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THE DEVELOPMENT, DESIGN AND CONSTRUCTION OF GLIDERS AND SAILPLANES*

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INTRODUCTION

The Gliding and Soaring Flight movement is as old as history. The observation of bird flight must have shown the men of former centuries in the same way as our own generation, that apart from power flight with wing beats there must be another flight possibility, enabling the use of the energy in the movement of air masses for flight without the expenditure of other power. The experiments undertaken in these times on the solution of the flight problem have come down to us only through myths and sagas, and we cannot differentiate between truth and imagination in these stories.

Experimental research, which can certainly be considered as the foundation of modern physics, has also in the realm of aerodynamics laid the basis for modern aeronautics. In this gliding and soaring flight plays the role of full-scale experiments, not as an end in itself, but as a proving ground and last station before the invention of power flight.

The actual gliding and sailing flying had its beginning in the sailing flight movement which took place after the war and which was a result of the Rhön Sailplane Contests.

PART I

So if I commence my lecture with a few remarks about the development of the gliding and sailing flight movement, I will begin this outline with the successful sailplane of the first Rhön Sailplane Contest.

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Figure 1 shows the aircraft "Schwarzer Teufel" (Black Devil) of the Aachen Flying Club, designed by W. Klemperer.

The underlying idea of the design is on one side low structural weight and on the other side the greatest possible reduction of the parasite drag. Especially notable in this and other designs by Klemperer is the unusually carefully carried out structure. By this means Klemperer was able to attain an empty weight for this machine of 133 lb. (61 kg.) or a wing loading of 1.86 lb./sq.ft.

This type was not copied in the years following due to the fact that although the sinking speed was satisfactory, the gliding angle was too great. This matter depends to a considerable extent on the low-wing construction.

The sailplane which has to-day almost become a classic is the "Vampyr" (fig. 2) of the Flying Club of the Hannover Engineering School, which was designed by G. Madelung.

In this design we find for the first time the essential lines of thought clearly worked out in the design of a sailplane.

The problem is to build an aircraft with low sinking speed, good gliding angle, sufficient strength and good maneuverability.

The solution is: A cantilever high-wing type with a thick highly cambered wing section with large span and aspect ratio.

In this type a single-spar wing was used for the first time in which the torsional forces were taken by the leading edge. This was built up as a thin-walled tube, closed at the rear by the spar proper. This "torsion-nose" allowed at the same time of the possibility of keeping the most sensitive part of the wing section, the leading edge, the exactly correct shape. Plywood is the essential material which first made this construction possible.

Further notable characteristics of the "Vampyr" are: The three-part wing of the fuselage completely built of plywood and with a landing gear consisting of three football wheels, and the pendulum-type elevator.

The complete superiority of the "Vampyr" in the contests of 1921-1922 shows the correctness of the way that was taken.

It is obvious that the following years would bring a further development of the "Vampyr" idea.

At this time a rivalry sprang up to see who could get the greatest span and the best aspect ratio.

The first who dared to build with large span, cantilever, and with relatively thin wings, disregarding the necessarily appearing deflection due to bending, was the cabinet-maker Espenlaub. (Fig. 3.)

Even although the aircraft concerned was not successful, it set the example for the successful designs "Strolch" and "Konsul."

The "Strolch" (fig. 4) which was designed by A. Martens, is a refined development of the "Vampyr" with lower empty weight, increased span, and further, lessened parasite drag. Special care was taken over the rapid and simple assembly, an important point when regarding the use in contests.

As competitor the "Konsul" (fig. 5) of the Darmstadt Academic Flying Club also appeared in 1923. This aircraft, which was designed by Botch and Spiess, began the series of sailplanes which have come from the Darmstadt School. Certain differences from the "Vampyr" are unmistakable. The span is considerably increased, the wing-plan approaches the elliptic form, the fuselage is round in section, the empennage is considerably enlarged, and divided into fin and rudder. So as to guarantee the aileron effect with the great span the rudder was differentially connected with the ailerons. The "Konsul" may rightly be considered to be the first long-distance sailplane. The flying qualities of this aircraft were considered excellent by all pilots. The aircraft which surpassed the performances of the "Konsul" was also a design of a Darmstadt student. This was the sailplane "Roemryke Berge" (fig. 6) which was designed by Schatzky in 1924 for the Niederrheinischer Verein fuer Luftfahrt.

This sailplane hardly appeared in 1924 and 1925, as the Club had no suitable pilot for it. J. Nehring was the first to master this aircraft which was undoubtedly difficult to handle, and by his flight to the Milseburg proved the superiority of this sailplane. The beautifully streamlined fuselage had the smallest possible cross section. The wing rested on the narrow base of a centerpiece of the fuselage which served at the same time as streamlining behind the pilot's head. The wing section was Goettingen 426, a slightly cambered, thin section, with remarkably small drag, and the aspect ratio was suitable for the wing section.

The design of a sailplane from this latter point of view will be more exactly investigated later.

The center section had a rectangular plan-form and a flap along the whole trailing edge, which could be adjusted to vary the wing section. This mechanism was, however, never used and was later removed. Next year (1927) the Darmstadt Club built the type "Darmstadt I" to take the place of the decrepit "Konsul," from which it was developed. The influence of the "Roemryke Berge" is as regards the position of the pilot, unmistakable. The work of development in this case and also in the types that followed is directed more on the lines of the technical details. The "Darmstadt I" is smaller than the "Konsul" and, therefore, for contest purposes more useful, and as a result of the smaller structural weight no less capable of good performances.

As the aircraft was sold to the United States, the club built "Darmstadt II" (fig. 7) in 1928. As compared to the "Darmstadt I" the wing section and span were different.

As a variation of the Darmstadt type are the "Westpreussen" (fig. 8) designed by Dipl. Ing. Hofmann and the "Wuerttemberg" and "Lore" designed by Laubenthal. Both designers were formerly members of the Darmstadt Club. Accordingly, these types have a number of points in common, for example:

Wing.-Three-part, single-spar, rectangular (plan) center section with tapered elliptical outer sections.

Fuselage.-Egg-shaped cross section, with sharp edge underneath, cabane compact or nonexistent, fuselage ending in a vertical edge.

Empennage.-Attached to small built-in fin and tailplane. Otherwise no damping surfaces.

It is easily understood that this wing plan-form is uneconomical to build after reaching a certain span, as as the spar depth would not be great enough for the cantilever type.

To avoid this difficulty from the beginning, the lecturer designed the type "Professor" (fig. 9) in 1928 as a high-performance training aircraft. I consciously departed from the usual cantilever construction with compact short fuselage. As the aircraft was designed to be built by the various clubs and for training, the strength and stiffness had to be as great as possible. This is easiest to achieve by using a braced wing and a long fuselage. The inherent vibration period of the wing is very short, the elevator is not too sensitive, and damping and longitudinal moment of inertia great enough. By bracing the wing, a relatively thin wing section could be used (Gött. 549) so that the drag of the struts could be neutralized. A simpler construction resulted from making the fuselage six-sided.

As a logical development from the "Professor" came the "Wien". (Fig. 10.) By means of refined design of details the empty weight of the "Professor" was barely exceeded. The further development consisted obviously of increasing the span, using a higher cambered wing section, a more rounded fuselage cross section and faired fittings.

Apart from the "Professor" type, the aircraft built for the Munich Club by Dr. Kupper are a departure from the Darmstadt types. This Munich type began in 1928 with the "Kakadu," (fig. 11) a cantilever type with a large span, and has been notable in the following years. The wing-form, section and spar design are original. The latter is a thin-walled box spar of plywood of almost rectangular cross section. This stressed-skin type had only been used up to this time in metal aircraft. As only a few experiments have been carried out over the behavior of such plywood box spars, and mainly because the buckling strength of the thin skin is not exactly known, this design met with no approval,. and is now not even used by Kupper himself.

Figure 12 shows the three main steps of advancement from the "Vampyr" type. The "Professor-Wien" type was more a result of the experience gained in the development of training and practice aircraft, of which I shall now give a short resume.

The first training glider was the suspension type glider which was used by Pelzner in 1920-1921. (Fig. 13.) It was similar to the Chanute glider. In 1921 the Nuernberger Club developed a small biplane seat-type glider out of the above type, and which became the first training glider. One could hardly say, however, that this glider had any remarkably good characteristics. At this time the biplane was favored as better flying characteristics were expected from this type. Actually, this glider flew like a parachute. A notable step forwards was the primary training biplane "Frohe Welt" (Happy World) designed by F. Stamer. The construction was simple and serviceable, the flying characteristics very pleasant, and at the same time the gliding angle and sinking speed were quite suitable for the passing of the glider pilot's examination of the time(present A Licence). There was much trouble caused by damage to the lower wing due to wing-down landings, and later it was also found difficult to pass the tests for B Licence in this machine.

For these reasons the monoplane type came into favor after this time. The development began with the Munich glider of 1921. (Fig. 14.) This machine was, however, not designed as a training glider and had a special control system. The structure was merely taken over. Then came the Schulz glider of 1922, (fig. 15) which was built of broomsticks and tin cans, and in which Schulz flew for eight hours. On the basis of this forerunner I built the practice sailplane "Djävlar annama" in 1923 (fig. 17) with the idea of building the simplest and cheapest sailplane possible. If one limits the span one comes, as will be seen later, necessarily to this form. This type was continued from year to year in the slightly changed editions built by Schleicher in Poppenhausen, and has been further in great numbers built as a purely beginner's glider. A notable example of the type concerned is the "Pegasus" (fig. 16) of the Martens Flying school, whose simple structure enabled it to be produced very cheaply. From experience with the "Pegasus" the "Zoegling" (Beginner) (fig. 18) was developed, and as a further continuation of this series, the Stamer-Lippisch glider, known in England as the R.F.D. "Dagling."

It now remains to discuss the development of the practice sailplanes. The founder of this type was the Darmstadt aircraft "Edith" (fig. 19) of 1922, which was a braced high-wing type with an almost rectangular wing plan-form. From this type the "Bremen" (fig. 20) of the Weltensegler Society was developed. As the next type, I designed the "Hangwind" in 1924, from which I developed the

"Pruefling" in 1926. (Fig. 21.) Whereas in the years before, it had not been possible to train pupils who had never been power-pilots as far as the C Licence, the "Pruefling" made this possible, which was very vital for the further development of the gliding and soaring flight movement. The "Pruefling" was improved in 1928 and during the last year replaced by the "Falke" (Falcon) type. (Fig. 22.) In this design I had in view the production of a glider which combined the greatest possible safety against crashing with the best possible flying qualities. The principles underlying this type will be discussed later.

Besides this development of normal gliders and sailplanes the development of several experimental types also took place, so that already in 1922, for example, several tailless aircraft had been tested. These questions belong, however, already to that province which is connected quite generally with the meaning of gliding and soaring flight for the whole of aviation. In this connection motorless flight is to be the natural pioneer and guide for the future development of aviation.

PART II

Before I go into the details that determine the carrying out of the design of a glider or sailplane, it is nec- to discuss briefly the physical basis of soaring flight.

There are two possibilities of soaring flight:-

1. Static soaring flight, which depends on the presence of rising air currents.
2. Dynamic soaring flight, which depends on the presence of air currents varying in direction and strength.

Horizontal flight in an upwind takes place when the rising speed of the air is equal to the sinking speed of the aircraft. Therefore the best aircraft is the one which has the least sinking speed. This sinking speed may be derived in the following manner.

We use the symbols:-

W = weight (lb.)
S = area (sq.ft.)

s = semispan (ft.)
V, V_z, V_x = velocities (ft./sec.)
ρ = density of air (lb. sec.^{2}/ft.^{4})
k_R = resultant air force coefficient
k_L = lift coefficient
k_O = drag coefficient
ϵ = gliding angle
A = aspect ratio
$A = 4s^2/S$.

As you can see by the help of the diagram (fig. 23), the following conditions must be fulfilled:-

$$\text{Weight} = \text{resultant air force} \qquad (1)$$
$$\text{Tan wind direction} = \text{drag/lift} \qquad (2)$$

or expressed in formulas:-

$$W = \sqrt{}\,(L^2 + D^2) \qquad (1)$$
$$\tan \epsilon = D/L \qquad (2)$$

that is

$$\sqrt{}\,(L^2 + D^2) = \sqrt{}\,(k_L{}^2 + k_D{}^2)\,S\,\rho\,V^2 = k_R\,S\,\rho\,V^2$$

$$V^2 = V^2/\sin^2\epsilon = V^2\,[1 + (k_L/k_D)^2] = V^2(k_R/k_D)^2$$

accordingly the sinking speed is,

$$V = \sqrt{}\,(W/S\,\rho)\,k_D/\,k_R{}^{1\cdot 5} \qquad (3)$$

when one considers that the lift coefficient approximates to the total air force coefficient, and when one assumes normal air density and lets $S = 4s^2/A$, one obtains

$$V_z = 10.3\,\sqrt{}\,(W/s^2)\,k_D/k_L{}^{1\cdot 5}\sqrt{A} \text{ (in ft.-sec. units)}$$

The derivation with W/s^2 and A is better, as one can clearly see the direct effect of the span on the sinking speed. We call this function W/s^2 the span loading. In the second factor $(k_D/k_L{}^{1\cdot 5})\sqrt{A}$ the aerodynamic characteristics of the aircraft concerned are brought together, and we can calculate this factor for one or several wing sections in dependence upon the parasite drag and A. You will see that one can calculate by this means all the necessary facts for a project or for checking purposes. It must not, however, be assumed as a result of the above elementary details that a low sinking speed is the only measure of the worth of a sailplane. Apart from this the gliding angle and the necessary forward speed at the smallest sinking speed is very important. Generally speaking, one tries to achieve a good range of attitudes with low sinking speed, and at the same time good gliding angles. For one thing, the pilot cannot always be flying at the minimum sinking speed, and on the other side the continual variations in the wind direction and strength are always changing the attitude of the aircraft. Thus, for the purpose of attaining the smallest possible deviations from the most suitable attitude, quite a large number of other facts must be considered. The most important ones are:

Stability, especially longitudinal stability.
Maneuverability, even in unusual flight attitudes.
Sufficient flying speed.

In discussing the aerodynamic basis of sailplane design, I will go into these questions in detail.

Only in the last couple of years in the development of soaring flight has it been possible to make use of the great atmospheric upwind areas. It is thus only too easy to understand that in the times when human soaring flight had not yet been achieved, many phenomena in the natural soaring flight of birds, due to ignorance of these upwind areas, could not be explained as static soaring flight. I would like to make reference here to the extremely interesting explanation of the theory of soaring flight by your countryman, F. W. Lanchester, in the second part of his Aerodynamics, in which he writes a very thorough discussion of the matter. For this reason the name of that other type of soaring flight, "dynamical soaring flight," originated from Lanchester. This kind of flight is made possible due to the fact that irregularities in the wind without an average upward movement are present. I will show you (fig. 24), by means of a simple example, how this "dynamic soaring effect" can occur. The bird which flies forward with the help of wing beats receives the necessary forward thrust through the considerable up and down movements of its wings. The horizontal motion implies then, that the up and down moving parts of the wings follow a path of wave form relative to the air. If one fixes, as a first approximation, the path of the chief moving wing parts as a sine curve, one can calculate the course and variations of the vertical and horizontal air forces which are caused by such a motion. As you may see from the diagram, when the forces are integrated over a period of one complete oscillation, there is a definite forward thrust and lift.

Let us now assume the air to be in such a motion of oscillation due to friction with the earth's surface or to variously moving air masses. By flying through this air in an aircraft with stationary wings the above-mentioned vibration effect would occur. As both forward thrust and lift result, it must be clearly possible to soar in such layers without the help of actual upwind. This effect, which is caused by the periodically changing vertical speed of the wind, is called the "Knoller-Botz effect" and played a great role in the first years of soaring flight.

