# 100 YEARS OF SAILPLANE DESIGN AND BEYOND

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## ABSTRACT

The first successful attempts initiating mankind's history of flight were flights with airplanes without engines. These flights were performed by Otto Lilienthal in the last decade of the 19th century in Germany and by the Wright brothers in the first years of the past century in the USA. With the installation of an engine the Wright brothers were the forerunners of the development of modern aviation. For some time the interest in flying unpowered airplanes, later called gliders or sailplanes, faded away. In the twenties a remarkable rebirth of sailplanes occurred, leading to sailplanes now capable of covering distances of up to 3000 km with average speeds of around 200 km / h, using as single source of propulsion the energy inherent in the atmosphere.

The present paper describes important milestones

- in the use of natural energy resources,
- in the strategy of flying and
- in the technical development of sailplanes.

In addition, ideas are discussed with respect to the further improvement of sailplane performance in the coming century.

## INTRODUCTION

Lilienthal's glider was the starting point for an evolution of sailplane design which has culminated in the high performance sailplanes of today. Their highly sophisticated aerodynamic and structural design enable them to fly distances of up to 3000 km, flight durations of 60 hours, and reaching altitudes of more than 12 000 m. In a short survey a historical overview on the evolution of the sailplane will be given, emphasizing some important milestones in the design principles of sailplanes, in the exploration of the energy sources of the atmosphere, and the development of the flight strategy of the pilots. Some important technological aspects forming the background and basis for the development of sailplanes will then be discussed.

The four following lectures in this session1), given by Horstmann and Boermans, Maughmer, Kensche and Stemme, will go more into the details of wing section design, of wing and fuselage design, the selection of materials for the structure of the sailplane and sailplane manufacturing. Readers interested to penetrate more deeply into the design principles of the sailplane will find more information in F. Thomas [1]. Those who want to follow the historical evolution of the sailplane in more detail will find this in G. Brinkmann and H. Zacher [2]. The pilot's flight strategy is thoroughly described by H. Reichmann [3].

## HISTORICAL OVERVIEW

When Lilienthal made his first flights in the nineties of the 19th century, he used a flying machine without an engine which could therefore only fly downhill from the top of a mountain. Lilienthal for the first time had systematically studied the relations of lift and drag depending on the wing's angle of attack, and the influence of camber on the profile characteristics. On that basis he had designed a glider of very low weight with a very thin wing, the structural strength of which was provided by external bracing. This caused a low wing loading, leading to a low forward speed and a comparatively low sink speed, and a poor aerodynamic performance in terms of glide ratio as well as a critical stall behavior. The pilot, hanging downward from the wing, used the weight of his body to control the plane by movement of the center of gravity (see Fig. 1).

**Fig. 1 Lilienthal (1894)**

The Wright brothers tested their flying machine first without an engine. Their most important progress compared to Lilienthal's glider was a completely new philosophy of controlling the airplane. Instead of moving the center of gravity, the pilot used variations of the geometry of the glider to provide moments about the three axes of rotation. This was done by movable control surfaces creating moments around the lateral and vertical axes, and by nonsymmetrical wing warping for moments around the longitudinal axis of the airplane (see Fig. 2). This was an enormous step forward and although the Wright flyer was probably not statically stable without the control inputs of the pilot, it was a much more powerful and safer method of control.

With the installation of an engine the Wright brothers initiated the development of modern aviation. The early aviators concentrated all their efforts on improving the quality of the powered airplane and its engine. The interest in powerless airplanes faded away and nearly no progress was made during the next 20 years. When after the First World War Germany was forbidden to develop and fly "real" aircraft, a new interest in flying powerless airplanes arose among German students. In 1920 they organized a meeting on the Wasserkuppe in the Rhön Mountains and attempted to fly hastily designed and constructed flying devices. It was a collection of rather strange-looking flying machines which resembled more the present day ultra-lights than sailplanes. From the top of a mountain they flew for but a few seconds or minutes, covering only very short distances. The time required to carry the airplane uphill again took more than ten times the flying time. The design of these kites was aimed only at low weight. Strength and stiffness were provided mainly by external struts and bracing. The aerodynamic quality was very poor. Flight altitude and - due to the low wing loading - flying speeds were very low, which left the pilots in most of the many crashes more or less unhurt.

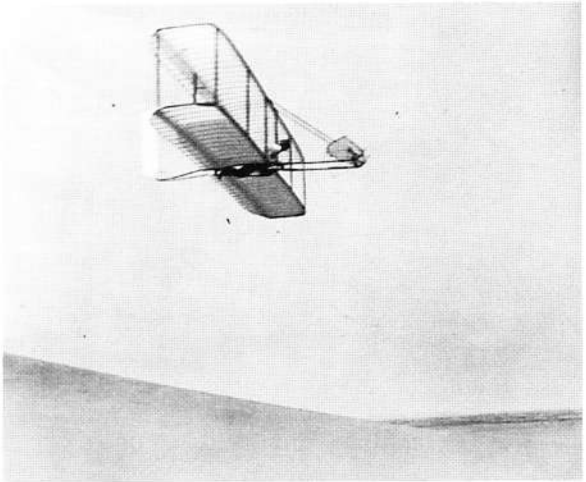

**Fig. 2 Wilbur Wright (1902)**

Soon afterwards, new ideas were developed improving the airplane performance. A breakthrough was achieved when students of the Academic Flying Group of the Technical University of Hannover systematically studied the influence of various parameters on the sink speed of a powerless airplane. They introduced their results in a completely new design, called "Vampyr". The fact that aerodynamics was recognized as the predominant factor in the design of sailplanes led for the first time to a design having a certain resemblance to sailplanes of today. The "Vampyr" wing used profiles of the well known Göttingen wing section series with sufficient thickness to accommodate a load-carrying internal spar and a D-shaped torsional box forming the nose part of the wing. Sufficient structural strength and stiffness could thus be provided for a comparatively large aspect ratio wing with no external bracing. The pilot was sitting in a cockpit of an enclosed fuselage. Already during the 3rd Rhön meeting in 1922, flights of 1 hour and later of 3 hours were achieved due to the lift from a steady horizontal wind deviated upwards by the windward facing slopes of the Rhön Mountains. The design of the "Vampyr" was a very important milestone in the development of the sailplane (see Fig.3).

**Fig. 3 Vampyr (1922)**

Flight durations were soon extended to around 12 hours and more. This, however, was not due to an improvement of the sailplanes but more a question of pilot endurance and steady meteorological conditions. However, when in the late twenties the prospect of thermal soaring was explored, this gave sailplane design a new stimulus. Birds have used this source of energy for millions of years already. With that it became possible to depart from the geographical constraints of mountain slopes, and to fly cross-country. The design target was increasingly directed not only at low sink speeds but also at good glide ratios at high horizontal speeds. This gave aerodynamics an even more predominant role. In powered airplanes, compromises in aerodynamic quality can be made because, to a certain extent, it is easier and cheaper to increase performance by stronger engines instead of improving aerodynamics. Sailplanes allow no such compromises. Always the best possible aerodynamics must be achieved within the limitations of structural weight and cost.

The annual sailplane competitions in the Rhön Mountains provided a good indication of the progress made until the beginning of the Second World War. Distances of around 500 km became possible in those days and the glide ratio of the sailplanes used in the competitions approached 30.

