aerodynamic knowledge had grown so far that wood and metal, the materials existing at that time, became a limitation for further improvement. The solution then came with the introduction of GFRP in 1957 and was completed by CFRP. These materials enabled the highest flight performance, maneuverability, passive safety and other features, pilotkind was longing fore. It was shown that for the application of new materials, certification rules must be obeyed which had to be developed in parallel to the introduction of the new materials.

What will come in the next years? It will be nearly impossible to top the "Eta". A limitation of span is given by the maximum admitted weight. New materi-als are not known at the moment which could replace the HM fibers.

Further improvements of glide ratio seem only to be possible with aerodynamical means as e.g. suction. According to L. Boermans, a glide ratio of 100 could be possible, however, there is still a lot of research to be done12. Once a proposal is made by the aerody-namic scientists, there will certainly be new challenge for another material application.

There are however still problems which have to be solved in cooperation of industry, certification bodies and research. A big task for the near future is the existing lifetime limitation of 12.000 flight hours for FRP gliders. As some sailplanes are already near to this threshold, the work for prolongation of the certi-fied flight time is mandatory. This includes experi-mental and analytical research. A new research pro-gram is being started at the moment.

Also the improvements of crashworthy cockpits have not yet been finished.

A great potential lies still in the development of manufacturing technologies to possibly improve the structural strength and stiffness. A good example is the application of prefabricated CFRP rods in the spar caps avoiding undulation of the fibers which may occur in the conventional technology.

Attention has focused on sailplanes which are certi-fied according to JAR22. Ultralight sailplanes are being successfully developed since some years and may become a very interesting market, since they can be purchased more easily than conventional gliders. Here is a potential to use existing materials for ex-treme light weight designs. However, apt safety and airworthiness requirements have to be established and applied.

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