If, for the polar of a given wing, one substitutes a parabolic function of about the form

$$k_D = a\, k_L^2 - b\, k_L + k_{D_0}$$

in which $a = S/4s^2$ + constant, the increase of the induced and profile drags being considered, one finds that the average coefficient of the horizontal air forces is

$$kx \sim \tan \varphi\, k_L - k_D$$

The curve followed by the wing relative to the air is expressed as

$$Y = m \sin X$$

while the variation of the lift distribution caused by the change in the direction of the air motion along the length of a complete oscillation can be expressed as

$k_L = k_{L_m} + \Delta\, k_L \cos X$ (m denoting mean value).

One could also give the wing a variable angle of attack to better the effect. As you see, there is no forward thrust if there is no change in lift along an oscillation, or if one keeps the angle of attack with respect to the air constant. The maximum forward thrust occurs for

$$\Delta\, k_L = m/2a$$

and then amounts to

$$k_{X_{max}} = m^2/8a - k_{D_m}.$$

In further reference to Figure 24:

$$X = \sin \varphi \, L - \cos \varphi \, D$$

$$Z = \cos \varphi \, L + \sin \varphi \, D$$

$$K_X \cong t_g \, \varphi \, K_L - K_D .$$

$$K_Z \cong K_L$$

$$t_g = m \cos X .$$

$$K_{L_x} = K_{L_m} + \Delta K_L \cos X .$$

$$K_D \cong a \, K_L^2 - b \, K_L + K_{D_o} .$$

$$\Big|_{o}^{2\pi} \; K_X = (\Delta K_L/2) \; (m - aK_L) - K_{D_m} .$$

$$K_{X_{max}} = m^2/8a - K_{D_m} \; \Big|_{= m/2a}^{\Delta K_{L_{best}}.}$$

This great variation in lift makes it necessary to have the wing polar as straight as possible. Of course the above considerations are only approximate and disregard acceleration forces.

Even though this effect has never yet occurred to any traceable degree, wind tunnel tests undertaken by the Vienna Aerodynamic Institute check qualitatively with the above considerations. You see here (fig. 25) the test results on two wing models which were tested in a periodically oscillating wind stream.

It is obvious that horizontal oscillations of the wind could cause similar effects. Consider for a moment a wing flexibly mounted on a fuselage. A strengthening of the wind would cause an upward movement of the wing, and by means of the energy collected in the sprung connection, a forward thrust could be exerted in the following lull by means of the downward beat of the wing. The motion of the wing is thus caused by the pulsation of the wind, so one can consider the aircraft as "an aircraft driven through wind pulsations by wing beats." This effect which, as far as I know, was first discussed by W. Birnbaum (Zeitschrift für Flugtechnik und Motorluftschiffahrt, 1924, page 128), reveals a number of matters connected with the performance of cantilever sailplanes of large span in very gusty winds. The superiority of this type over the stiff-winged braced types is very striking. Nevertheless, this effect is very small, and is only of secondary importance as compared to upwinds. In spite of this it is, in my opinion, not wise to ignore this dynamic soaring flight entirely. So long as there exist no incontestable tests carried out with suitable aircraft, it is premature to disregard this kind of soaring flight. There is, unfortunately, in this present lecture no room for a more detailed consideration of this most interesting question, and I think you can read Lanchester if you wish more details.

PART III

I would now like to consider the aerodynamical and statical bases which determine the design of modern gliders and sailplanes.

The glider which is to be used mainly for elementary training is not supposed to have a high performance. This gives one the opportunity to fit the aircraft to the purpose of training, and to give first emphasis to safety. It is basically wrong to wish to design such aircraft with the lowest possible sinking speed or especially good gliding angle. One doesn't learn to ride on racehorses!

It is therefore idle to waste many words over the aerodynamic principles underlying the design of elementary gliders.

The choice of a wing section showing a flat curve at high lift coefficients is important so that one can pancake or pull the stick pretty far back in flight (slots are certainly suitable here). It is also important to make all control areas suitably large, through which one must try to combine stability with effective control. Such machines as have insufficient control are unsuitable, for the pupil must know when he has made a false control movement. But I think that last year Mr. Stamer went into these matters with you in great detail.

In the design of a sailplane, as you have already heard, the sinking speed and then the gliding angle are of the foremost importance, and that means that, inside practical limits, we must try to get the best combination of span, empty weight and cost. Of course one starts by trying to find the best possible wing section. When one, after a long search, has actually found a really wonderful wing section, and designed the wing accordingly, one is again in doubt as to which aspect ratio one should choose, and whether or not a change of the wing section would be better in this case, and so on.

The more one works himself into the problem, the more new problems crop up, so that one is finally left to one's discretion. In time such a wandering about is not very satisfying, so that one begins to look for a method which, on the basis of test results and theoretical considerations, would give a general solution of the problem.

We begin with the wing section. As the characteristics of any one wing section cannot give a general view of the problem, in which the probable inaccuracy of single results is to be especially noted, we try to make a systematic determination of values from a large number of tests. We eliminate the induced drag, and then sketch all the profile drag curves together. (Fig. 26.) Diagrammatically, we get somewhat the following picture: You see that we can substitute a general polar for all the individual polars. The best part of a curve then lies in the neighborhood of the point of contact with the general polar. Any further calculations we make using the general polar. If by means of this representation we decide on a certain part of the general polar as the most useful in any special case, we choose that section which is tangent at this point of the general polar. We can now substitute the general polar by a suitably chosen function. If, however, we want to achieve a fairly satisfactory agreement, we must use a function of at least the third order, and then the analytical development is very difficult. Therefore we use a mixed graphical analytical method. We have already shown that the sinking speed can be expressed as

$$V_z = 10.3 \sqrt{(W/s^2)}\; k_D/k_L^{1.5} \sqrt{A} \text{ (ft.-sec.)}$$

And now to determine $(k_D/k_L^{1.5})\sqrt{A}$ generally, we proceed as follows: The polar of the complete aircraft is replaced by $k_{D_A} = (1/A\pi)\, k_L^2 + k_{D_\infty} + k_{D_{st}}$

in which

$$k_{D_{st}} = \Sigma\, k_D\, S'/S,\quad k_{D_\infty} = f\,(k_L)$$

then

$$k_{D_A}/k_L^{1.5} = (1/A\pi)\, k_L^{0.5} + (k_{D_\infty} + k_{D_{st}})\, k_L^{-1.5}$$

By differentiating through k_L we get the desired minimum from the following:

$$k_L^2/2A\pi + (dk_{D_\infty}/dk_L)\,k_L - 1.5\,(k_{D_\infty} + k_{D_s}) = 0$$

So that we obtain the equation

$$A_{best} = k_L^2/\pi\,(\Phi + 3\,k_{D_{st}})$$

and then also

$$(k_{D_A}/k_L^{1.5})\sqrt{A} = (1/\sqrt{k_L\pi})\,\left\{(\Phi + k_D + 4k_{D_{st}})/\sqrt{\Phi}\right\} = \varphi$$

The expression

$$\Phi = 3\left\{k_{D_\infty} - (dk_{D_\infty}/dk_L)\,(k_L/1.5)\right\}$$

can be determined for the individual points of the general polar and we can get the aerodynamic sinking speed coefficient $(k_D/k_L^{1.5})\sqrt{A}$ expressed in A and k_{D_s}. In further calculations, for the sake of simplicity, I will designate this expression by φ. Here we see the result of such a determination (fig. 27) in which the results of the Aeronautical Research Institute in Göttingen were used as a basis. In the same manner as for φ, one can also fix the lift-drag ratio, and also sketch it on the diagram. Although the use of the general polar is in this case not quite exact (the actual values of the individual sections would be somewhat smaller) it is quite good enough for a check calculation. The shape of the curve $\varphi = f\,(Ak_{D_s})$ shows first that the coefficient φ changes only a little when A has a value greater than ten, and secondly, the minima of φ lie between $A = 10$ and $A = 20$. Aspect ratios over 20 are then unfavorable when considering the least possible sinking speed. Merely the improvement of the gliding angle requires a large aspect ratio. And now to be able to judge the conditions for some definite design, we must either decide on the wing area or the span. Then it is still necessary to evaluate the parasite resistance. The existing results in this connection from experiments show much smaller values than those actually shown in flight tests. When one, for example, knows the sinking speed of a sailplane by calculating the same from barographs or test flights, and has further measured the gross flying weight and the span, then φ is determined as

$$\varphi = v_z/10.3\sqrt{(W/s^2)}$$

If one sets the values found in the diagram over the A concerned, one can determine the value of k_{D_s} and also of course, the so-called "reduced drag area," or $\Sigma k_D S'$, where k_D is the drag coefficient of the part concerned and S' the area of same normal to the wind direction. I have placed these points for three well-known high performance sailplanes on the diagram, and found as a result that the average value for the reduced drag area is

$$\Sigma K_D S' \text{ (average)} = 4.6 \text{ sq.ft.}$$

Even although these values seem very great, and one might assume that the machines concerned were not flown to the best advantage, it would be well to use these values in working out projects, as most aircraft are considerably better on paper than in the air.

To make use of this diagram further. If, for example, we want to build a sailplane with a span of 50 feet, we calculate the necessary wing area and aspect ratio for various k_{D_s} with the help of the above values and $\Sigma k_D S' = 4.6$, so that one can place these points on the diagram. From this we can clearly see the effect of change of wing area or of change of aspect ratio. In this connection comes the conclusion that the lift-drag ratio is only noticeably affected by lower aspect ratios. Even from $A = 8$ on the change of the lift-drag ratio is very small. This result is also notable and shows the disadvantage of using too large aspect ratios.

In our determination of the sinking speed we have still to estimate the empty weight. For this purpose I have collected a number of actual weight figures, and have attempted to show an analytical connection between this static material (fig. 28). In accordance with a derivation by Dr. Lachmann, I have let the wing weight be

$$W_s = m\,S + s^3/n.$$

Further, let the fuselage weight be

$$W_f = k\,s$$

in which, for this approximation, the weight of the empennage is added to that of the fuselage. The experimental results show that these formulas can be safely used. The gross flying weight may now be expressed as

$$W_{total} = m/S + s^3/n + ks + W_o$$

where W_o = weight of pilot and equipment. Now the span loading is

$$W_{tot}/s^2 = m/A + s/n + k/s + W_o/s^2 .$$

The coefficient concerned may be expressed as

$m \sim 0.78$ [lb./sq.ft.] $n_c \sim 1000$ [ft. /lb.] cantilever

$k \sim 4.4$ [lb./ft.] $n_b \sim 1840$ [ft. /lb.] braced

For our design, which we shall consider as being cantilever, we obtain the curve of sinking speed plotted as a function of the area. It can also be seen here that in no case does an extremely large aspect ratio, i.e., small area, give the smallest sinking speed. Although there is no exact relationship expressing the effect of the gliding angle on the "soaring ability," and the general worth of a design, it would seem to be better to use the larger aspect ratios.

If we now go into the design in more detail, we will draw a so-called "speed diagram," using as a basis the now chosen wing section and the calculated values of the final design. (Fig. 29.)

One tries to obtain as flat a curve as possible, which can be achieved through the choice of a good aspect ratio. The mean value of the sinking speed, as influenced by changing the air speed, would not vary very much from the best value. Such a diagram is of special importance for pilots who wish to carry out long-distance flights in the aircraft. The parts of the flight during which there is no upwind must obviously be so flown that the gliding angle with respect to the earth is as good as possible. Because of the effect of the wind (head or following) this angle is different to that relative to the surrounding air. With the use of the speed diagram the flight attitudes concerned are easily determined, as one fixes the best attitude by lessening the air speed in case of head wind or increasing it in the case of following wind. One realizes that it is correct to fly at higher speed with head wind and at lower speed with following wind, rather than fly at the best gliding angle. If there is upwind or even downwind present, one must subtract it from, or add it to, the sinking speed as the case may be, and then one obtains the best flying attitude by consideration of both effects.

I can unfortunately not go very deeply into the other matters which decide the detail construction of the aircraft. First of all, the designer must always realize that even the machine which is aerodynamically best will be incapable of good performances if the flying qualities are not also good. If the pilot has not perfect trust in his machine and does not know whether she will leave him in the lurch in a difficult situation, it would only be possible under especially good conditions for him to achieve good performances. Because of this it is my opinion that, if it is necessary, it is best to sacrifice a certain amount of aerodynamic efficiency to achieve good flying qualities.

The large spans of sailplanes are naturally only practicable when one uses wings tapered in plan form. The rectangular plan form has static and dynamic disadvantages, which cannot be disregarded even for reasons of cheapness of production. This holds true in the same way for the design of engined aircraft, and although there are even today many people with the opposite viewpoint, I can only advise them to go to the shipbuilders and tell them that it would really be the best thing for them to build all their frames the same shape and size! The answer that the shipbuilders would give, is also my opinion. Generally one uses plan forms such as you see sketched in Figure 30, of which (I), for example, is for a braced type, (II) is cantilever, and (III) could be either braced or cantilever.

One could base one's choice on the induced drag of these forms which could be worked out by H. Glauert's method. You will, however, find that there is very little difference between the various forms if they do not deviate too much from the elliptical lift distribution. The effect of the plan form on the manouvorability is more important. To achieve good control action, one must make sure that in the case of stalling the air flow breaks away first from the inner portions of the wing. Then one still maintains lateral stability. The shape of the ailerons should guarantee that there is a reasonably great chord right to the outer ends. The shapes shown in dotted lines on the diagram are therefore considerably better. Sweptback and twisted wings have shown very pleasant flying characteristics (IV). Such forms are practically spinproof. The training sailplane "Falke" which I have designed has confirmed the experience made many years ago. The best position of the fuselage with respect to the wing cannot yet be laid down definitely. (Fig. 31.) As far as wind tunnel experiments show, the arrangement (I) is the most suitable. The necessary cut-out in front of the wing makes this arrangement, however, somewhat worse. For this reason type (II) has proved to be better and at present is generally used. The disturbance of the lift over the center section in soaring flight is very noticeable, because most of the flying is done at a high lift coefficient, and the polar curves are approximately as shown in the diagram. The pure low-wing type has similar disadvantages. While the latter form has often been used successfully in engined aircraft mostly inspired by Junkers, it must not be forgotten that the effect of the slipstream on a wing when the propeller axis is above the wing is more favorable, and that a saving in weight more than balances out a corresponding increase in drag.

The static construction of sailplanes is to-day almost always of the "Vampyr" type. (Fig. 32.) One spar at the thickest part of the wing, about 30 to 35 per cent of the chord from the leading edge takes the bending moments. The forward part of the wing, built up as a box or tube, resists the torsional forces. A lighter secondary spar serves as aileron-attachment spar, and to connect the rib ends together. The shearing strength of the nose wing covering can, however, only be guaranteed when the ribs are close enough together to prevent any possibility of the covering buckling. Otherwise, folds will appear before the breaking stress is reached. In my experiments I have found that by using plywood attached with grain diagonally over leading edge, the breaking strength is twice as great as normal and the stiffness four to five times as great. A spar built as a thin-walled rectangular box is theoretically best, and is used generally in metal aircraft at present. How to make the thin walls perfectly or suitably stiff with wood construction and also lightly is, however, still a matter for discussion. One is therefore forced to use more material than is necessary, so that the advantage of the construction is only very small. There must be tests carried out in this direction to make the matter clear. A very important matter is the stiffness of the wings to resist bending and torsional vibrations. The latter can be completely overcome when one places the elastic axis of the wing in front of the most forward position of the center of pressure. Apart from this one must be careful that there is no aileron flutter present.

