TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 780

GLIDER DEVELOPMENT IN GERMANY

A Technical Survey of Progress in Design in Germany Since 1922

By B. S. Shenstone and S. Scott-Hall

Aircraft Engineering, October 1935

Washington
November 1935

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM NO. 780

GLIDER DEVELOPMENT IN GERMANY*

A Technical Survey of Progress in Design in Germany since 1922

By B. S. Shenstone and S. Scott-Hall

In 1922 the world was startled by the announcement of a motorless flight of one hour's duration made at the Wasserkuppe by Martens. The machine on which this flight was carried out was the "Vampyr", the first true glider, and the forerunner of all the types which have been designed in the ensuing years, whose development has made possible the achievement in the soaring competitions of 1935, when four pilots flew on the same day from the Wasserkuppe to Brünn, a distance of approximately 310 miles at an average speed of 40 miles per hour.

What are the fundamental features of the glider, and what has been the course of its development during these thirteen years of activity in motorless flight?

The designer of the "Vampyr", Professor Madelung, realized that in order to maintain flight in the upcurrents off the hills in the Rhön, a low sinking speed for this glider was essential. This rather obvious fact had been appreciated by the constructors of many previous gliders, but in spite of this, these had failed to produce aircraft capable of soaring flight. The reason for this failure was due to the fact that no logical thought had been applied to the problem. Two solutions lay open, and the fact that the designer of the "Vampyr" chose the one he did, not only made soaring flight in topographical upcurrents possible, but also made available a glider which, with but relatively slight modifications, was capable of utilizing thermal and other types of upcurrent for long-distance flights. The second and more limited solution was fortunately not developed until later.

The two solutions are indicated by the following expressions for sinking speed (at sea level):

---

*From Aircraft Engineering, October 1935.

$$V_s = 20.6 \frac{k_D}{k_L^{3/2}} \sqrt{\frac{W}{S}} \text{ ft./sec.}$$

and

$$V_s = 10.3 \sqrt{\frac{W}{s^2}} \frac{k_D}{k_L^{3/2}} \sqrt{A} \text{ ft./sec.}$$

where W = weight (lb.)

S = wing area (sq.ft.)

s = semispan (ft.)

A = aspect ratio

As can be seen from these, the two paths leading to soaring flight are firstly reduction of wing loading, and secondly an increase of span.

The first of these is achieved by increasing wing area, at the same time keeping down weight by using the most economical form of structure, i.e., external bracing. This is perhaps the more obvious solution, but is also by far the less useful. The second, that adopted in the design of the "Vampyr", was obtained by a considerable increase in wing span, as compared with any aircraft previously designed.

The aspect ratio of the "Vampyr" was of the order of 10, and this change from gliders previously built, produced immediate results in the duration of soaring flight. Referring to the general arrangement drawings shown in figure 1, it will be seen that not only in the absolute value of aspect ratio, but also in the plan form selected, was an effort made to keep the induced drag as low as possible. Parasitic drag also received unusual attention in that the landing gear, consisting of three leather balloon tires, was almost entirely withdrawn into the fuselage - a complete innovation at this date; a strong effort was made to enclose the pilot, and notwithstanding the span, a cantilever wing was employed. A structural innovation was the use of a single spar and stressed skin nose. This allowed a very accurate shape to be given to the leading section of the wing, and not only given initially, but retained during the subsequent life of the glider. The importance of this from the point of view of aerodynamic performance will be readily appreciated at the present time.

Such was the forerunner of high performance gliders. After development by the Hannover Group it was modified by Espenlaub rather daringly, but not very thoughtfully, and the development continued in the hands of the Darmstadt Group.

As a result of attempting to build too lightly, considerable trouble was experienced on account of the extreme flexibility of the wings - several structural failures in flight occurring (Weltensegler, Strolch, Pelikan). As a result of these failures a semiempirical rule, to safeguard against this type of breakage, was evolved. This rule, which is still in force, lays down that the natural period of oscillation of a wing in still air shall not be less than 120 per minute. An aircraft is tested by deflecting a wing tip and timing the ensuing oscillations. Although this rule is crude, it has been found to give satisfactory results since its introduction, and even up to the present date no further safeguard either in the form of stiffness calculations or test has been found necessary. In designing to comply with this requirement, constructors rely entirely on past experience. This would imply a definite handicap in the direction of reduction of structural weight.