After a stagnation period during the war, sailplane development was resumed in the late forties and early fifties. First experiences with laminar wing sections of the famous NACA-6-series during the war promised progress also for sailplanes. The application of laminar profiles required an extremely smooth wing surface and a high accuracy of the profile shape. This was difficult to achieve as long as wood, or in some cases metal (primarily in the US), were the materials for the sailplane structure. With some effort a generation of wooden sailplanes with limited laminar flow on the front part of the wing was developed. The Ka 6, for example, dominated the competitions in the late fifties and the early sixties (see Fig.4).


**Fig. 4 Ka 6 (1966)**

A completely new design philosophy arose when Eppler designed laminar wing sections specially adapted for sailplanes in the fifties. New technologies using fiberglass composites enabled the construction of sailplanes with extremely clean and smooth surfaces and high profile accuracy. The potential of laminar flow could now be extended to the special demands of sailplane design. The development of fiber-reinforced structures together with the improvement of laminar wings have revolutionized the world of sailplanes. The "Phoenix", designed and built by Eppler and Nägele in Stuttgart, flew for the first time in 1957 and started a new era of sail-plane design (see Fig. 5). It certainly marked one of the most important milestones in the history of sailplane development.

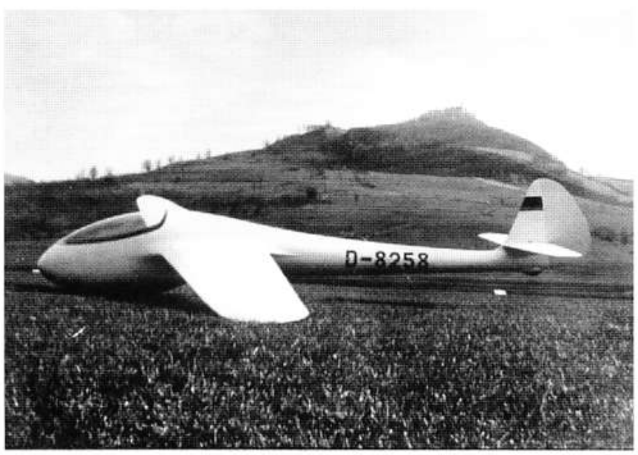

**Fig. 5 Phoenix (1957)**

In the sixties the students of the Academic Flying Groups (Akafliegs) of the Technical Universities of Braunschweig, Darmstadt and Stuttgart developed a number of successful sailplanes using and improving the new design philosophy.

A few years later some of these students (G. Waibel, K. Holighaus, W. Lemke , W. Dirks and others) found their way into the design bureaus of the sailplane manufacturers. The industry adopted the new design methods very quickly. Companies like Schempp-Hirth, Schleicher, Rolladen-Schneider, Glaser-Dirks, Glasflügel, Grob, Stemme and others pro-duced a new generation of sailplanes which fly now all over the world, and which have led to a real explosion in general performance and the list of world records. In less than a decade wooden designs disappeared from the important competitions and were replaced by a fleet of composite sailplanes. Typical examples are shown in Fig. 6 - 10.

Further improvements were possible with the use of carbonfibers, which surpass glassfibers in strength and even more in stiffness. Large wingspans and aspect ratios with thin wings became now possible. In combination with improved wing sections, sailplanes with outstanding performances could be realized culminating in the "eta" design (see Fig.11 and 12). With a span of 31 m, an aspect ratio of 51 and a glide ratio of 70, it is the most advanced sailplane so far.

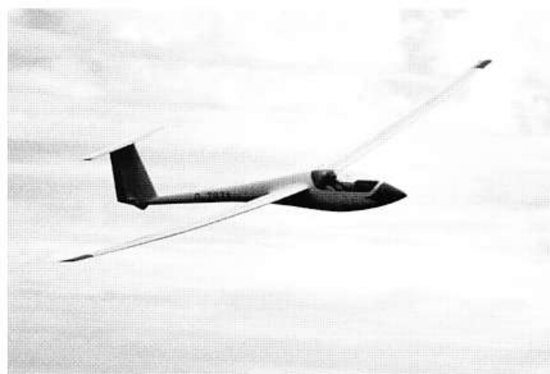

**Fig. 6 Standard Class ASW 19 (1975)**

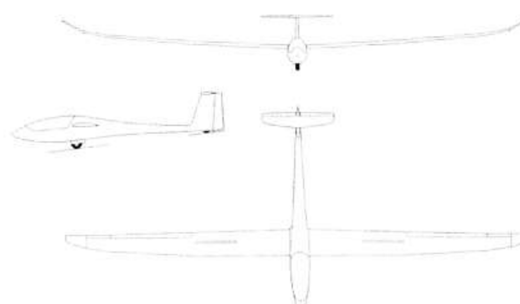

**Fig. 7 Standard Class Discus 2b (1998)**


(Foto von G.Marzinzik aus Aerokurier 6, 2001)