Those latter as well as other parts of the outer wings must be very lightly built for this reason. The bending stiffness of this large-span cantilever is in the first place dependent on the height of the spar considered in relation to the length of the cantilever, and also on the load (lift) distribution. Thus in every respect the tapered wing is superior to the wing of rectamgular plan form. The same can be said for the torsion-resisting structural members. I show you here a comparison between two wings of the same span and area, one with a rectangular and the other with a tapered trapezoidal plan form. Referring to Figure 32:

$$c_1/c_0 = n.$$

$$y_b = (x^2/s)\ [3 + x\ (n - 1)]/[1 + x\ (n - 1)].$$

$$y_t = \int_0^x [2/(n+1)+x(n-1)/(n+1)]^2/[2/(n+1)+ 2x(n-1)/(n+1)].$$

Assuming the same wing section and angle of attack, figures to represent the two flange cross sections and the "torsion noses" were calculated. You see that in this case by the use of tapered wings one would save 50 per cent in weight in the cases of the nose covering and the spar flanges, over the rectangular wing. It is further clear that for the same loading, the bending and twisting is much greater for the rectangular wing than for the other. For large spans, the most favorable as far as weight is concerned, is the braced (Professor Wien) type. The extra drag of the struts is almost neutralized by the use of a thinner wing section. This type is only reasonable when torsion and bending can be taken up by the struts, as the torsionally stressed parts are at least as heavy as the parts stressed in bending. We can, of course, not exactly say what is the very best type of wing. Nevertheless, calculations which take into consideration both the aerodynamic and statical points of view are very informative. All these considerations are not only applicable to sailplane design. As far as design is concerned the construction of sailplanes is really a natural experiment plant for all problems connected with power aircraft.

Fuselages of high-class sailplanes are nowadays always of round or elliptical cross section, and covered with plywood. (Fig. 33.) The three longeron type with a rounded edge underneath is simple to construct and fits the shape of the sitting man very well. In smaller training aircraft the fuselages are four- or six-sided structures. Fuselages of extremely small cross section permit, of course, only of the use of wheel control. For high-performance sailplanes this control is therefore generally used. The control surfaces are designed in the same manner as the wing. In high-performance sailplanes the pendulum type of elevator is generally used. The construction of the fuselage and like that of the "Professor" or "Wien" is usual. In the case of primary training aircraft the regulations state that the horizontal control surfaces must consist of a fixed stabilizer and elevator. There have been no accidents caused by the use of the pendulum type elevator. One must only choose the gear ratio correctly.

In Germany the following regulations guide the strength calculations for gliders and sailplanes.

Group: Wing.

Loading case I.	Stress corresponding to flight with most forward position of center of pressure. Factor of safety, 6.
Loading case II.	Stress corresponding to flight with maximum torsional load. Factor of safety, 1.
Loading case III.	Stress corresponding to a landing (wing weight as load) 6-8 safety factor.

Group: Fuselage.

Loading case I.	Stress due to load on empennage. Breaking load of empennage is breaking load of fuselage.
Loading case II.	Stress by landing. The wing loads are 6-8 times breaking load.
Loading case III.	Stressing of wing-fuselage connection by landing on wing. Breaking load 110 pounds applied at wing tip in direction of wing chord.

Group: Empennage and Ailerons.

Elevator and rudder: Breaking load 31 lb./sq.ft.
Ailerons: " " 16 " "

The polar diagram of the wing and of the complete aircraft must be used in the strength calculations.

A proof of the static stability is also necessary.

You will perhaps be surprised that we have only taken two cases of loading into account in the strength calculations for the wing. But I do not see what use a point between the most forward position of the center of pressure and diving flight would be. The consideration of case (I) proves whether there is enough strength to take care of bending and forward thrust. The consideration of case (II) proves whether there is enough strength to take care of torsion and backward pressure. These cases take care of the extreme forces. Years of experience have shown that the above strength demands are enough. Apart from the above, the same methods and bases may be applied and used in sailplane design as are used in power aircraft design. The many detail questions, which would doubtless be very interesting would, I fear, take us too far from our subject.

By means of several photographs (figures 34-42) I would like to show you constructional details of several types.

The Importance of Motorless Flight to the Development of Aviation

I would now like to finally consider the meaning of motorless flight for power-driven aircraft.

Last year Mr. Stamer told you about the value of gliding as flying training. Therefore I do not really need to repeat that the pilot who has learned to master a light sailplane in wind and clouds, has gathered experience for his whole flying career which could never be so clearly taught in a power-aircraft flying school. He must have a thorough knowledge of weather observation and meteorology if he wishes to make any good performance. Soaring flight has brought new knowledge to aerometeorology, and the new researches on the vertical movement in the atmosphere have at least been stimulated by soaring flight.

The technical significance of sailplane design at the present time is made clear by the foregoing parts of my lecture. On this account I would like to consider merely one specially fruitful sphere of motorless flight research.

Since the end of the war (1914-18) one has begun to use aircraft for commercial purposes all over the world. This air traffic has grown from year to year and to-day covers wide districts of various continents. There is air traffic everywhere except where its proper field of activity is, that is, there is no air traffic between continents where rapid communication is really necessary, and where air traffic could actually "fly by itself" or pay its way. Now, I ask you, what is the use of this fastest of all means of communication, if it has no use in its proper field of activity? And what is the sense of this much-advertised speed when it is only procured by a phenomenal waste of energy? I cannot help but think that the main problem of this means of communication, that is, the economics of it, is carelessly handled.

What would you think of anyone who equipped a farmer's wagon with a 100-horsepower engine and drove from gasoline station to gasoline station at sixty miles an hour? The most sensible thing to do would be to advise him to use ball bearings to cut down the frictional resistance of his vehicle. Perhaps you laugh at all this, but you must admit that most of our present-day aircraft have not as good a frictional coefficient as our original farmer's wagon (without ball bearings). Or perhaps you don't believe that the wagon would roll down a grade of 1:15 by itself? But perhaps you can tell me of an airplane which has a gliding angle as good as 1:15? The only aircraft which can compete with this honorable rival are a couple of high-performance sailplanes which struggle for the first prizes every year on the Rhön. The comparison shows you where we must start to develop economical aircraft. The energetic reduction of the frictional coefficient is a vital necessity in aircraft design. One could, of course, make these tests in a wind tunnel and that is the usual thing to do at present. One soon notices that the wing alone has always a better gliding angle than the whole aircraft with fuselage and empennage. Then it would be clearly the best thing to do, if one tried to build an "all-wing aircraft." But why don't people build such aircraft? Quite obviously because one sees no possibility of safely developing the aircraft from the wind-tunnel state to full size. There is one perfectly safe and proved method and that is called motorless flying.

This method was actually known since the beginning of aviation, and it has only been given up to-day because, on the basis of long experimentation and experience, the behavior of a normally built aircraft is well enough known that the controllability and stability of a new type can be guaranteed before the first flight. But how a quite new type of aircraft would behave is beyond our knowledge, and even calculated characteristics with the help of wind-tunnel tests cannot be guaranteed. The method which we have used with good success for some years, I will now explain by means of a shortly sketched example.

We will now, for example, create an "all-wing aircraft," and have worked out a suitable project (fig. 43) on a basis of various theoretical and design considerations. Before we start designing a man-carrying aircraft, we build a model of such dimensions that we can use the laws of dynamic similarity to advantage. To do this, it is necessary, as is well known, that the Reynolds Numbers that appear in flight must exceed the critical region between laminar and turbulent friction, and also that the ratio of the wing-loading between model and full-size aircraft must be to scale. We test this model in free flight, notice the effects of various control settings, the behavior in flight in very gusty winds, and in short, everything that is included in dynamic and static stability. By changing the model we correct any possible deficiencies, and experiment until we are satisfied with the flying properties of the model. (Model 44.)

Now we can go a step further and venture into the design of a man-carrying glider. This aircraft will be so built, for practical purposes, that after a successful test an engine may be installed. Perhaps you might ask why we don't use a small engine in the first place? Mainly so that we can remove all possibilities of danger, as far as we are able.

The first short flight over flat land in the glider is absolutely safe, whereas the first flight with a power aircraft cannot be so, as an insignificant error can have a crash and fire as a result. Even if the glider did crash, it would not be dangerous because of the low speed. But it is quite a feat to crash from a height of a few inches.

By a progressive choice of ground with steeper slopes we gather experience on the behavior of the new aircraft. We study the effect of the various controls, the effects of outside disturbances, and can always fall back on the model tests in difficult cases. Finally, we are so far that we can carry out longer gliding and soaring flights with the aircraft. I hardly need to point out that by this means one can gather sufficient experience so that trials with an engine installation may be begun. If one still has doubts as to the operation of the propeller drive, one can use tests with free-flying motor-driven models, as an aid to the solution. If one hasn't a large landing field at one's disposal it is better if possible to use the skid (instead of wheel landing gear) for the first flights with the engine. The final steps are certainly not at all necessary to mention.

The successful experiments with tailless aircraft which have also been carried out in this country by Captain G. Hill, are the beginnings of a new development period in aviation. I realize that against the arguments which have been put forward, people have an army of doubts in reserve, and most of them wonder whether the longitudinal stability (dynamic and static) is sufficient in the tailless type, and consider that the structural weight of swept-back wings would be greater than that of a corresponding normal wing, and that the manoeuvrability is not sufficient. The researches which I have carried out have proved that these views are wrong because the original assumptions were quite different. Unfortunately, because of the lack of time, I cannot consider these questions in detail, but hope, however, that the discussion will lead in this direction.

I would like to stress once more that motorless flight and the researches stimulated by motorless flight are not only of use in the province of gliding and soaring flight movement. The value of this new branch of aviation lies in the broadening of our knowledge in scientific, technical, and practical flying fields, and those whose vocation is concerned with the success of aviation cannot help occupying themselves seriously with the gliding and soaring movement.

The meaning and purpose of my lecture would be fulfilled if I have succeeded in giving new knowledge to those who are already interested in these things and have won over, as future collaborators, those who have been looking on.

Discussion

The Chairman expressed, on behalf of all present, the most sincere thanks to Herr Lippisch for his very interesting lecture, and said that obviously he had spared no trouble in the preparation of it.

The Chairman also expressed his extreme interest in the wing spoilers which had been referred to, and asked for more information concerning them.

Mr. E. C. Gordon England (Associate Fellow) (Chairman of the British Gliding Association), thanked the Royal Aeronautical Society for its unfailing cooperation with the association in all matters in which they were jointly interested, and said it was due to the Society that the members of both bodies had had the benefit of hearing a lecture by Herr Lippisch.

He would not discuss at length the technical aspects of the problem, because he was interested in propaganda and, indeed, had almost given up his life to propaganda on behalf of the gliding movement. The lecture, he prophesied would do much to further the art and science of gliding, and in the future would be looked back upon as marking a new stage of progress. He expressed regret that only a few technicians from the aircraft manufacturing firms were present at the meeting, and was bold enough to suggest that perhaps they imagined they had learned all there was to know about their own problems, and were under the mistaken impression that gliding had not a great deal to teach them. Herr Lippisch had indicated, however, the ways in which gliding could greatly increase their knowledge.

A point with regard to which there was a great deal of variance of opinion as between those interested in gliding and those engaged in the manufacture of aircraft was that of the value of a true and highly finished surface as a factor in the efficiency of a soaring machine. He asked if Herr Lippisch set a high value upon a highly finished skin surface.

The work of Herr Lippisch and others justified the faith of the pioneers of aviation to a very marked extent. Mr. Gordon England expressed the opinion that in the course of time - and not a very long time - it would be proved that the late Joseph Weiss (under whose auspices he himself had been introduced to aviation) had made a very remarkable contribution to the science of aviation, and one which had not yet been fully appreciated. Like many pioneers, Joseph Weiss had lived before his time.

Having regard to the indication by Herr Lippisch of the value of the sweptback wing, he asked if Herr Lippisch believed in the theory that there was some wave motion in the air which called for the use of a sweptback wing or a wing of distinct plan formation, and that that plan formation was greatly influenced by the air speed of the machine; in other words, at varying speeds a varying plan formation was necessary, to say nothing of the cross section of the wing.

He would like to thank the Rhön-Rossitten Gesellschaft for having, with great courtesy, and in the most reasonable way from the financial point of view, placed at the disposal of the British Gliding Association the complete working drawings and specifications of the "Falke" machine. These were available to clubs and private constructors throughout the country, so that any who wished to test the merits of Herr Lippisch's latest intermediate machine had only to apply to the Association for the necessary information.

<u>Mr. Lowe Wylde</u>: He felt that, in view of the experience of Herr Lippisch, one could only listen to and thank him for having given the meeting the benefit of his experience in a concentrated form Frankly, as one who appreciated the work that was being done in Germany, and as one who was very desirous that we in this country should emulate it, he felt somewhat afraid. In view of the work carried out in Germany during the last ten years, he felt that they had before them a very great task; it would take ten years to get things fitted up and to gather the amount of knowledge that their German colleagues had already gathered. He joined in the hope that as the result of the meeting there would be a full realization in this country of the fact that this work in connection with gliding was helping in the perfection of motor-driven aircraft, and that with the greater interest and support which should be forthcoming, we should be able to carry out further investigations on behalf of aviation.

<u>Captain Latimer Needham</u> (Fellow): Referring to wing loading, he said that for the case in which the center of pressure was in the most forward position the factor given

in the paper was 6, but he believed that many of the German sailplanes were built to factors of 9, 10, and even higher. He asked if Herr Lippisch would discuss that matter further. With regard to the ply covering over the leading edge, which was supposed to take the torsion, he said that, since it passed over and under the main spar, it must be subjected to the maximum bending stress to which the spar was subjected. Therefore, it had to take that stress before it could take any stress due to the torsion. He would appreciate the lecturer's comments on this point. With regard to the elevator and rudder, the loading given for the limiting velocity nose dive was 31 pounds per square foot. That appeared to be unduly high, but undoubtedly Herr Lippisch would be able to explain the reason for that.

Furthermore, by fixing the tail load in pounds per square foot instead of a load of so many pounds spread over the whole tail, designers might be inclined to cut down the size of the tailplanes.

Captain G. T. R. Hill (Fellow). emphasized three important points in design which had been made in the course of the lecture. The first was that, in the opinion of Herr Lippisch, tapered wings were greatly superior to parallel wings when they came to the big aspect ratios; secondly, that there were great virtues, from the point of view of stability, in the sweptback wing; and thirdly, it was clear, from one of the diagrams - which he hoped would be reproduced in the Journal - that the strutted wing was definitely considerably lighter than the pure cantilever wing. Those statements were all supported by a detailed mass of evidence, which was very valuable, and in that respect they contrasted favorably with the usual sweeping assertions, unsupported by evidence. The fact that the lecture included much detailed data made it an extremely valuable contribution to the Society's proceedings.

When visiting Herr Lippisch a few weeks ago he had seen on his table papers, journals and technical information of all sorts and in various languages, and was glad to say that copies of The Journal of the Royal Aeronautical Society were prominent among them.

Captain Hill asked if Herr Lippisch would be good enough to elaborate his remarks on the bending stiffness of the wings. Trouble had been experienced in some planes, he said, due to the wings being too flexible in bending, resulting in what he believed was called a "personal oscillation" - a longitudinal oscillation, as distinct from a lateral oscillation. The pilot was unable to distinguish between the movements of the machine due to bending of the wings and those due to wind gusts, and in trying to correct the motion, he actually forced an oscillation, which on one occasion had had disastrous results.