The next important contribution came from the Group at Darmstadt, and consisted of the development of the elliptical wing. The "Darmstadt I" was characterized by a cantilever wing having an aspect ratio of 16 set upon a narrow cabane the width of a man's head. The cabane was built up from an oval section fuselage of good streamline form. The landing gear by this time had become a simple ski-like skid mounted on rubber shock absorbers. The intrinsic simplicity of the Darmstadt design proved highly successful, as is indicated by the 37-mile flight by Nehring in 1927, which stood as a record at this period. It was not at first realized, however, that the aircraft represented in certain aspects an ideal, and an attempt to improve the design by an increase of span was entirely unfruitful, the aerodynamic improvement being neutralized by the increase in weight involved by this modification.

This failure led to the conclusion that the elliptical cantilever wing had reached its limit of development and Lippisch in the famous "Professor" and "Wien" types, reintroduced bracing in a refined form by the use of a semicantilever wing supported by V struts. In this way the span was increased without the corresponding increase in weight previously met with. The aspect ratio of the "Wien" was 20 (fig. 2). In these aircraft the wing was raised farther from the body in order to give the wing struts an efficient angle, and also to obviate the interference of the pilot's head with the wings. An attempt to counteract the drag of the struts was made by reducing the wing thickness over the center section. A reversion to the straight taper for the outer wings enabled yet another saving in weight to be made. The performances of the "Wien" in the hands of Kronfeld more than proved that these alterations were justified. Of them, the outstanding flights were - 93 miles in 1929 and 102 miles in 1930.

Up to the present time all the gliders had suffered from one outstanding defect - the lack of rolling and yawing maneuverability. This made itself felt detrimentally when soaring in upcurrents of limited extent, as it was found impossible to keep within the boundaries of the rising air. When steeply banked turns were attempted, the slow recovery incurred considerable loss in height. Consequently, as is well known, the turning technique for gliders at this time insisted on the use of a very flat wide turn.

Realizing this limitation, Lippisch set himself the task of producing a glider of improved maneuverability and at the same time of reduced drag. Rolling maneuverability was improved by three definite steps:

(1) The rolling inertia of the aircraft was reduced by heavy taper of the wings, and by mounting them directly on to the fuselage, thus concentrating the wing weight nearer to the center of gravity of the glider. In this connection it should be pointed out that the weight of the wings of a glider is approximately 40 percent of the total flying weight, whereas the corresponding figure for a power aircraft is of the order of 15 percent. The importance of this step in the case of a glider can thus be appreciated.

(2) A large aerodynamic twist (about 12°) was applied to the wing by a systematic variation of section, thus giving a sufficiently reduced incidence at the tips to guarantee that premature stalling in the neighborhood of the ailerons did not take place. The lack of aileron effectiveness at slow speeds due to this cause had been a large factor in the poor maneuverability of previous gliders.

(3) Owing to the increased taper of the wings, and also to the fact that the chord of the ailerons was increased at the tips and reduced at the inboard ends, the percentage of the chord occupied by these controls, and thus their rolling moments were greatly increased without a corresponding increase of control.

The large span coupled with the fact that the wings now sprang from the body itself necessitated some form of dihedral to give tip-ground clearance. The two most obvious forms were either a constant dihedral or a gull wing. The latter was chosen in the hope that rolling maneuverability and directional stability would benefit.

Yawing maneuverability was improved by lengthening of the tail arm and at the same time by a reduction of the depth of the fusèlage to an absolute minimum, concentrating the fin area in the rudder. The maneuverability about the yaw axis was also benefitted by the reduction of inertia indicated above.

In passing, it should be mentioned that the pitching maneuverability of sailplanes or gliders of any form is always good owing to the natural concentration of weight in these aircraft near the pitching axis. Thus this characteristic required no special attention in the design of the "Fafnir", as the new glider was called (fig. 3).