**Fig. 8 18m Class LS 9 (2001)**

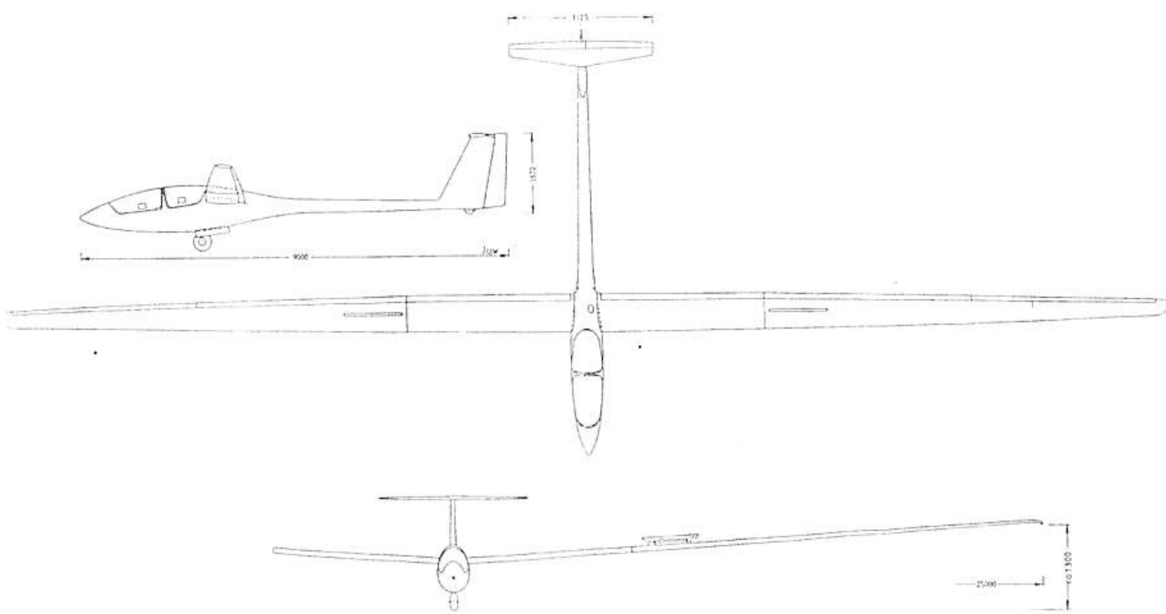

**Fig. 9 Multiplace Open Class ASH 25 (1986)**

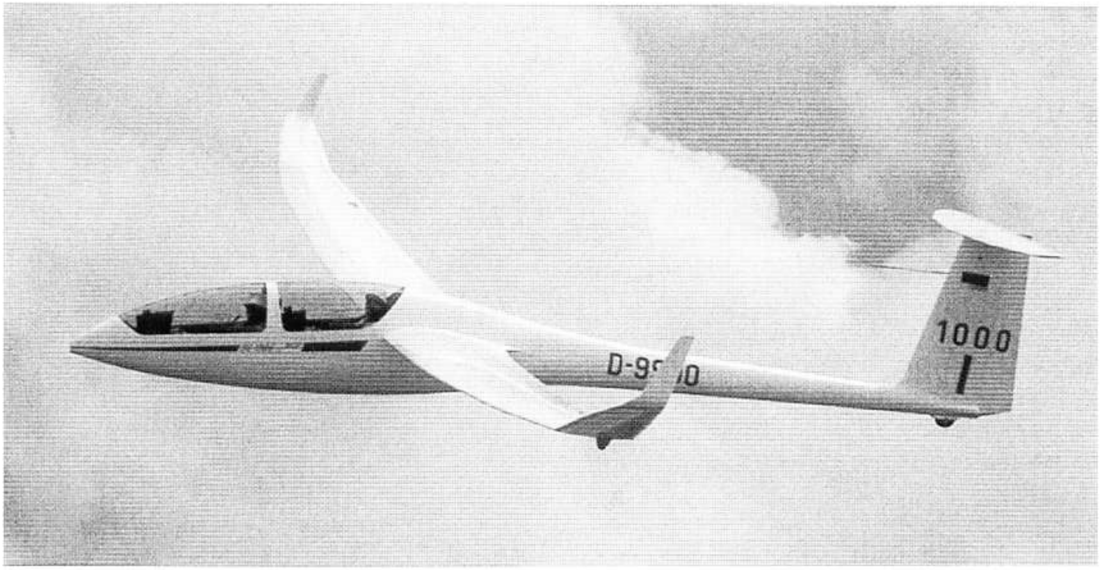


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**Fig. 10 Multiplace Open Class DG 1000 (2000)**

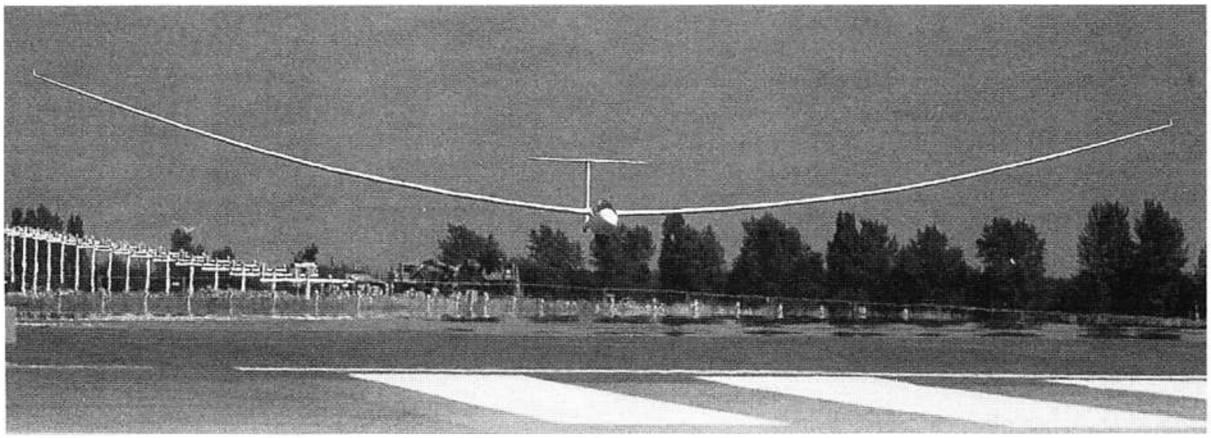


**Fig. 11 eta (2000)**

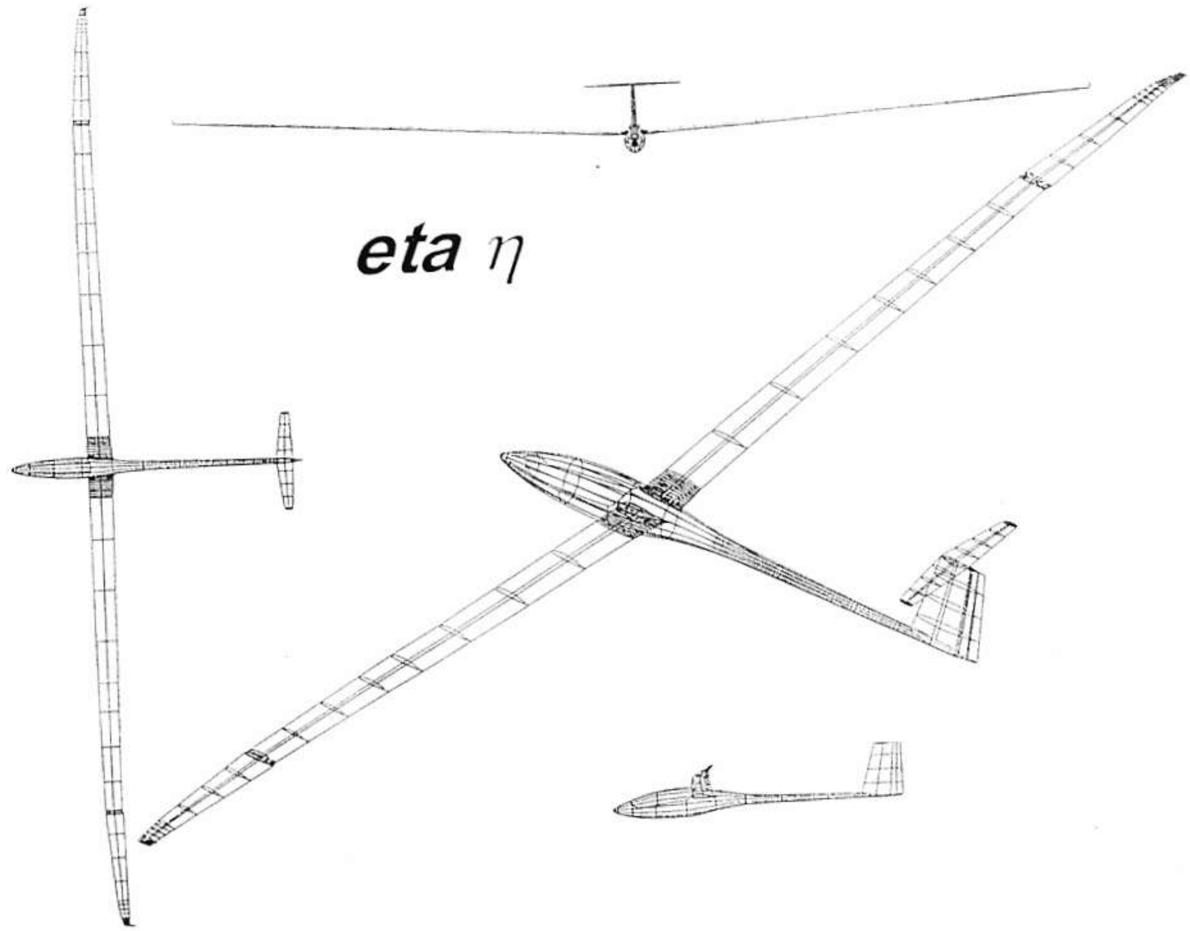



**Fig.12 eta**

The comparison of some typical parameters in the following table shows the unbelievable progress which has been made in the past 100 years.