In emphasizing the concluding paragraphs of the lecture, Captain Hill recalled that recently, when travelling home from Germany by air - in an airplane which he would refer to as the "A" type - he had seen through the cabin window something dear to the textbook writer, a rectangular flat plate, placed at 90° to the wind stream. The plate was about one foot square, and after puzzling for some time over its object, he had realized that it was a means of blanketing off the oil cooler in cold weather in order to keep the oil from becoming cooled too much. If that sort of thing could be done on modern air liners, he said, one felt that the message contained in the concluding part of the lecture could, with great advantage in certain quarters, be very fully digested.

Captain Entwistle was particularly interested in the reference by Herr Lippisch to dynamic soaring flight and asked whether, in the full-scale tests which had been carried out in Germany, any quantitative measurements had been made of the lift obtained in the conditions referred to and also what maximum values had been obtained in soaring flights made in a definite upward current. He agreed with Herr Lippisch that the effects experienced as a result of variations in the strength of a horizontal wind current were negligible in comparison with the large scale effects which were due to large masses of rising air, but he also agreed that the former might ultimately prove to be of practical value, particularly in relation to glider design. He also asked whether Herr Lippisch could give any information in regard to the instruments which had been found in Germany to be most useful from the point of view of the measurement of the magnitude of the upward currents experienced in soaring flight.

Squadron Leader England (Associate Fellow): In most of the sailplanes illustrated, he noted that the fixed tailplane had been dispensed with, and would like Herr Lippisch to state whether the movable tailplane had found favor in the sailplane, whereas it was of little use on power-driven machines.

He would like to be enlightened as to why the controls on the "Zoegling" glider, which was definitely intended for training were, with the exception of the elevator, inferior. Surely on a training glider it would appear undesirable to have a powerful elevator without good directional and lateral control.

Mr. Dagnall: wanted to know whether Herr Lippisch recommended a dihedral or a flat angle.

Dr. Lachmann (Associate Fellow): The lecture was a compilation of the essentials of sailplane science, and those who were concerned with this science in all countries would be very grateful to Herr Lippisch for having done that work. Some of the formulas which Herr Lippisch had given had been guarded for some time as holy secrets by the various gliding corporations. Every aircraft designer must admire the refinements which had been achieved and must also envy the sailplane designer the possibilities which the sailplane afforded of the application of aerodynamics to such fine limits. It was easy, of course, to blame the poor aircraft designer for bad aerodynamics in the design of his machines, but there were a good deal more practical limitations. Assuming that a highly efficient sailplane had a span loading of about 10 lb. per sq.ft., in order to achieve the same result in the latest Handley Page 42-seater, it would be necessary to have a wing span of 3,000 feet. Everyone concerned with practical aircraft design knew that there were specifications which did not always allow of the proper application of aerodynamic refinements. Dr. Lachmann asked what were the bending deflections measured in the air in bumpy weather on the high-span sailplanes.

Commenting upon the influence of sailplane design upon motor aircraft, he said it was not by accident that the designer of one of the most efficient German commercial airplanes, Messerschmidt, was formerly a designer of sailplanes, and he had incorporated in his latest designs all the characteristic features of the highly successful sailplanes, i.e., large span, tapered wings, and single-spar construction. These airplanes were considered to be highly efficient; he recalled that when Messerschmidt had commenced to apply his sailplane experience to commercial aircraft, many people in Germany had been very doubtful as to the outcome of it, but ultimately he had been successful. Dr. Lachmann expressed the belief that monoplanes of large span with tapered wings and single spar construction would be the future type for commercial purposes.

Mr. J. H. Payne: It seemed that in the sailplane wings of the mono-spar construction there were no drag forces of any sort. He understood that the main spar bore the lift forces and that the tube at the front bore the torque, and he asked if the main spar also bore the drag forces on the wing.

Mr. C. T. Cuss: Speaking as Chairman of the Wiltshire Light Aeroplane and Glider Club, and not as a technical authority on the design of gliders, he suggested that danger might arise through the partial success of any one type of glider having undue influence on other types. Having observed that in 1922 and 1929 the champion gliders of the world had come to grief, it had occurred to him that careful research was necessary with a view to reducing the resistance to gliding arising from the use of the usual types of ailerons, elevators and rudders. He recalled that about ten years ago he had had the good fortune to shoot a 5-cwt. porbeagle shark off the North Devon coast. The exquisite streamline speed form of it had made a most lasting impression on his mind. He asked Herr Lippisch if he considered that there were possibilities of reducing resistances and eddying from ailerons, elevators and rudder by using a flexible fuselage, wings and tail, all inflated and operated by pneumatic controls, which would take a bump without damage, and better than the very delicate plywood. He pointed out that the vertebra of the shark (of which he exhibited a model) had no bones in it; it was just cartilege and skin. He asked if there were prospects of developing a flexible fuselage on similar lines, i.e., having a vertebra through the center and an inflated fuselage around it. If that were so he would suggest that it might be possible, by pneumatic controls, gradually to curve the fuselage in any desired direction, still maintaining the streamline effect and in that way reducing resistance. There would also be a movable snout worked by controls, to assist turning. He also mentioned the fact that the shark referred to was covered with a slime, as the result of which resistance was reduced, and he asked what importance Herr Lippisch would attach to that fact. By giving the least shudder the shark could slip away at speed - and, of course, it was dependent upon speed for its existence.

Mr. Howard-Flanders (Associate Fellow) asked Herr Lippisch what was the torsional deflection of the spar in, say, 25 feet, of the large span sailplanes in flight. If a single spar was used, it was fairly obvious that the torsional resistance of the tip of the wing would be less than that at the root when in flight, and he would like to know what was the allowable deflection.

Mr. Ashwell-Cooke (Companion) asked for the opinion of Herr Lippisch on the use of slots on high efficiency sailplanes. Also, speaking as one who was connected with the London Club, which owned no less than three gliders of Herr Lippisch's design, he asked for information concerning any system that might be in use in Germany to ensure adequate maintenance of club-operated gliders.

Mr. W. O. Manning (Fellow): Referring to one of the diagrams which had been exhibited, he said it appeared that three-ply was shown as being used for the web of a spar. He felt sure that, on a spar of a power plane, three-ply would not be used in compression; possibly there was something slightly misleading in the drawing. With regard to gliding angles, and the suggestion that a farm wagon would roll down a gradient of 1:15 by itself, so that it had the equivalent of a gliding angle of 1:15, Mr. Manning said he believed there had been several aircraft built in this country having a gliding angle slightly better than that. He mentioned the matter in order to show that the aircraft designers in this country had not been altogether unmindful of the importance of reducing resistance. As well-known examples, he mentioned some of the gliders used for the Schneider Cup contest, in which the reduction of head resistance had been carried out quite effectively.

The high aspect ratios used could not be used in power-driven aircraft, not only because of the increase of weight but also because of the lack of rigidity in the wing development, and on those lines must therefore be confined to gliders.

Colonel the Master of Sempill (Past-President of the Royal Aeronautical Society) (Fellow): Those who were interested in motorless flying had been asking for some time past for information which Herr Lippisch's paper had now supplied. As showing how much the visit of Herr Lippisch to this country was appreciated from the scientific point of view, he mentioned that the Aeronautical Research Committee - the first committee of its kind to have been set up in any country - had invited Herr Lippisch to attend its meeting on February 3, and to give it the benefit of his advice. Further, Herr Lippisch was to visit Yeovil and had kindly consented to address that branch of the Royal Aeronautical Society on Monday, February 2. Anyone who had to grapple with the preparation of a lecture would realize the enormous amount of work involved, but if one had to prepare a lecture in one language, translate it into another, and convert all the figures of another standard of measurement, and prepare special slides, the labor involved would certainly be trebled. It would be impossible to find suitable words to express our gratitude; they must, in fact confess that they were ashamed of themselves as they realized that they had no one capable of dealing with this subject in a foreign language in the very clear way that the lecturer has done. Colonel the Master of Sempill also mentioned that Herr Lippisch had been greatly assisted in the preparation of the lecture by a student member of the Royal Aeronautical Society, Mr. B. S. Shenstone, who was studying at the Wasserkuppe in the Research Section under the direction of Herr Lippisch. He (the Master of Sempill) asked Herr Lippisch, on behalf of the Royal Aeronautical Society, the British Gliding Association, and all those interested in motorless flying in this country to take back to the Rhön-Rossitten Gesellschaft, and particularly to the President (Professor Georgii), the very cordial thanks for the considerable help afforded in the past and proffered for the future.

The vote of thanks was accorded with acclamation.

Air Commodore J. A. Chamier (Associate Fellow) (communicated): With reference to Herr Lippisch's lecture, he would like to ask if he has ever tried wings with flexible trailing edges?

He states in his lecture that in gusty winds there is a marked difference in performance between cantilever sailplanes, of which the wings were somewhat flexible, as compared with the stiff-winged braced type. He attributes this to the dynamic soaring effect and the beating of the air by flexibility in bending of the wings.

Is it not possible that the single spar wing has a considerably more flexible trailing edge than the double spar braced wing, and that it is to the superior efficiency of the flexible trailing edge that the improvement may be attributed?

He also wished to ask whether Herr Lippisch could tell them to what extent gliding has confirmed wind tunnel results? It is in this check of wind tunnel results, unhampered by such things as the influence of slipstream of propellers, that to his mind the greatest scientific value of gliding lies. The lecturer, he understood, designed some of the Göttingen wing sections, so it is almost certain that he must have been interested to make comparisons between free gliding and the wind tunnel.

Mr. Scott-Hall (Associate Fellow) (communicated): While at the Wasserkuppe he was singularly impressed by the magnitude of the deflections which take place at the wing tips of some of these very high aspect ratio sailplanes under gusty conditions. On at least one machine the wing tips could be seen with the naked eye deflecting when the aircraft was flying at close quarters, and indeed, he was informed that this inherent "springing" of the structure made the aircraft very comfortable to fly. Naturally the first thoughts that this sight produced were upon the likelihood of dangerous flutter conditions arising. Has serious trouble of this kind ever been experienced? While on the same subject, he was very interested in the flutter "acceptance" test carried out on all aircraft competing in the annual R.R.G. competitions, in which the wing tip is deflected by hand (the aircraft being stationary on the ground) and the oscillations per minute counted. He understood that if the oscillations were less than 120 per minute the aircraft was limited to flying in light winds. Is this figure correct?

Herr Lippisch mentions in his paper the good antispin effects of sweepback and twist on wings. What experience has he had with spinning on the ordinary types? It would seem very easy to get into a spin on one of these aircraft while cloud soaring, and he was given to understand at the Wasserkuppe that once these aircraft reach the stall they spin suddenly, due to the high lift wing sections commonly used. Has any difficulty ever been experienced in recovery?

Reply to Discussion

In answer to the Chairman.- The wing spoilers were tested on the two-seater of the Dresden Academical Flying Club, being inspired by wind tunnel tests made in Holland. The Dresden machine had 60 feet span and the wing spoilers were each about one foot long. The effect of the spoilers was very satisfactory. By their use, the normal (almost elliptical) lift distribution is disturbed, and the induced drag at high angles of attack very much increased. It should be noted, however, that the actual lift is affected to only a very small degree.

Mr. Gordon England.- A highly polished wing surface is of the utmost importance for the maximum lift. Even a dusty wing is noticeably inferior at low speeds. This is not only important in soaring planes, but also in power aircraft, especially when stretching a glide to make a forced landing field. Observations of bird flight in nature uphold Mr. England's views on plan form. In the case of the vulture, at low speeds it has a swept-forward plan form with a lift distribution fuller than elliptical. When flying normally, the plan form is practically straight and the lift distribution elliptical. In the case of high-speed flight, the plan form has sweepback and the lift distribution is flatter than elliptical, which is not unfavorable, as the induced drag in the high-speed flight case is of no importance. The main reason, however, for sweepback is for the sake of increased stability and manoeuverability.

Captain Latimer Needham.- Although only a factor of safety of 6 is demanded in the c.p. forward condition,, it usually occurs that in a carefully worked-out design the final factor is considerably greater. In the case of school gliders, the writer considers that a higher factor of safety is necessary, not because of air evolutions, but because of ground evolutions. Regarding the question about spar bending and the torsion nose, it must be remembered that plywood has a lower modulus of elasticity than the normal wood of the spar underneath. Therefore the plywood layer is not so highly stressed in bending as would at first be assumed. Of course the torsion nose can take up a certain amount of bending. It should be remembered, however, that in the case of maximum bending, the torsion is very small, and in the case of maximum torsion the bending is almost zero. The high tail loading of 31 lb. per sq.ft. is necessary because of the high terminal speed that can be reached by high performance sailplanes, because of their very low drag. The size of the tailplane is not fixed by the load but by the stability calculations, which are also demanded by the Technical Commission as one of the airworthiness conditions.

Captain Hill.- The longitudinal oscillations of the aircraft caused by the wing oscillations can certainly become very serious. Thus all wings which have a period on the ground in still air of less than 120 per minute, are given only a "limited" soaring certificate.

Captain Entwistle.- There have been no quantitative measurements made on dynamic soaring flight at full scale. Such measurements are especially difficult, as the structure of the air itself is very difficult to determine. As far as instruments are concerned, the sailplane is the best instrument for measuring upwinds when equipped with meteorograph, accelerometer and variometer, and air-speed indicator. The sinking speed of the sailplane is determined by barograph readings taken on a long glide out of the influence of upwinds after the sailplane has been towed to a great height (say, 6,000 to 10,000 feet). Also the use of weighted pilot balloons has been very satisfactory.

Squadron Leader T. England.- The movable tailplanes are much lighter, and with suitable gearing down are not too sensitive. The fixed tailplane is used in powered aircraft because the flying requirements demand that the aircraft fly "hands off." Regarding the "Zoegling," due to the very low C.G. and low speed, it is very difficult to make the ailerons and rudder sensitive. However, the most important control for the "ab initio" student is the elevator, and this has been made sensitive.

Mr. Dagnall.- A flat angle is recommended.

Dr. Lachmann.- There is considerable difference between the performance calculations for sailplanes and powered aircraft. A simple consideration leads to the conclusion that for a sailplane, sinking speed is of most importance. Sinking speed depends on "span squared loading" = $W^{1/2}/2s$. For an engined aircraft, the power required is of first importance, i.e., weight times sinking speed is the measure of quality, or power required is proportional to $W^{1-1/2}/2s$. As the span affects the weight of the aircraft considerably, it is easy to understand that the "span squared loading" of powered aircraft must be higher than for sailplanes.

In spite of this, I am of the opinion that a decrease of the span loading in modern aircraft would give better performance, which is shown in practice in the Messerschmidt commercial monoplanes.

Mr. J. H. Payne.- Under normal flying conditions, no drag is caused by the wing relative to the chord axis, in sailing and gliding. The torsion nose takes up the thrusts under other conditions.

Mr. C. T. Cuss.- No considerable decrease in drag is to be expected by using a flexible fuselage. The control surfaces could, however, be improved by flexibility and this was also tried during the first years of soaring flight. Due to practical and technical difficulties, the further use of flexible control surfaces was given up. In my opinion, the same difficulties would occur with attempts to use pneumatic flexible fuselage and wings. Even though there might be an increase in safety, the pilot would probably get heart failure, due to the strenuous exercise necessitated by having to pump up every puncture or blow-out, or make a forced landing. But joking aside, it may be stated that there have already been patent applications for wings and fuselages of this type. Although it is admitted that the slimy coat certainly lessens the water resistance of a body, the most important matter in decreasing air resistance is to make the surface as smooth and clean as possible.

Mr. Howard Flanders.- In normal flight the torsional deflection of the spars of high performance cantilever sailplanes is usually not more than 1 or 2 degrees at the wing tips. Although in engined aircraft a limit of $3\frac{1}{2}$ degrees is given, there are no limits with sailplanes, for it would be impossible to build a wing of reasonable weight having an angle of torsional deflection as small as $3\frac{1}{2}$ degrees in the diving flight condition. On the other hand, this deflection is not dangerous and has a stabilizing effect if the torsional axis lies forward of the center of pressure.