It was realized that the lowering of the wing might possibly greatly increase interference drag, due mainly to the proximity of the pilot's head to the leading edge. The obvious step here was to enclose the cockpit completely, and this was done, fairing the cover into the wing. In doing this, however, an aerodynamic error was made. The cover over the pilot's head was kept as narrow as possible in order to affect little of the nose of the wing, and a sudden increase in width to accommodate the pilot's shoulders occurred just below the leading edge. Although this junction was carefully faired, flight tests showed that something was seriously amiss with regard to resistance characteristics. This junction was suspected of being the cause and the head fairing was broadened to the full width of the fuselage. This had the desired effect and flight results were improved immensely.

As had been hoped, the maneuverability of the glider proved to be far superior to that of any previously built, and steep turns could be made without noticeable loss of height. Although this maneuverability was intended to aid "topographical" soaring, it was later found of inestimable value in the exploration of thermal upcurrents, about which more will be said later.

The performances of "Fafnir I" in the hands of Groenhoff were outstanding. Of these, perhaps the best to mention was the flight of 170 miles in the spring of 1931, from Munich to Kaaden, at a point-to-point speed of about 20 miles per hour, by the use of the vertical air currents of thunderstorms. This flight brought out the practical value of the enclosed cockpit since heavy hail was encountered which would have rendered it impossible to continue in an open glider.

From the time of the "Vampyr" when little was known as to what was desirable in the wing section used, a fairly definite development took place in the direction of increased maximum lift by increase of camber. Thus in the Darmstadt gliders Göttingen 535 was used, and in the "Fafnir" Göttingen 652 was employed as a basic section. The latter section appears to be a practical limit to increase of camber since, although its maximum lift and value of $\frac{k_L^{3/2}}{k_D}$ are very high, slight deviations from the true section affect them to a large extent. Also, owing to the high drag at low values of k_L the section was not efficient at high speeds. It was now becoming apparent that for long-distance flights this characteristic was essential in order to extend the maximum possible range within the purely practical limits of daylight. The next development was therefore a decrease of camber.

This would at first sight seem a retrograde step since the performance of the aircraft in upcurrents of low value was adversely affected. Before discussing the reason why this was but of secondary importance, it is necessary to trace briefly the development of soaring technique which had taken place since 1922.

In the first instance, soaring was of a purely topographical nature using currents deflected upward by local hills. A long-distance flight under these conditions was a very slow and extremely hazardous affair. Moreover, the length of the flight was limited by the extent of the range of hills. The possibilities of other types of upcurrent were realized in 1926 when Kegel was carried up into a thunderstorm and carried off by it for a distance of 34 miles. This flight, with the exception of the catapult start and initial climb, was purely independent of topography. Kegel, however, had little or no control on this occasion, having no instruments except an A.S.I. Moreover, had it not been for the fact that the upcurrents were of wide extent and extremely violent, there is no doubt that, even if instruments had been fitted to the glider, the lack of maneuverability already referred to would have brought Kegel down.

Following this flight, efforts were made whenever possible to make contact with thunderstorms and line squalls, though owing to lack of knowledge of blind flying and the absence of instruments necessary for this, they were treated with extreme caution, the pilots endeavoring to keep just below and in front of these storms, this being considered the most favorable position. The more obvious instruments, such as air-speed indicator and altimeter, were now generally fitted.

Between 1930 and 1931 the potentialities of thermal currents were realized. These currents are created by heat rising from the ground under certain conditions, such as those existing on a hot summer afternoon. When the hot current reaches a layer of air of such temperature that condensation of the moisture which it contains takes place, a cloud is formed, and thus the existence on summer afternoons of scattered cumulus indicates the presence of thermal currents. Notwithstanding this fact, condensation does not always occur, and many thermals are not accompanied by cloud or any visible signs of their presence. On this account and owing to their low velocity, they are difficult to detect initially, and once found, demand an entirely different flight technique if the aircraft is to be held in them. A funnel of warm rising air of comparatively small diameter necessitates continuous spiral flight, and a small radius of turn with steep bank. Thus here the maneuverability which had been sought for other reasons proved of great value, while the wide flat turn which had hitherto characterized soaring flight gave place to the more normal maneuver as practiced on power airplanes.

The difficulty of detecting these currents, however, remained, and for this reason the variometer was developed. This instrument, which is really the statoscope of performance testing in another form, has become the most important accessory used in motorless flight.