| | Lilienthal Glider | Modern Designs |
|---|---|---|
| Span | 7 m | 12 - 31 m |
| Empty mass | 20 kg | 150 - 400 kg |
| Aspect ratio | 6 | 18 - 51 |
| Wing loading | 8 kg/m$^2$ | 20 - 60 kg/m$^2$ |
| Sink speed | 1 m/s | 0.40m/s |
| L/D | 6 | 30 -70 |
| Flight duration | seconds, minutes | 60 hours |
| Distance | 250 m | 3000 km |
| Flying speed | 30 km/h | 70 - 250 km/h |

How could such a progress be achieved?

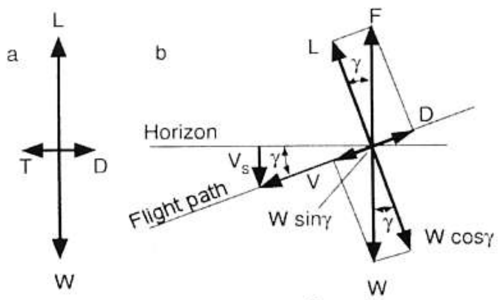
Three different development areas have contributed to this success:

- the exploration of the energy sources of the atmosphere;
- the optimization of the pilot's flying strategy;
- the development of better airplanes.

Let us now look a little deeper into the evolution of these qualities

## THE ENERGY SOURCES OF THE ATMOSPHERE

In order to perform a steady horizontal flight, or even more to climb in flight, the airplane requires lift to compensate for its weight, and needs propulsion to compensate for the inevitably produced drag. The sailplane has no internal energy source to provide propulsion. Consequently, the only way to fly is the use of a component of the airplane weight to compensate the drag. This is only possible with an inclined flight path which consumes potential energy (see Fig. 13).




$$W = L = 0.5 * \rho * V^2 * S * c_L$$
$$T = D = 0.5 * \rho * V^2 * S * c_D$$

**Fig. 13 Equilibrium of Forces**

The pilot can select the angle of the flight path against the horizon by setting the control surfaces. Different flight path angles are correlated to different combinations of lift and drag, or to different combinations of forward speed and sink speed, respectively. These correlations are shown in Fig. 14.

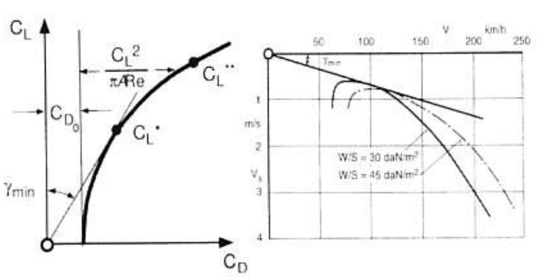



**Fig. 14 Drag- and Speed-Polar**

The lowest sink speed is achieved at nearly minimum flight speed. Higher speeds are correlated to higher sink speeds. The forward speed V and the sink speed VS depend on the wing loading W/S (W = weight, S = wing area), the density of the air _, the lift coefficient cL and the drag coefficient cD, the latter two depending on the aerodynamic quality of the airplane.

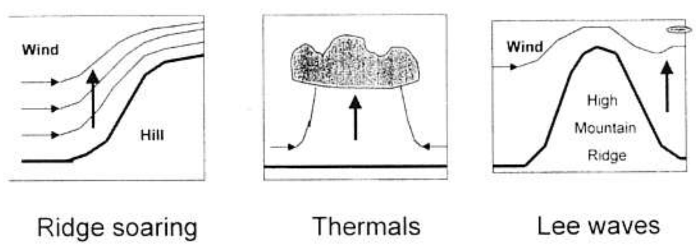
Forward speed: $V = \sqrt{(2/\rho)(W/S)(1/c_L)}$
Sink speed: $V_S = (c_D/c_L)\,V$

The correlation of lift and drag coefficients is called the drag polar, or Lilienthal polar, because he introduced this correlation in dependence of the angle of attack for the first time. The correlation of the forward speed and the sink speed is called the speed polar, and is the most important indicator of the aerodynamic quality of the sailplane. The speed polar can be calculated directly from the drag polar by the above two equations. For each wing loading a different speed polar is obtained. Heavier wing loading shifts the speed polar to higher speeds.

An airplane sinking in the surrounding air can gain altitude only when flying in an upwardly directed air stream, the climbing speed of which is higher than the sink speed of the airplane. There are several different types of atmospheric energy sources which can be used by sailplanes (see Fig. 15):

- ridge soaring on the windward slopes of a mountain
- thermal soaring
- lee waves soaring at high altitude behind massive mountain chains
- dynamic soaring in the boundary layer of strong horizontal winds close to the earth surface.

These energy sources are very different from each other and demand different flight strate-gies.




Ridge soaring requires steady horizontal winds directed perpendicular to a more or less extended mountain slope. Soaring is possible if the upward deviation of the horizontal wind exceeds the sink speed of the sailplane. This kind of lift occurs only close to the ground at flight altitudes not exceeding a few 100 m. The flight path is dictated by the geographical shape of the mountain. There are many areas in the world which allow ridge soaring, flying figure-8-type flight patterns of limited extension. The flight duration is limited only by meteorological conditions and the physical endurance of the pilot. Flights of up to nearly 60 hours have been performed on ridges. Only very few areas, however, allow long flight distances. The Appalachian Mountains in the US are a famous exception, where under favorable meteorological conditions flights of more than 1000 km have been performed.

The most important energy source for sailplanes, however, is the thermal source. Every day when the sun is shining the ground is heated by radiation. Depending on the thermal capacity of the ground the adjacent air masses are heated in different ways. Air masses over areas which become warmer than their surroundings become lighter and begin to rise upwards. These thermals have normally a diameter of around 100 to 300 m, sometimes more. They rise with speeds of several m/s and can reach altitudes of several 1000 m. Generally they can be recognized by the presence of Cumulus clouds. The vertical speed of the air is strongly dependent on the vertical temperature gradient of the atmosphere. Although the thermals progress beyond the base of the typical Cumulus clouds, sailplanes are normally restricted by Air Traffic Control to fly under VFR, barring penetration into the clouds. On a fairly large number of days in spring and summer sufficient sun radiation and a favorable temperature gradient of the atmosphere allow flying for many hours in many areas on all five continents. Distances of up to 1500 km have been flown with thermal energy.