Mr. Ashwell Cooke.- From my point of view, the addition of slots to a high-performance sailplane would be of little value, for in spite of the most careful design they would probably add a certain amount of parasite drag, and increase the inertia of wings which are already rather heavy. However, flight tests with slots are to be carried out at our Institute in order to test them thoroughly on sailplanes. This has been made possible by the very friendly cooperation of Handley Page, Limited. In Germany there exists the system of construction inspectors which are licensed by the R.R.G., and almost all clubs have such an inspector among the members. The inspector is responsible for all repairs and airworthiness. In the absence of the inspector, the manager of flying of the club takes control.

Mr. Manning.- I am very glad to hear that several English aircraft have gliding angles of over 1:15. The very careful design of the Schneider Trophy machines has awakened the admiration of the world, and the lecturer counts himself among the admirers. The Schneider Trophy machines give a practical proof of the effect of streamlining on performance, and this streamlining should be applied also to normal aircraft with equal care. Even to-day there are many designers who do not seem to realize that a number of details not carefully carried out when added together make a very large drag. It must not be thought that these remarks are meant to be especially applicable to English aircraft, as they are applicable to the aircraft of all countries. The drawing of the box spar of the "Kakadu" shows three-ply used as spar web, as the Munich group were not able to make special plywood out of veneer with mostly longitudinal grain. This matter of producing a special plywood was one of the reasons why this structural method, as mentioned in the lecture, was not continued. If such a special plywood could be suitably produced, thin-walled spars such as those used by Rohrbach could be successfully built of wood. Regarding the matter of the high aspect ratios, the answer to Dr. Lachmann may be referred to.

Air Commodore Chamier.- Although the lecturer has not built wings with flexible trailing edges, he agrees with Air Commodore Chamier regarding the value of the flexible trailing edge. Regarding the question on flight and wind-tunnel tests, these fulfill quite different purposes. The free flight tests of one-third to one-quarter scale models were carried out more as stability tests than for any other reason, and no measurements were made. Free flight testing of stability of some of the rather radical types considered at the Wasserkuppe was of great importance, as even the most careful calculations need practical checks.

Mr. Scott-Hall.- The figure of 120 per minute is correct. The springing of the cantilever wings certainly aids the machines in soaring, having a wing-beat effect, causing a certain amount of dynamic soaring. Of course the springing helps to wash out the effect of bumps. In the early days there was a certain amount of trouble due to flutter, but this has been successfully overcome by the flutter acceptance test. In the case of ordinary large span sailplanes in which the whole wing stalls at approximately the same angle, a steep spiral commences easily and often develops into a spin. They come out of the spin normally. The only thing to note in practice is not to use too much bank at low speeds, as the great span makes the lift on the upper wing increase rapidly, and so the bank increases, developing into the spiral. At such times the aileron control will not bring the machine out of the bank. The tendency of the machine must be followed, and the machine brought out of the dive in the ordinary manner after sufficient speed is gained.

Colonel the Master of Sempill.- I thank the Master of Sempill for his extremely kind words which he has expressed on behalf of the R.Ae.S. and the B.G.A. I will not deny that the preparation of the lecture was rather difficult. But these difficulties were very small compared to the recognition which motorless flight has won by means of the lecture. From my point of view, it was to be taken for granted that the lecture must include everything of importance which has been achieved in the last ten years' development, and that these things be handed over complete without hesitation. I believe that it is obvious, that among friends one must always be open and helpful, as it is only on this basis of mutual effort and working that anything of value may be brought forth.

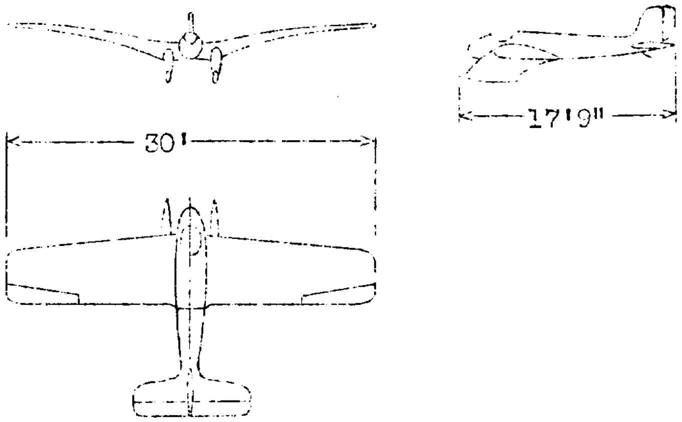


Fig.1 Schwarzer Teufel.Empty weight,133 lb.Wing area,161 sq.ft.

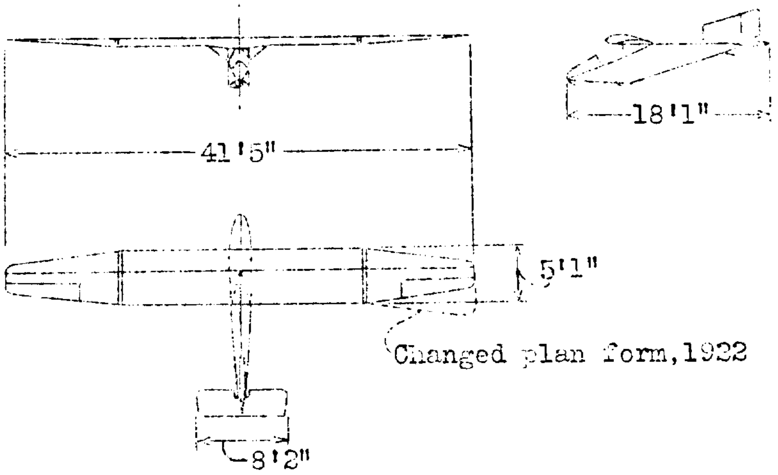


Fig.2 Vampyr.Empty weight,287 lb.Wing area,172 sq.ft.

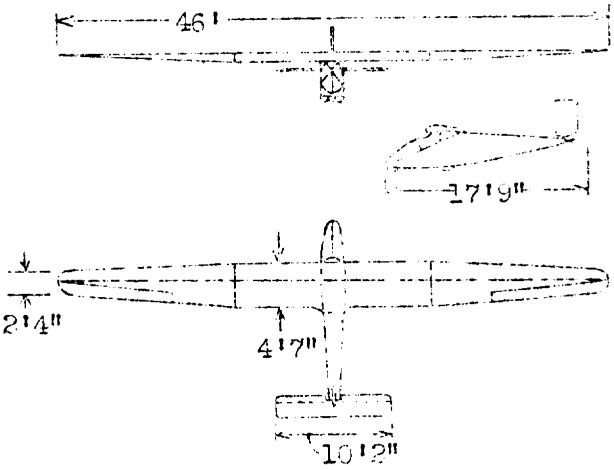


Fig.4 Strolch(1923).Empty weight,183 lb.Wing area,151 sq.ft.

Fig.3 Espenlaub's glider.

Fig.6 Roemryke-Berge.

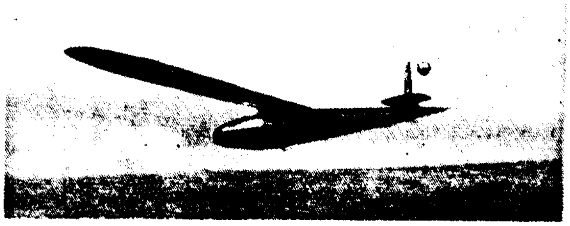


Fig.8 Westpreussen.

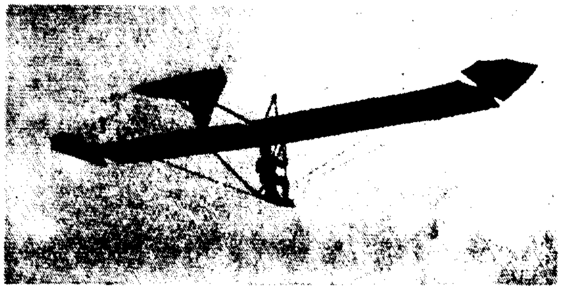


Fig.15 F.Schulz(1922).

Fig.14 München(1921).

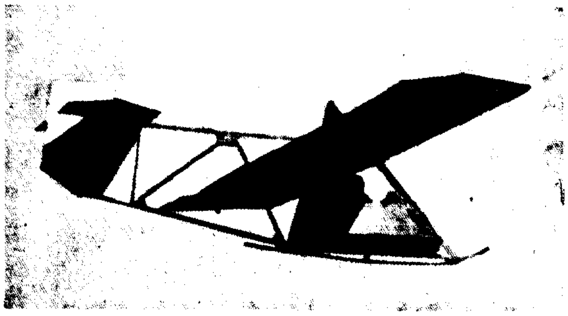


Fig.17 Djävlar annama(1923)

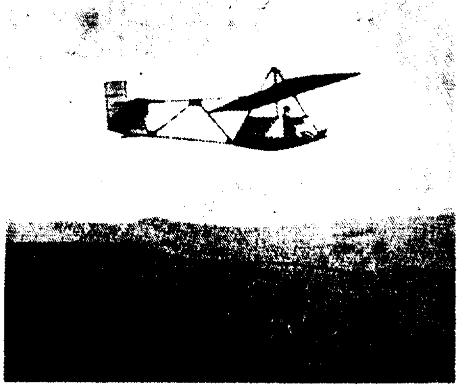


Fig.16 An early trainer, the Pegasus(1925).

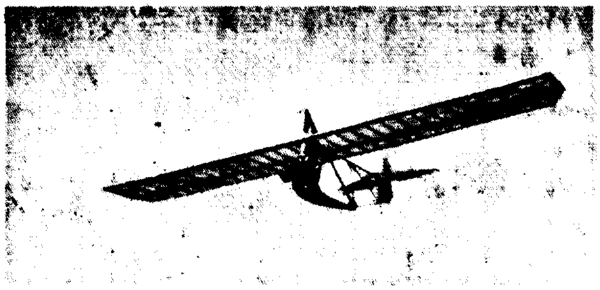


Fig.18 Zoegling.

Fig.20 Bremen.

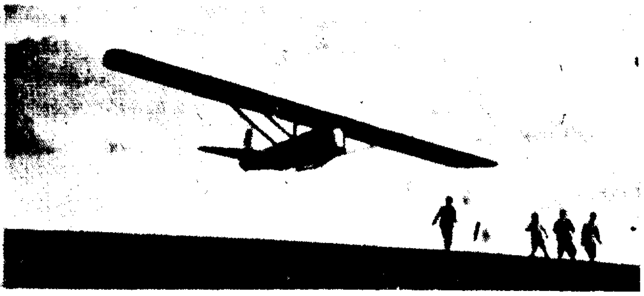


Fig.21 Prüefling.

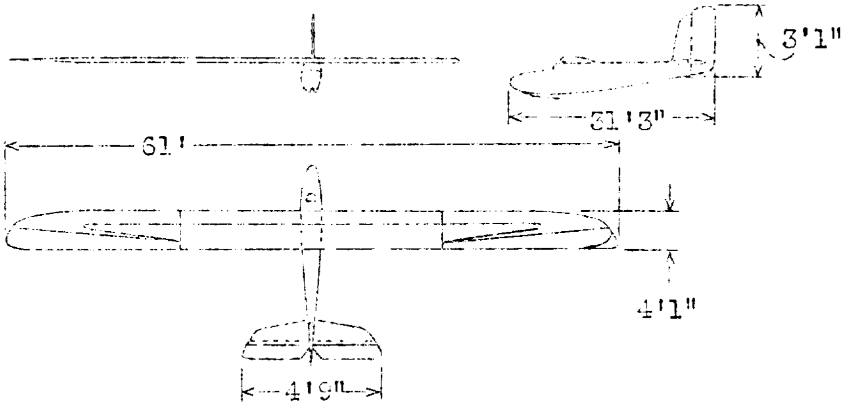


Fig.5 Konsul,Darmstadt.Empty weight,418 lb.Wing area,232 sq.ft.

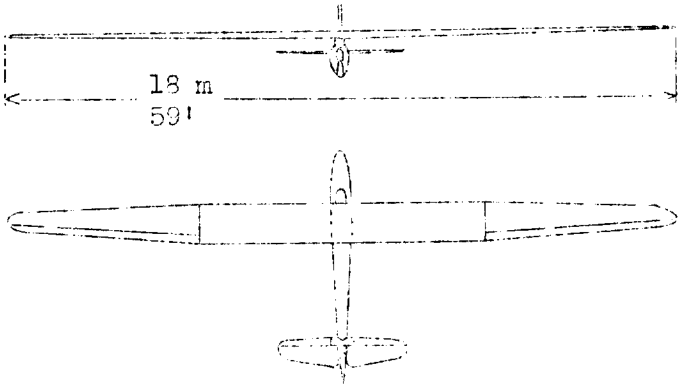


Fig.7 Darmstadt II.Aspect ratio,19.6.Wing area 182 sq.ft.
Weight,253 lb.

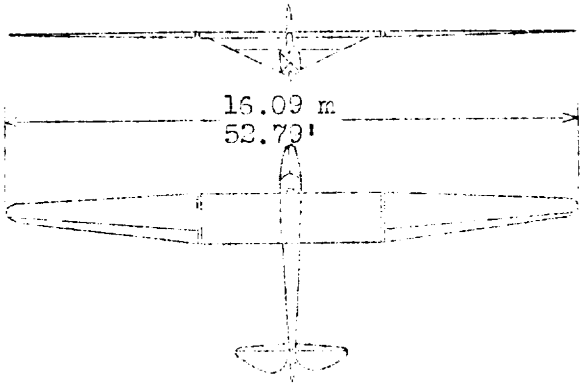


Fig.9 Rhöngeist(Professor).Aspect ratio,13.9 Wing area,203 sq.ft.
Weight,334 lb.

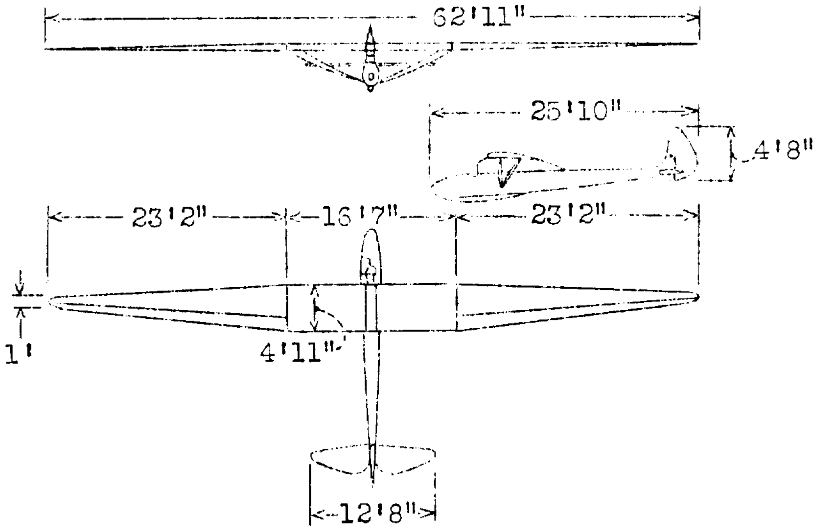


Fig.10 Wien. Empty weight, 353 lb. Aspect ratio, 20

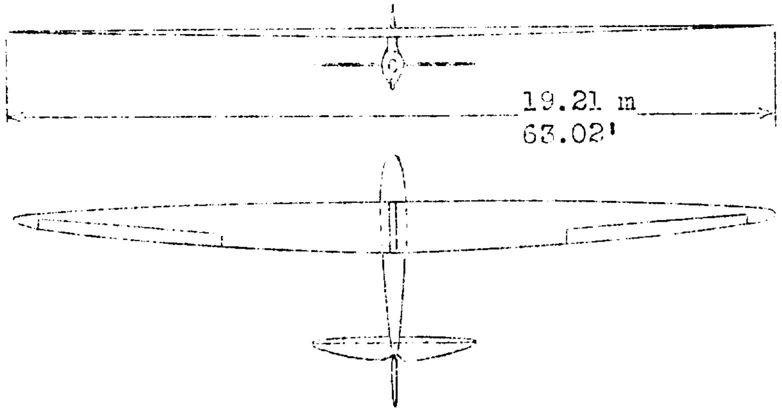
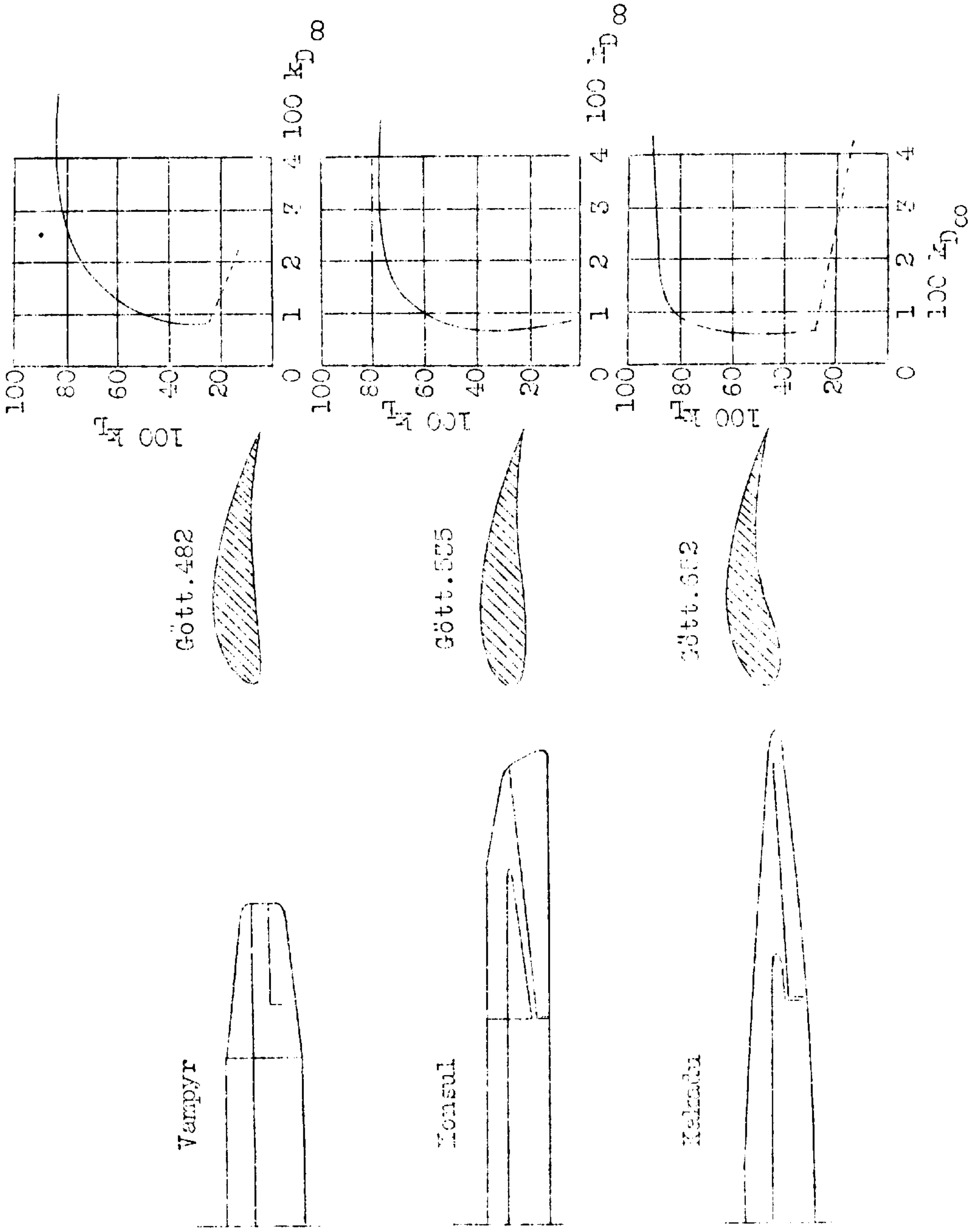


Fig.11 Kakadu. Aspect ratio 21. Wing area, 190 sq.ft. Weight, 298 lb.


100 k_D
8
4
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2
1
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Gött.535
Gött.532
Vampyr
Konsul
Kakadu

Fig.12

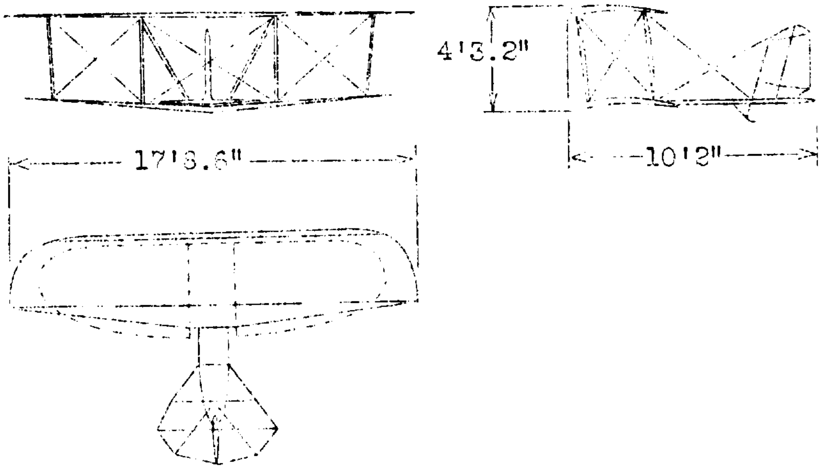


Fig.13 Pelzner 1920-1921.Empty weight,20 lb.and development to seat-type glider.

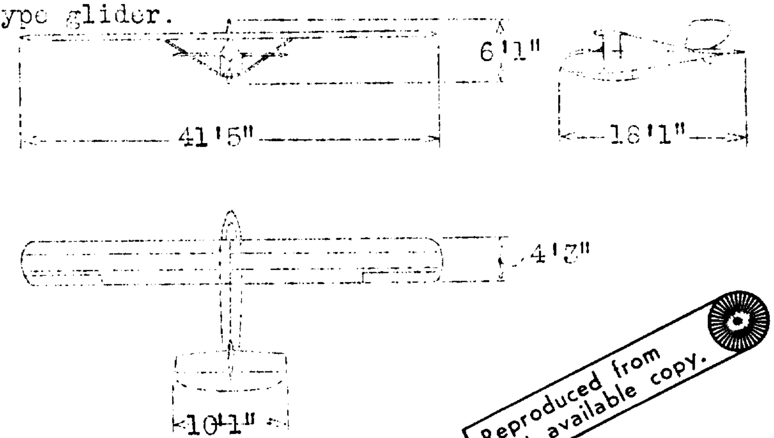


Fig.19 Edith,Darmstadt.

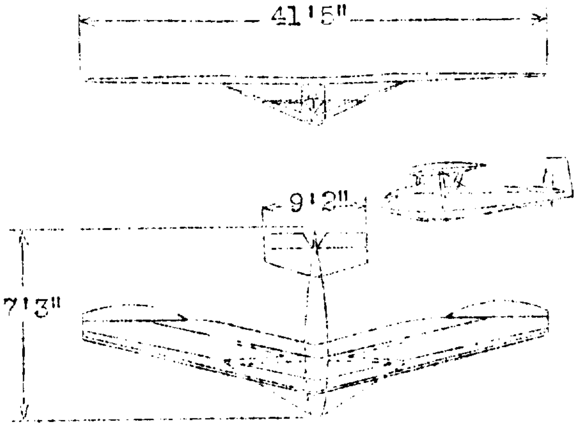


Fig.22 Falke(1930).R.R.G.

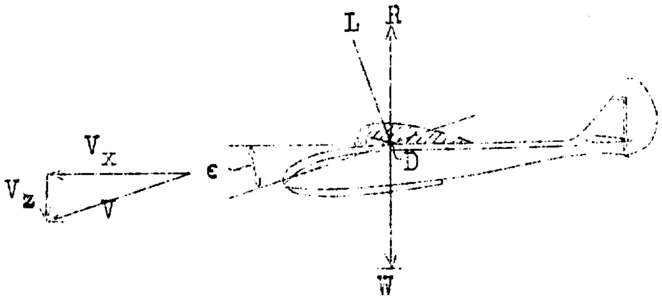


Fig.23

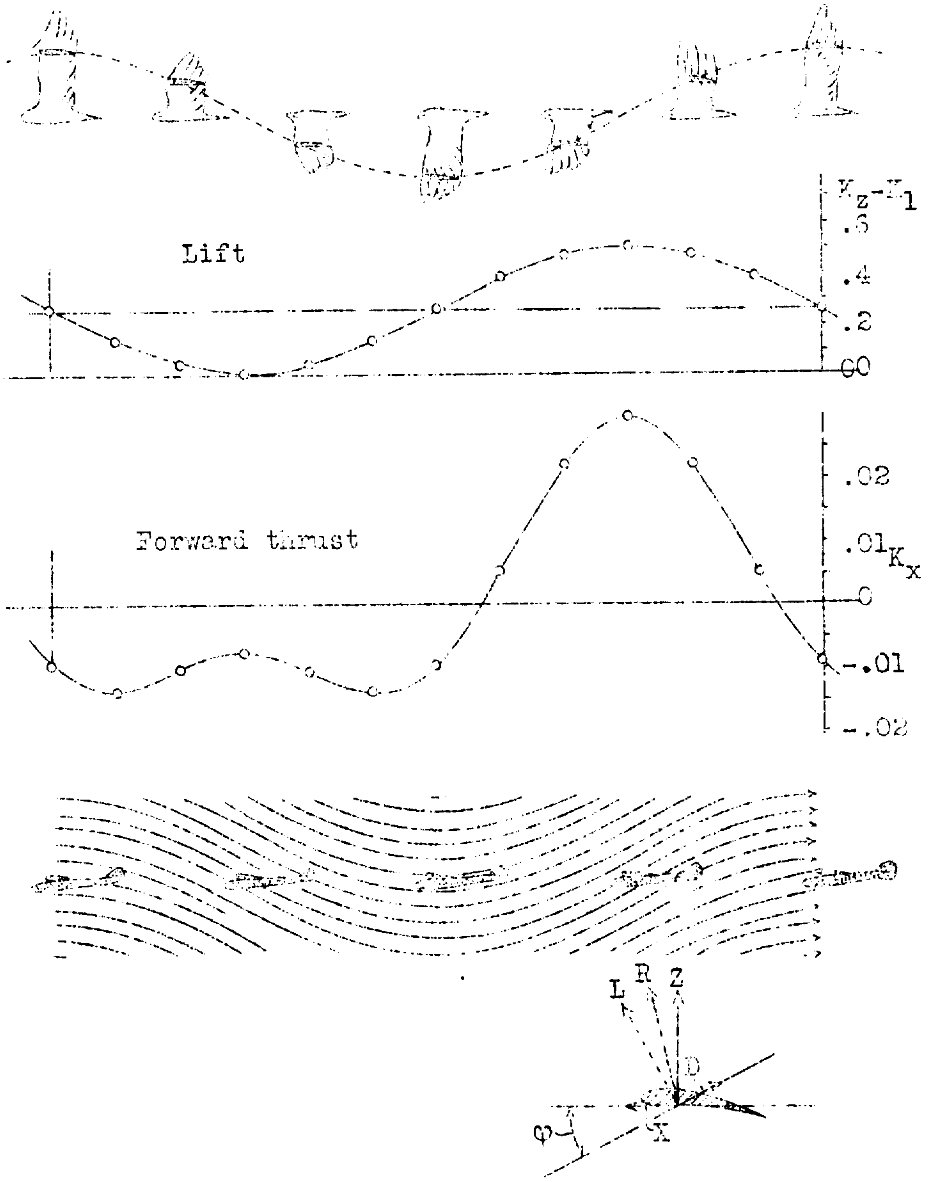
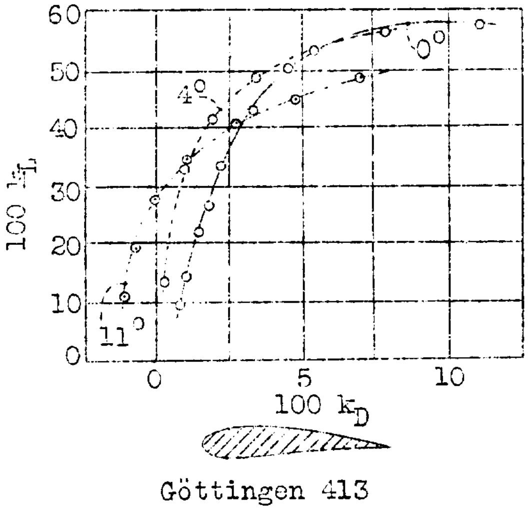


Fig.24 Dynamic soaring flight as inversion of flapping flight.