Lee waves occur behind massive mountain ranges like, for instance, the Rocky Mountains, the Alps and the Andes in South America, when steady strong horizontal winds impact these mountains. At rather high altitudes these winds produce oscillations on the lee side of the mountains over extended areas which are often indicated by Lenticularis clouds. Lee waves occur only in selected areas under certain meteorological conditions at a limited number of days per year. Under favorable conditions extremely long distances can be flown. In the lee waves of the Andes a flight of more than 3000 km has been performed within 15 hours in January 2003. Lee waves also allow reaching very high altitudes. Altitudes of 12 km have been attained with the help of oxygen for the pilot. Beyond 12 km, pressure suits or pressure cabins as well as special precautions for the very low temperatures are required to explore these altitudes.

An energy source which is used by albatrosses is found in the boundary layer of the steady western winds over the oceans in the southern hemisphere. Without going into details the use of this energy source requires an extremely high maneuverability at very low altitudes. This is obviously out of reach for sailplanes but, with a skilful flight strategy, birds can stay airborne for days.

## THE STRATEGY FOR CROSS-COUNTRY FLYING

Around 90 % of today's flying activities use thermal lift as an energy source. The typical thermal cross-country flight is a series of sequences of two flight phases:

- circling with a narrow radius at low speed in a thermal in order to gain altitude

- flying straight forward in the direction of the target with a relatively high velocity in order to cover a long distance.

A typical segment of a cross-country flight is shown in Fig. 16. Because the daily time of sun radiation is limited, it is necessary to attain the highest possible average cross-country speed (including the time for climbing and flying on course) in order to reach the longest possible flight distance on a certain day. Fulfilling a given task in a competition in the shortest time leads to the same requirement.

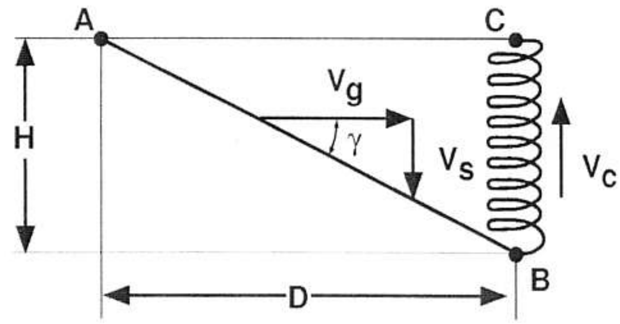



**Fig. 16 Segment of Cross-Country Flight**

The target is

- for the pilot, to find the optimum speed in the thermal and the optimum speed for the flight between the thermals and

- for the design engineer, to find a correlation between the average cross-country speed and the design parameters of the airplane and their optimization.

Let us first look at the pilot's decisions. Within the thermal the pilot may choose the flying speed and the radius of the circle. These two parameters also define the bank angle of the sailplane by a simple equation. The turning flight polar shows the sink speed of the sailplane in calm air (see Fig. 17.)

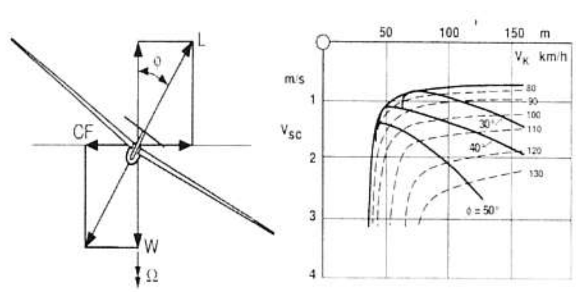



**Fig. 17 Turning Flight**

The sink speed increases with increasing flight speed and bank angle or, in other words, with decreasing turning radius. The optimum climbing speed in the thermal is depending on the distribution of the lift in the thermal (see Fig. 18). The climbing speed is the difference between the climbing speed of the air in the thermal and the sink speed of the sailplane at a certain flying speed and a certain bank angle. Without going into the details, the resulting optimum bank angle for most weather conditions is close to 45° and close to the lowest possible flying speed.

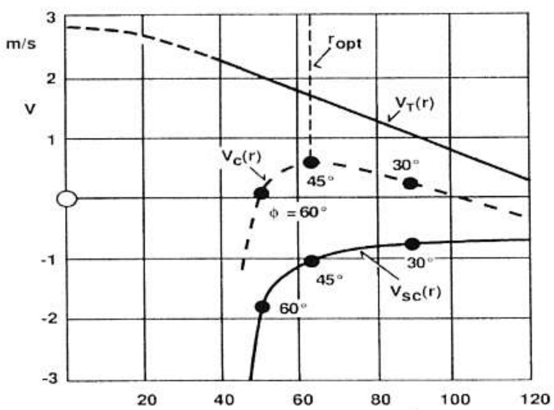



**Fig. 18 Climbing in Thermals**

The optimum speed between the thermals is depending on the strength of the lift in the following thermal. Fig. 19 shows that there is a certain optimum. Let us consider three pilots choosing different flight speeds keeping in mind the speed polar of Fig. 14. Pilot A is obviously flying too slow. He is loosing only a small amount of altitude but a lot of time. Pilot C is flying too fast. He gains time but is loosing much altitude. Pilot B is in between. The correct decision of the pilot depends on the climbing speed which he may expect in the next thermal. In our example in Fig. 19 pilot B has made the best decision.

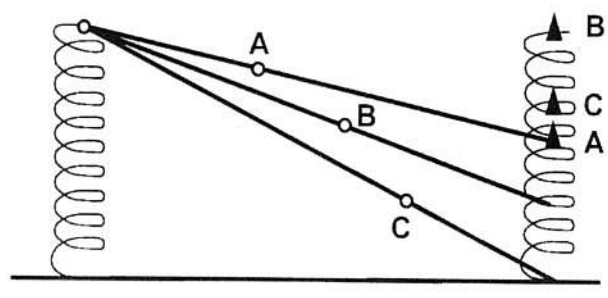



**Fig. 19 Optimum Gliding Speed for Cross-Country Flight**

Nickel and MacCready have developed the theory for the optimum speed between thermals. This was an important step forward which has improved the average cross-country speed considerably. A lot of additional knowledge has been accumulated over the years which led to a better and better understanding of the meteorological conditions and the best strategy of flight. Modern GPS-based navigational aids have also contributed to improve the pilot's capability to follow the chosen flight path.

Cross-country strategy has been described very thoroughly by the former world champion H. Reichmann [3].

## THE DEVELOPMENT OF SAILPLANE TECHNOLOGY

After analyzing the pilot's strategy on the basis of the available atmospheric energy sources, it is now possible to define the design task for the optimal sailplane. From the model of the cross-country flight it is possible to derive a mathematical equation, which connects the average cross-country speed with the design parameters of the sailplane and with the meteorological conditions (see also [1]). The goal is to design a sailplane capable of achieving the highest average cross-country speed for a given meteorological situation. The main problem of the design process is the existence of two design points with partly contradicting design requirements:

- climbing in the thermal with low sink speed at high lift coefficient and

- flying straight with high forward speed (low lift coefficient) and low sink speed.

Without going into the details of a mathe-matical optimization process, the achievement of very low aerodynamic drag in both design points is mandatory. We distinguish three different contributions to drag:

- induced drag
- friction drag
- parasite drag

The induced drag is inevitably connected with the production of lift of a three dimensional wing even when no friction is considered. It increases with the square of the lift coefficient and is reduced by increasing the wing aspect ratio (see Fig. 20). The induced drag is the dominant drag contribution in the climbing phase (around 60% of the total drag).