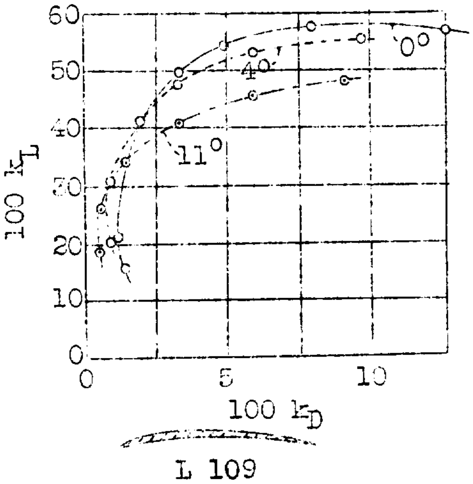
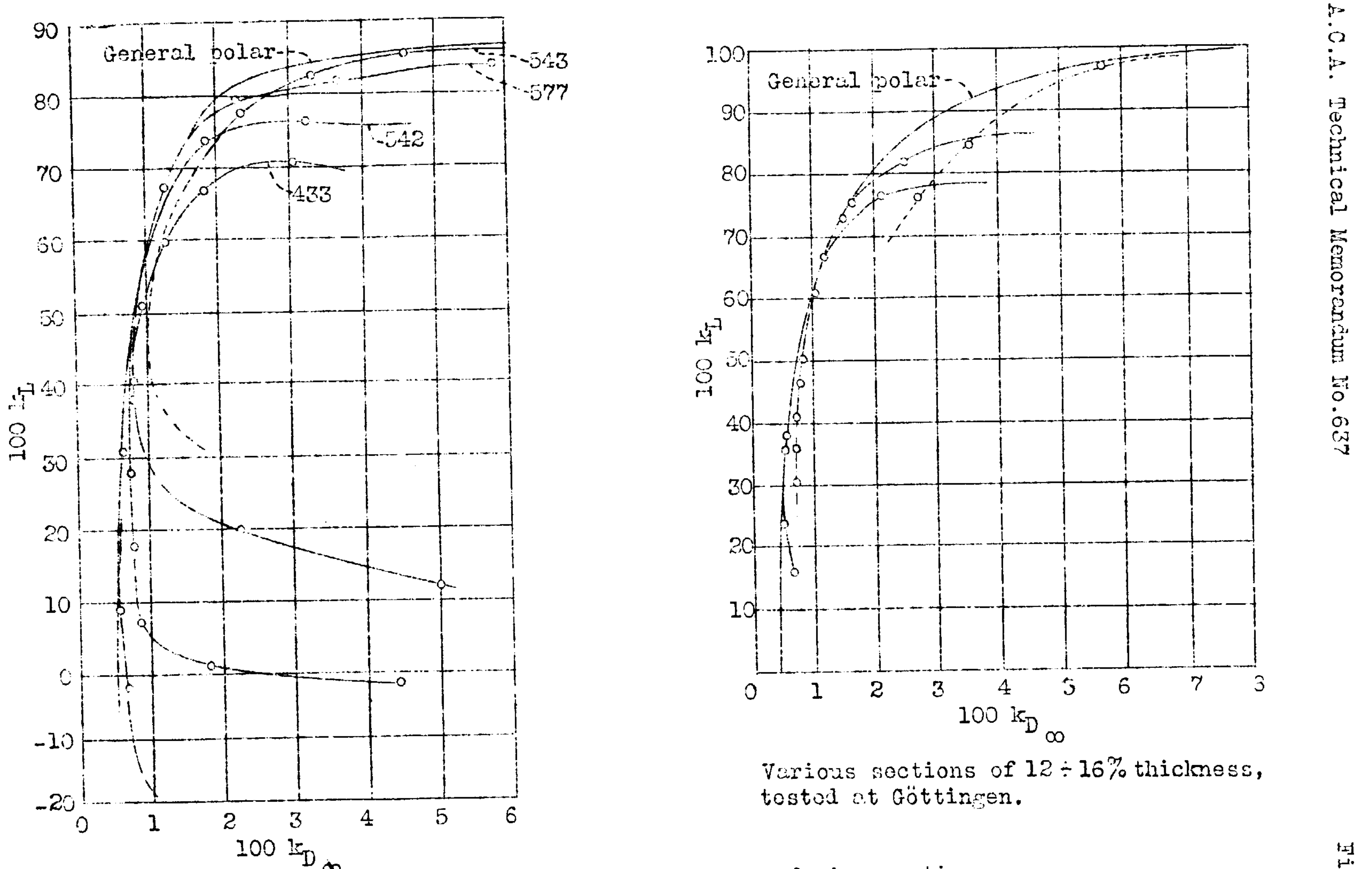


Fig.25 The influence of vertical wind oscillation from tests of the Aerodynamic Laboratory,Techn.Hochschule,Wien.



Joukowsky sections with various camber and constant thickness. Tested at Göttingen.

Various sections of 12 ÷ 16% thickness, tested at Göttingen.

Fig.26 Choice of wing section.

Graphs for calculating sinking speed.

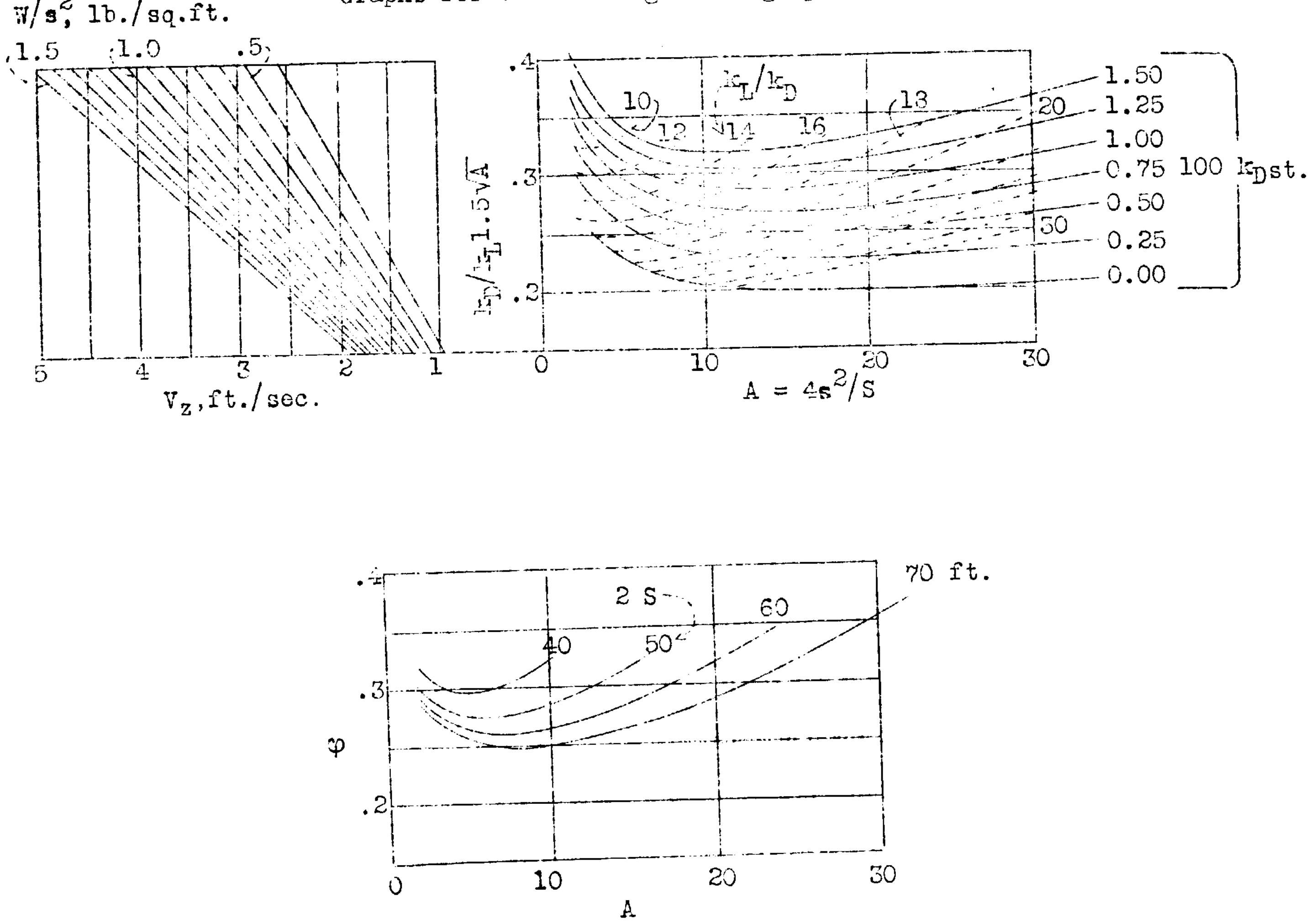
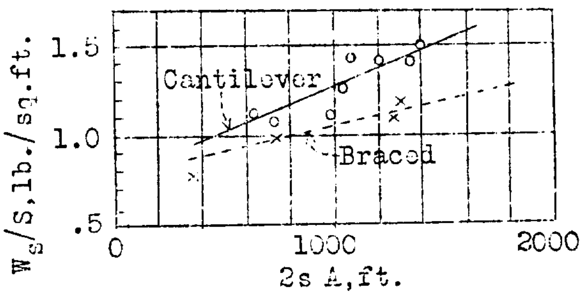
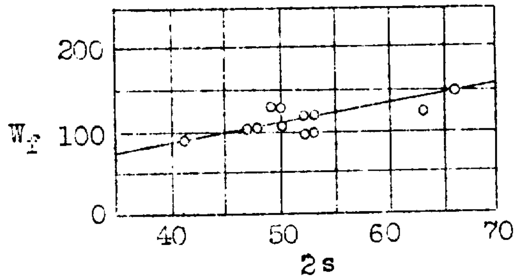


Fig.27 Calculated for a structural drag surface of 4.6 sq.ft.



Weight of wing per unit wing area.



Weight of fuselage and tail plane.

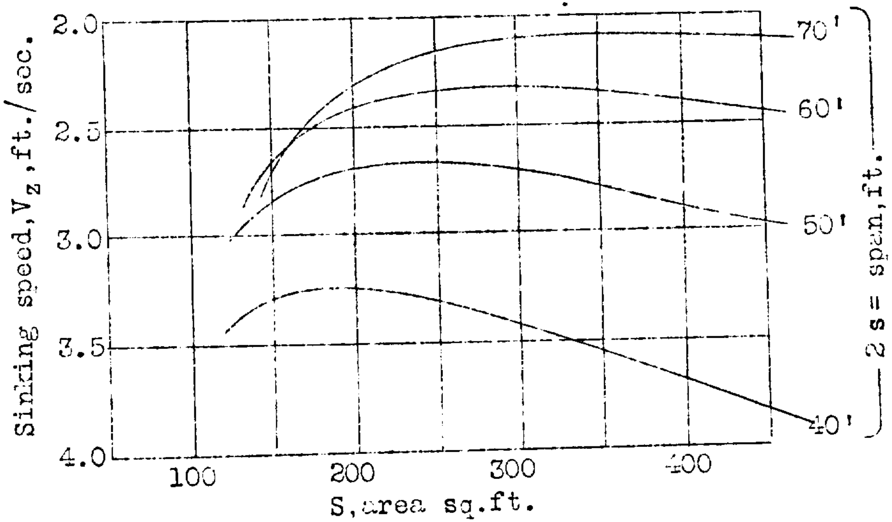


Fig.28 Calculated for cantilever sailplanes with reduced structural drag surface of 4.6 sq.ft.

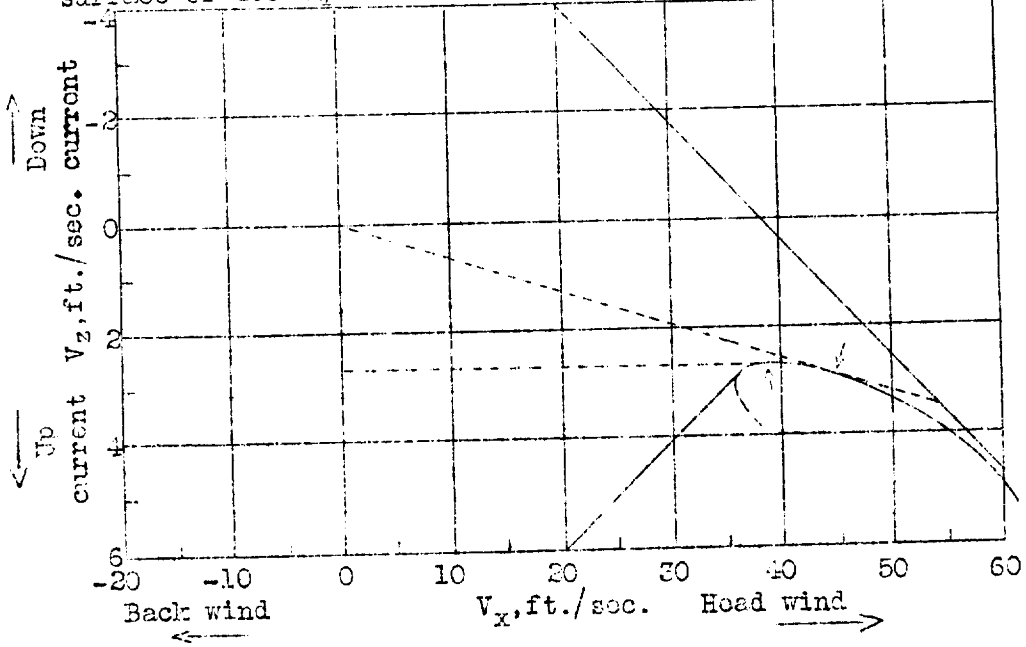


Fig.29 Diagram of velocities. Calculated for a sailplane of section Göttingen 535. Span, 50 ft. Area, 208 sq.ft. Aspect ratio, 12. Total weight, 485 lb. (cantilever). Reduced structural drag surface = 4.6 sq.ft.

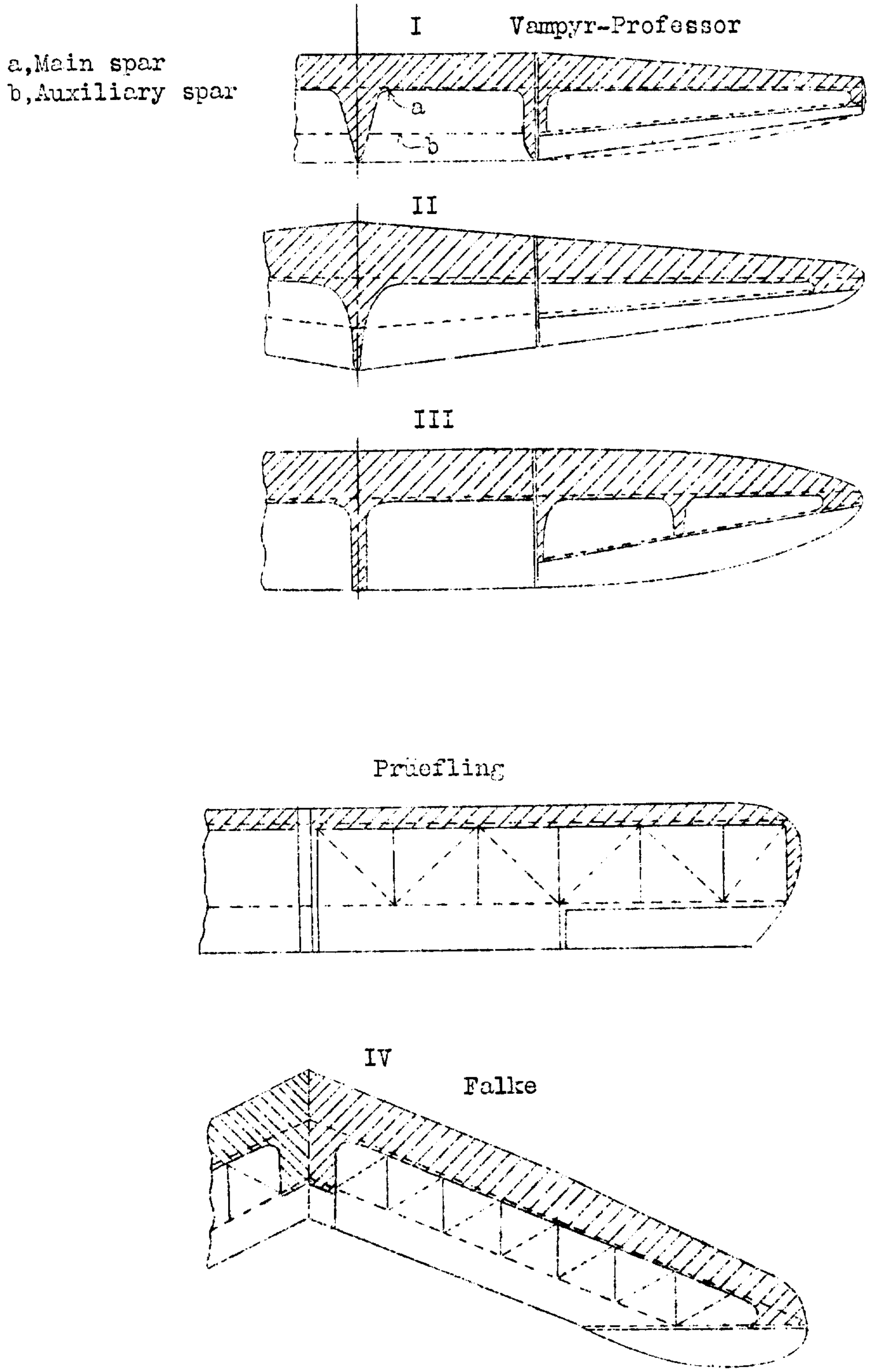


Fig.30 Different wing forms.