The friction drag is strongly influenced by the character of the flow in the boundary layer: laminar or turbulent. The friction drag can be reduced by a suitable profile and fuselage shape and by reduction of the surface area of the wing and the fuselage, which leads to a high wing loading. Friction drag contributes around 60% to the total drag in forward flight.

The parasite drag is produced by separation of the flow behind blunt bodies like under-carriage, antenna wires, struts, wing-fuselage junction and empennage junctions. Parasite drag has to be avoided by careful shaping.

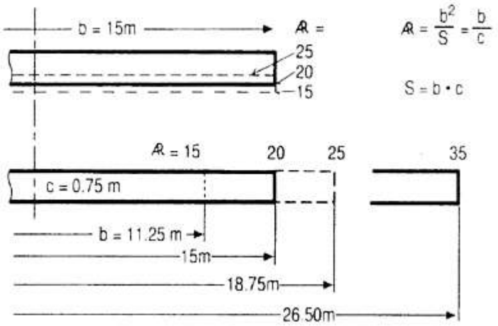
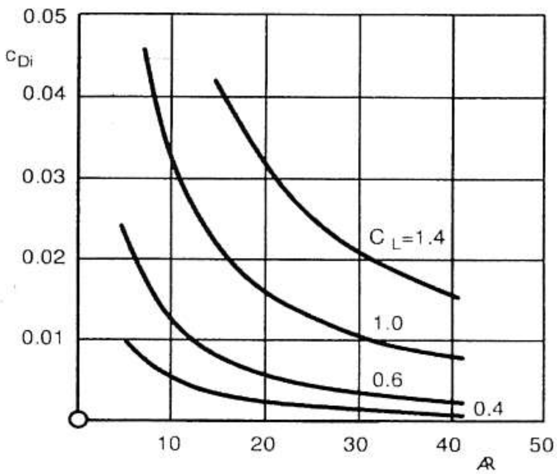



**Fig. 20 Lift, Aspect Ratio and Induced Drag**




It is evident that a compromise between the requirements for climbing and for flying forward must be found:

- Climbing requires a very large aspect ratio and a low wing loading in order to reduce primarily the induced drag.
- Forward flying needs a small surface which means rather high wing loading and a lower aspect ratio in order to reduce primarily the friction drag.

Both flight phases require as low a friction drag as possible. The friction drag is produced in the boundary layer. The boundary layer is the part of the flow adjacent to the surface of the airplane. Here the flow velocity changes from zero velocity on the wall surface to the free stream velocity. In the boundary layer we distinguish three different types of flow (see Fig.21):

- laminar flow
- turbulent flow
- separated flow.

The flow starts in the stagnation point at the nose of the wing or fuselage in laminar condition, some way downstream it changes to turbulent condition in the transition point. If the flow has to move against an increasing pressure the probability of transition and/or separation is increased. Separation can happen with turbulent flow, and even more so with laminar flow. The thickness of the boundary layer on a sailplane starts with millimeters, increasing downstream to a few centimeters.

In a laminar flow all particles flow parallel to each other and to the wall without changing speed and direction. The turbulent flow is also flowing parallel to the wall in general, but the main stream is superimposed by small high frequency random fluctuations in all directions with speeds of a few percent of that of the main stream. Separated flow is a chaotic flow with no clear direction and occurs only when the flow moves against a rising pressure gradient. This is typical for the downstream area of the wing at high angles of attack and produces the stall of the aircraft.

These three types of flow produce very different amounts of drag. By far the lowest drag stems from laminar flow and by far the most drag is connected with separated flow.

What can we do to keep the boundary layer laminar? There are four main factors which have an influence on the status of the boundary layer:

- the Reynolds number
- the pressure distribution in the flow, depending on the shape of the wing or fuselage
- the roughness or waviness of the surface and
- the turbulence level of the flow.

The Reynolds number is the relation between inertial forces and friction forces in the flow. For a wing the Reynolds number can easily be calculated by the equation:

$$Re = V^*c/v$$

V is flight speed, c is chord length and v is a measure of viscosity. The Reynolds number has a very strong influence on the flow. The lower the Reynolds number the more stable is the laminar flow. With an increasing Reynolds number the flow tends more and more to change into the turbulent status. On the simple example of the flat plate the transition happens at Reynolds numbers of around half a million. Fig. 22 shows the enormous difference in drag of a flat plate in laminar and turbulent flow depending on Reynolds number and surface roughness. Airliners fly at very high Reynolds numbers and in that regime it is extremely difficult to keep the boundary layer laminar. Birds, however, fly at low Reynolds numbers and it is much easier for them to maintain laminar flow. Sailplanes fly in a Reynolds number regime where both laminar and turbulent flows are possible. In order to attain laminar flow over extended wing areas, a substantial effort is required. Typical sailplane Reynolds numbers are between 0.5 and 3.0 million. In this area laminar flow is possible on shapes

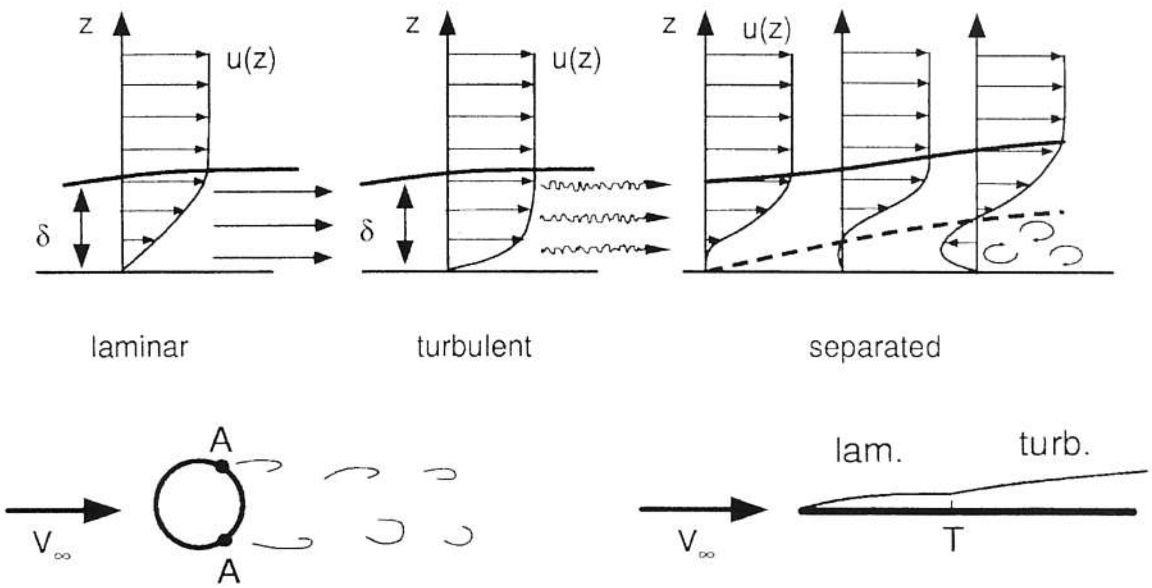



**Fig. 21 Boundary Layer**

which produce a favorable, that means negative pressure gradient on the surface by careful shaping. This is the case on the nose part of the wing and the fuselage. The pressure gradient on a wing is strongly dependent on the angle of attack (see Fig. 23). Favorable pressure gradients are only possible within a limited range of angles of attack. This range of favorable pressure gradients leads to an area of reduced drag in the lift-drag curve, which is called the laminar bucket.

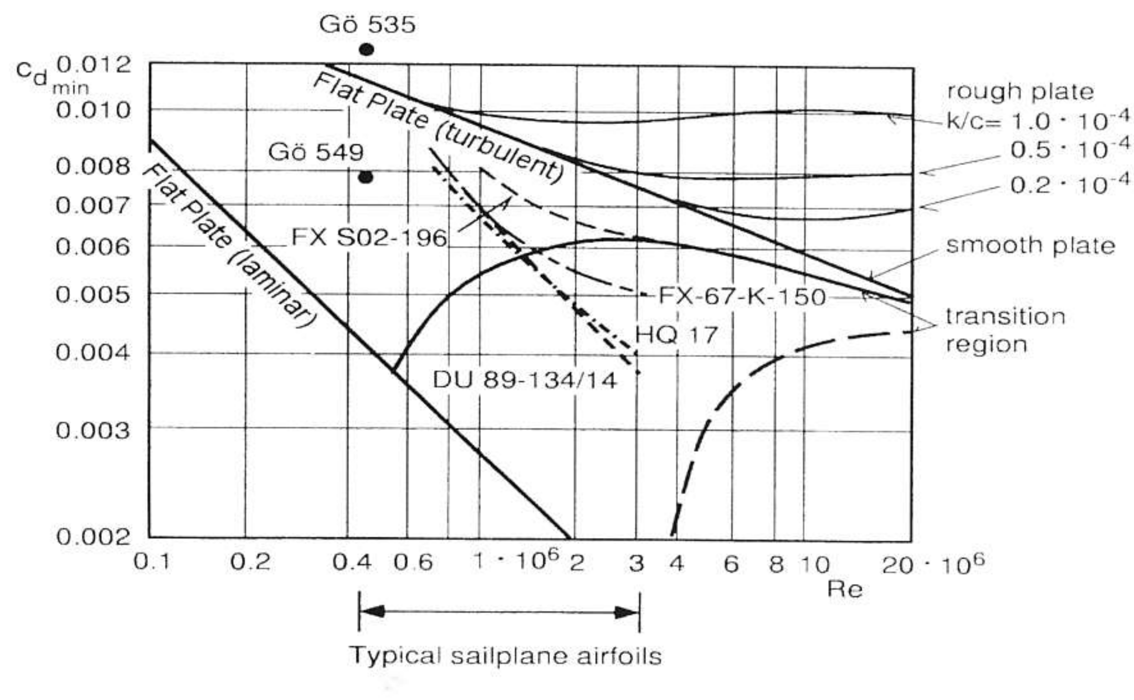



**Fig. 22 Drag of Flat Plate**

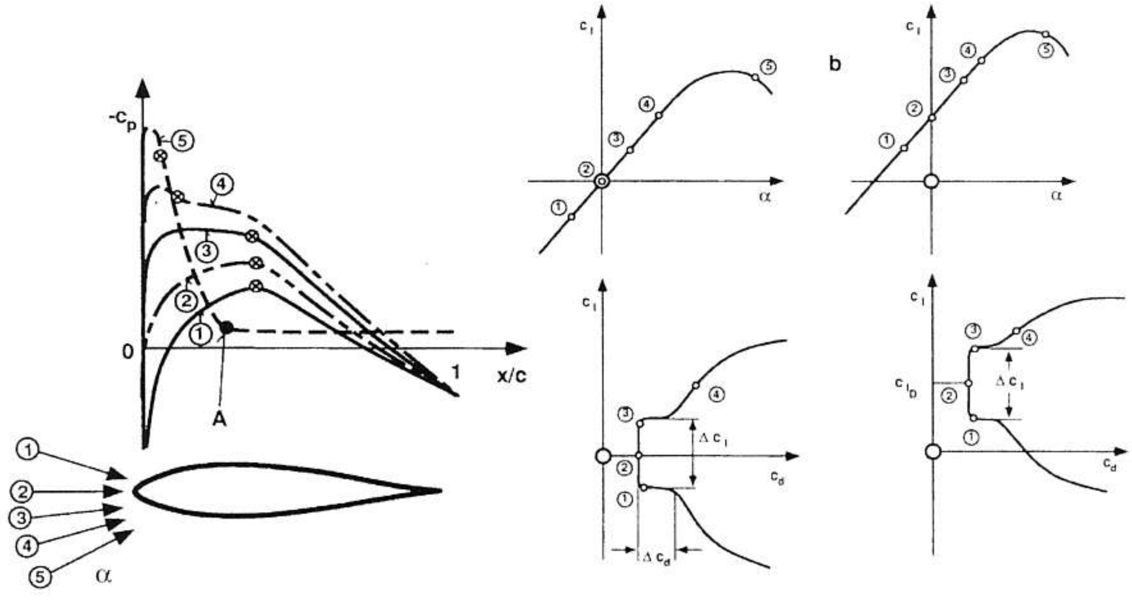



**Fig. 23 Angle of Attack and Laminar Bucket**

The design engineer needs a very broad laminar bucket in order to achieve low drag in both design points (see Fig. 24).

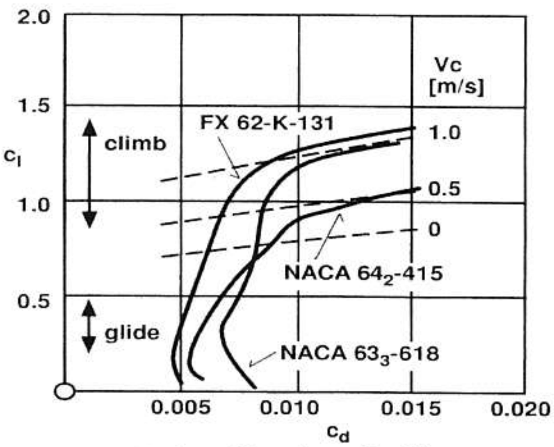



**Fig. 24 Drag-Polar of Laminar Profiles**

Especially for the design requirements of sailplanes the use of a small flap on the wing which can be set a few degrees up or down can move the laminar bucket to higher or lower cL values (see Fig. 25). Details of the profile, wing and fuselage design will be treated in the following papers by Horstmann, Boermans and Maughmer.

Transition from laminar to turbulent flow can also be effected by roughness and waviness of the surface. The same happens at a high turbulence level of flow to be found in most wind tunnels. The turbulence of the atmosphere has only a minor influence on transition, however.

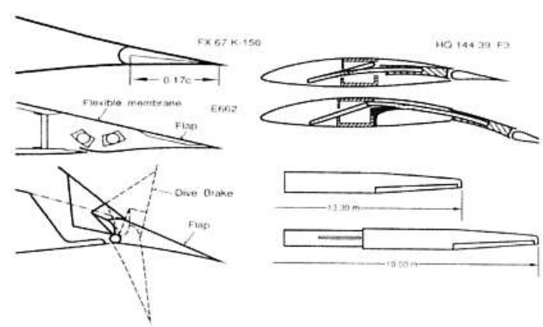


**Fig. 25 Variable Geometry**

First attempts to use laminar wing sections for sailplanes were already made by Pfenninger and by Raspet in the forties. Wing sections with a limited amount of laminar flow were used in the fifties and sixties with profiles of the NACA-6-series. The real breakthrough happened when composite materials replaced the so far wooden or in some cases metal structures of the sailplane. Composite structures made it possible to produce extremely smooth surfaces and profile shapes of high accuracy, which are necessary to achieve extended laminar flow areas on sailplane wings in a large range of angles of attack. With sophisticated theoretical and experimental methods wing section designers like Eppler, Wortmann, Horstmann, Quast, Boermans and Somers improved the wing sections more and more in the following years.