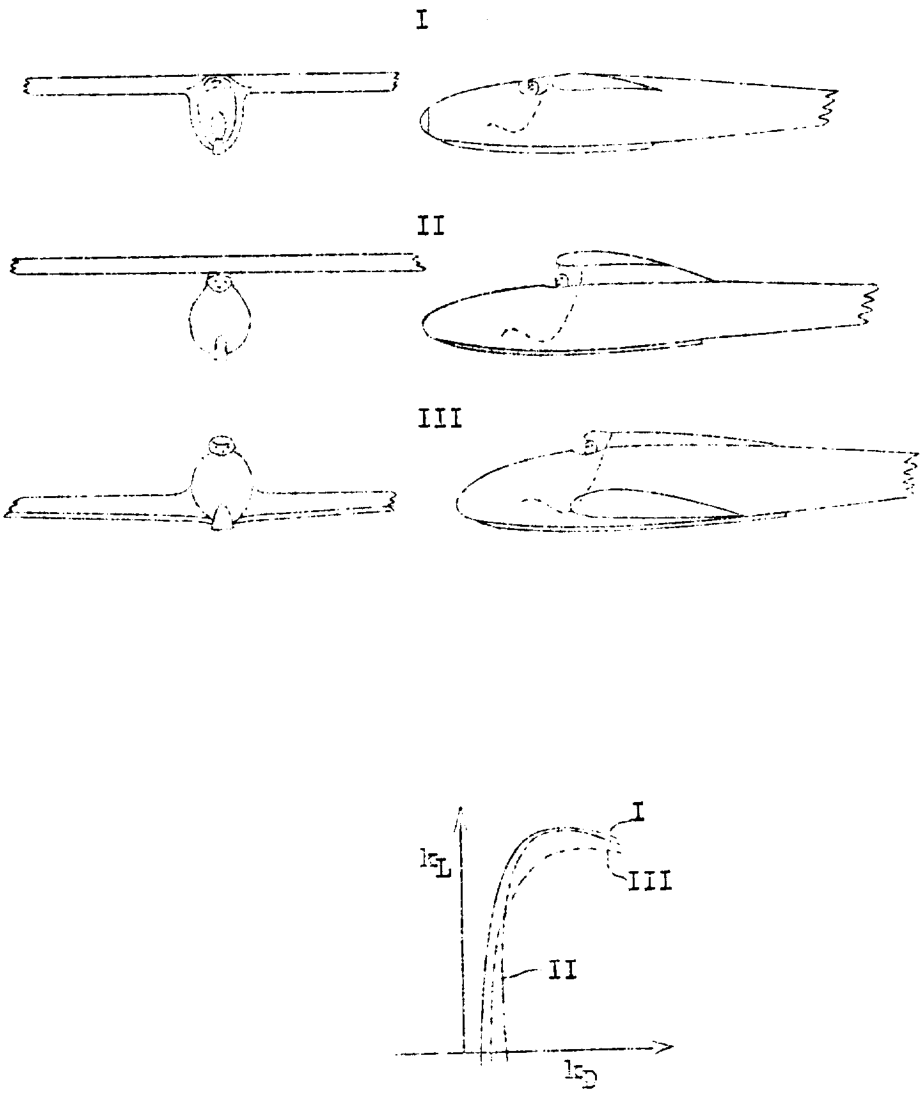
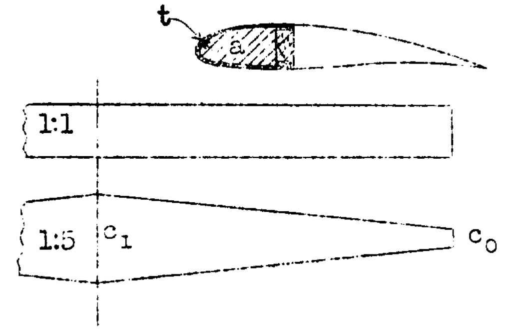
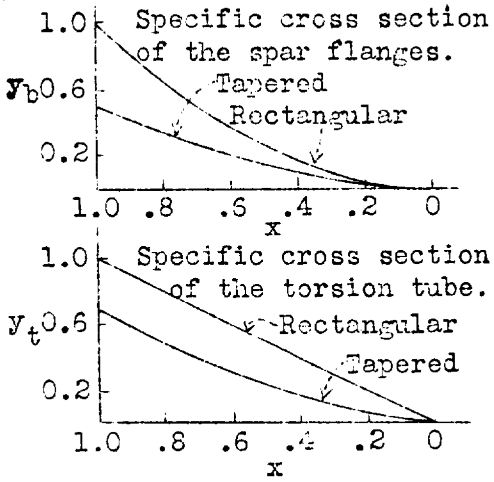
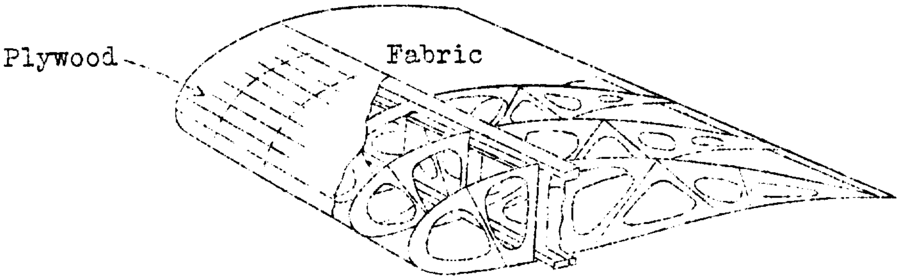


Fig.31 Wing fuselage connection.







Vampyr structure

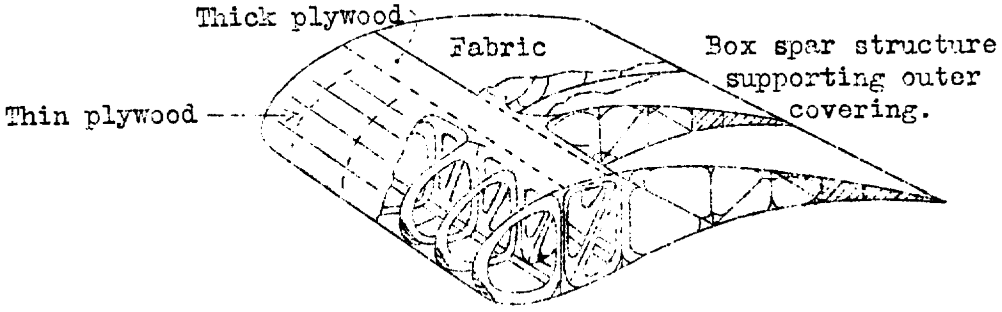
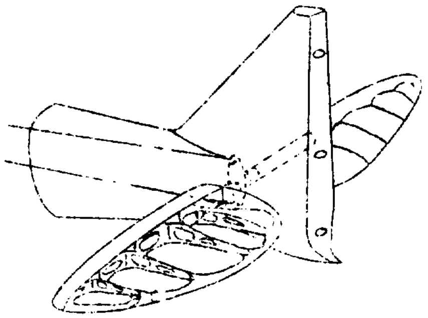
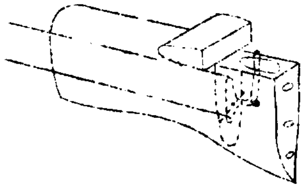


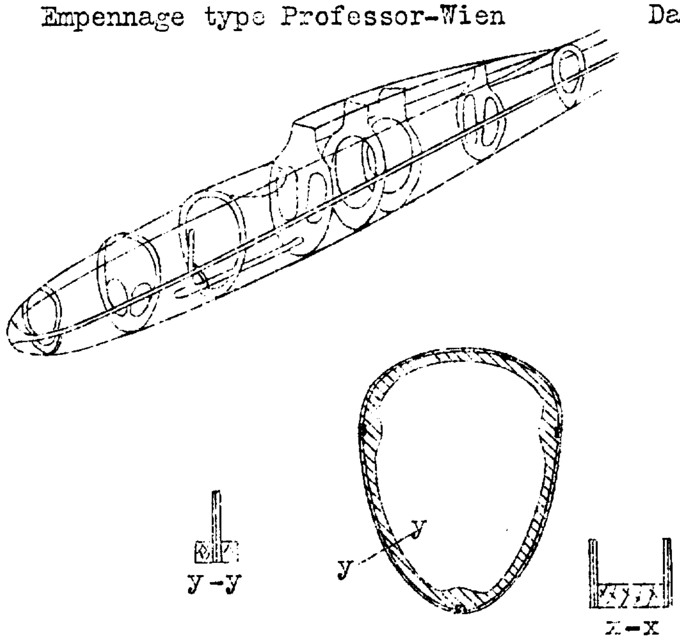
Fig.32



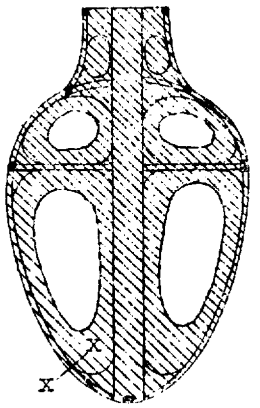
Empennage type Professor-Wien



Darmstadt type



Secondary frame



Main frame

Fuselage frame work of high performance sailplanes.

Fig.33

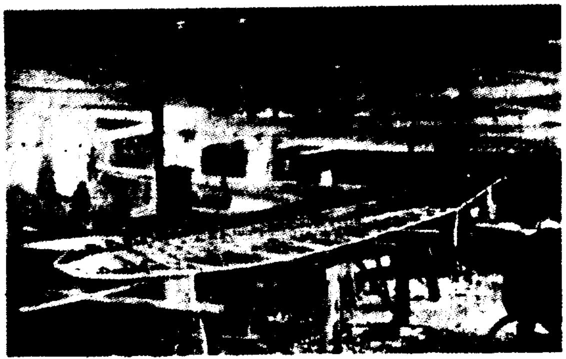


Fig.34 Wing construction, "Fafnir".

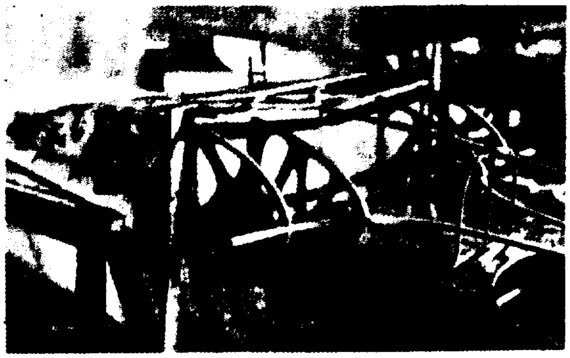


Fig.35 Wing fuselage connection and center section with fittings, "Fafnir".

Fig.36 Fuselage frame,

Fig.37 View of pilots seats and controls, "Fafnir".

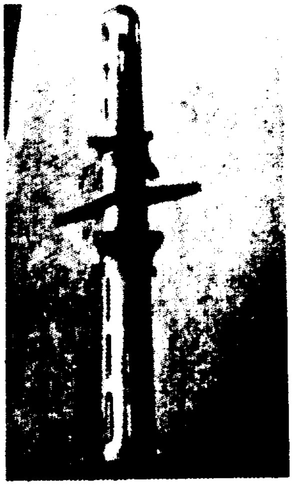


Fig.38 Elevator hinge tube, "Professor".

Fig.39 Empennage, "Luftikus".

Fig.40 Fuselage construction, "Prüefling".

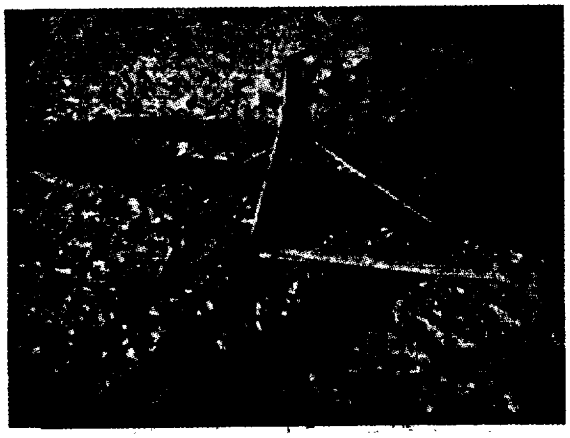


Fig.41 Uncovered empennage, "Pruefling" two-seater.

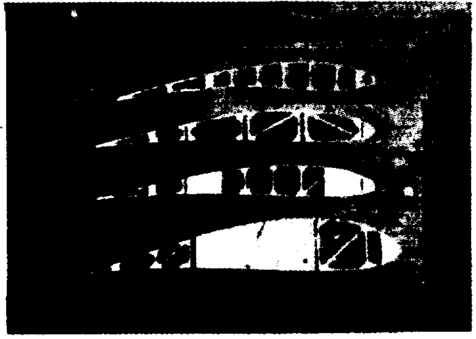


Fig.42 Wing ribs.

The ultimate
Fig.43 Lippisch's all-wing passenger-carrying airplane.

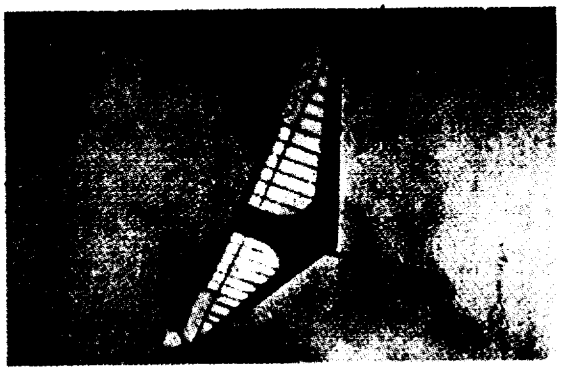


Fig.44 The first stage, a model in flight.

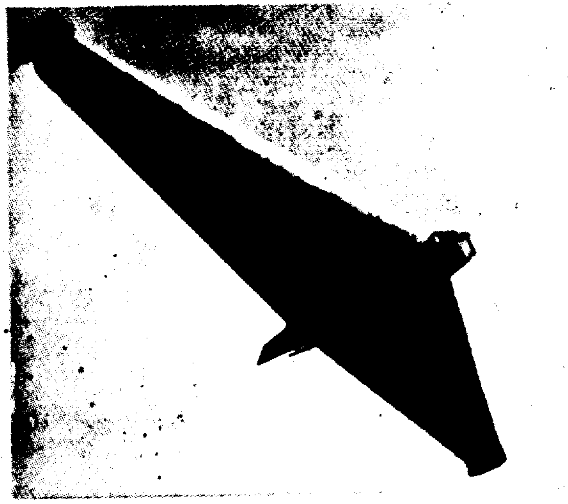


Fig.45 The second stage, the full size two-seat glider.

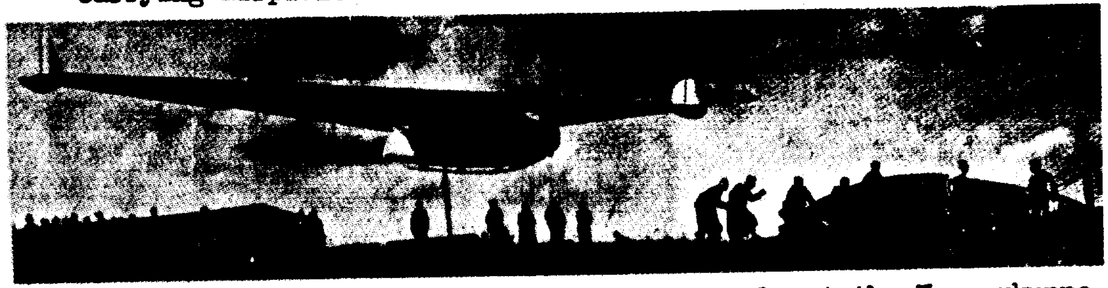


Fig.46 Lippisch's tailless glider does its trials at the Wasserkuppe.