Besides the development of laminar wings a lot of other improvements have been intro-duced. The wing planform is close to elliptical and has a straight trailing edge. Winglets use the advantage of non planar wing shapes.

Boundary layers are laminar at the forward part of the fuselages. To minimize the turbulent drag of the rear part, the surface area of the fuselage is reduced. More of these design aspects will be shown in the lecture by Mark Maughmer later on.

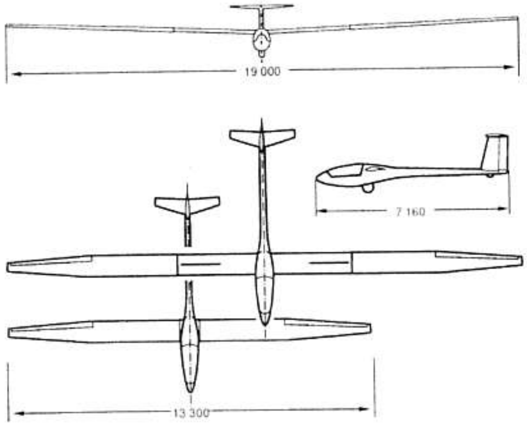



**Fig. 26 Telescope Wing fs 29 (1975)**

In order to have comparable conditions for sailplane competitions, a number of different classes have been defined with certain design restrictions like 15 m span limitation with (FAI 15 m class) and without (Standard class) flaps, 18 m span restriction and the unrestricted "Open" class.

Although most of the sailplanes of to day have evolved to a very similar configuration with large aspect ratio wings, slender fuselages and T-tails, there are still a number of very special designs which deviate considerably from the typical shape.

Attempts were made to adapt the sailplane even more to the different requirements of its two design points (see Fig. 25). The Akaflieg Stuttgart designed the fs 29 with telescope wings (see Fig. 26). Extended wings (high aspect ratio, low wing loading) were used during climb and retracted wings (small surface, high wing loading) in forward flight. Another concept was pursued with the SB 11 of the Akaflieg Braunschweig, which had large flaps extended to the rear when climbing and retracted in forward flight (Fig.25). Although both airplanes have proved the feasibility of these concepts in flight - the SB 11 was world champion in the 15m class in 1978 - they did not find their way into the industrial production lines.

Another ambitious project was the tailless SB 13 of the Akaflieg Braunschweig (Fig. 27). The design of a wing with laminar, low momentum wing sections for a tailless airplane is extremely difficult, not to mention the additional flutter and stability problems. The tailless sailplane had right from the early days in the Rhön a certain attraction. Especially the Horten designs are well known. Although the tailless planes demonstrated remarkable performance, they never were able to exceed the performance of conventional sailplane configurations. The less popular canard designs of the early days were not successful either.

Sailplane design has culminated in the design of the "eta", which flew for the first time two years ago. This remarkable sailplane of 31 m span, an aspect ratio of 51 and a glide ratio of 70, includes all the know-how accumulated until today. Although its performance is absolutely outstanding, its extremely high price will prohibit a widely spread use.

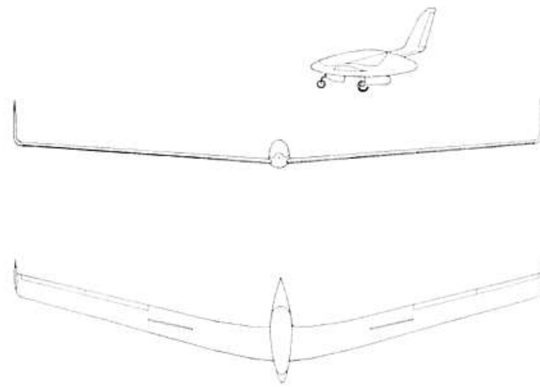


**Fig. 27 Tailless SB 13 (1988)**

Can we imagine that the future development will go beyond "eta"? The sheer size of the sailplane has come to a practical limit. Larger sailplanes have a lot of logistic disadvantages on the ground, and the cost increase is severe as well.

Nevertheless, there is some potential for future development. Further extension of laminar flow is possible with boundary layer suction with the help of a solar-energy driven pump and with automatically adapting wing shapes. Glide ratios of 100 are already discussed among ambitious designers.

The permanent improvement of the sailplane performance has the undesirable side effect of increasing cost. There is also a trend towards more simplicity. The range between the ultralights and the simpler sailplane designs is a so far not sufficiently explored area of development. A good example for this category of sailplanes is the "Archaeopteryx", designed in Switzerland (Fig. 28)

Other improvements are to be expected in the equipment of the sailplane. New rescue systems are under development and the chip technology will certainly be used for improved instrumentation.

**Fig. 28 Archaeopteryx (2002)**

Exploration of very high altitudes with a specially designed sailplane with a pressure cabin or with pressure suits is also feasible for research purposes.

## SUMMARY

Looking back to a century of sailplane development, I would like to recall some of the important milestones:

- 1890 - 1896: first flights of Lilienthal, cambered profiles, control by movement of the centre of gravity, lift-drag polar;
- 1903: Wright brothers: aerodynamic control around the three rotational axes;
- 1920: first Rhön meeting in Germany;
- 1922: design of the "Vampyr": aero-dynamic design, internal structure, D-shape torsional box for the wing, enclosed fuselage, no external bracing;
- 1922 -1928: exploration of ridge soaring for flights of extended duration;
- 1928 and beyond: exploration of thermal flying;
- 1949: Nickel-MacCready optimization of average cross-country speed;
- 1940 -1955: first attempts to use laminar flow wings;
- 1957: first sailplane built with fiber-glass composites in combination with laminar flow ("Phoenix");
- since 1960: successive changes in industrial production from wooden to fiber-reinforced structures, development of extended laminar flow for both design points, variable geometry;
- since the seventies: increased use of carbon fibers, very large aspect ratios, winglets, glide ratios of more than 50;
- future: laminar flow by boundary layer suction, improved rescue systems.

For those desirous to know more about the evolution of sailplanes, their design principles and flight strategies, see [1], [2] and [3].

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1)This paper was presented on the AIAA/ICAS International Air&Space Symposium: "The Next 100 Years" at the Dayton Convention Centre, Dayton, Ohio USA, 14-17 July, 2003 in Session 60-GA-15: Technologies for Sailplanes and Gliders, AIAA - 2003-2776


The same Session included the following papers:

M. Maughmer: The Evolution of Sailplane Wing Design, AIAA-2003-2777

C. Kensche: The Influence of Materials on the Development of Sailplane design, AIAA 2003-2778

K. H. Horstmann and L. M. M. Boermans: Evolution of Airfoils for Sailplanes, AIAA-2003-2779

R. Stemme: Manufacturing of Sailplanes and Motorgliders, AIAA-2003-2780