Soaring was still limited by cloud. Any attempt at prolonged blind flight was cut short in the way already familiar to power pilots, although vertical currents might be stronger within the cloud than they were beneath its base. The necessity for acquiring the faculty of blind flying was realized, and this in turn gave rise to the need for bank and turn indicators in the aircraft themselves. It was now apparent that the ability to fly in cloud was of inestimable value since upcurrents were found to be of an extent and intensity hitherto unsuspected except in the case of special kinds of storms such as the thunderstorm and line squall. Indeed, of such value were the velocities of these high-altitude currents that it was considered possible to effect changes to the aircraft which, although reducing their climbing qualities, would enable better speed performances to be obtained - so countering the daylight limit previously referred to.* This brings us back to the point where this discussion of soaring technique was started, namely, the reduction of wing camber. The first step in this new direction was made in the design of the "Fafnir II", better known perhaps as the "Sao Paulo" (figs. 5 and 6). Not only was the camber reduced, but the results of the more recent interference research carried out by Muttray were also incorporated for the first time in an aircraft. The glider is practically a middle-wing type, with the wing literally growing out of the body, rather than being attached to it. The "Sao Paulo" represents in this and almost every other way the peak of glider development, and broke the long-distance record in 1934 with a flight of 232 miles.

The polar diagram as obtained from full-scale measurements is shown in figure 7. The best angle of glide is 1:27 at a speed of about 50 miles per hour. This year the "Sao Paulo" did not compete for other than technical reasons. This glider would be much too expensive for most glider clubs to own, and as the first thought of all organization in Germany at the present time is the majority

---

*It may be wondered why the provision of night-landing equipment has not been used as the obvious answer to this limitation. It must be remembered that almost every long-distance flight ends in a forced landing and that as found in power-aircraft operation, flares are the only adequate means of enabling a safe landing place to be chosen under such conditions. Landing lamps are sufficient at prepared airports only. The weight and drag of flare equipment has been considered prohibitive for gliders hitherto.

rather than the minority, the next step was to investigate what simplifications could be made to the aircraft, while retaining the high performance as far as possible.

The "Rhönsperber" (fig. 9) developed this year by Jacobs, represents this move. The simplifications are:

(a) Constant wing section, and wing chord for the center section.

(b) Simplified fuselage.

(c) Simplified junction of wing and fuselage.

(d) Smaller over-all dimensions.

As this aircraft put up the best all-round performance at this year's contest, it is worthy of study. As seen from figure 9, the pilot's cabin protrudes above the fuselage. The cabin is a framework of welded steel tubing covered with Plexiglas, a supercelluloid which can be pressed into difficult shapes. The pilot has thus a better view than ever before in a glider. The cabin top and part of the front of the fuselage hinge as one, so that it is easy for the pilot to leave in an emergency. The instrument board also hinges up with the top and the instruments are easily removable. The inside finish is well carried out and has more of the refinement of an airplane than the usual crudity of a glider.

In view of the fact that the aircraft would be flown by a large number of pilots of varying experience, it was considered desirable in the interests of safety to replace the all-moving tailplane of the "Sao Paulo" by a fixed tailplane and separate elevator (fig. 12). While reducing maneuverability, this alteration rendered the glider stable with hands off. One glider only, built specially for a skilled pilot, had an all-moving tailplane.

The wing, of 50 feet span and 165 square feet area, has an aspect ratio of 15 and a loading of 3.03 pounds per square foot. The wing weighs 1.2 pounds per square foot, which is 60 percent of the structure weight or 40 percent of the gross weight. At the root and over the rectangular portion the section is Göttingen 535 (16 percent thickness: chord), and at the tip a symmetrical section. There is no geometrical twist, but there is an aerodynamic twist (washout) of $8\frac{1}{2}$ degrees. There is a slight gull-wing effect and the wing is in two parts. The main spar is jointed at the body center line, but at this point is not connected to the fuselage. The fuselage connections are outside, there being four bolts in all, one at the main spar and one at the auxiliary spar on port and starboard sides. The fairings for the boltheads are easily seen in figure 11. Joining the spars directly together instead of separately to a center section, as is more usual, saves considerable weight and makes for simplicity.

The first "Rhönsperber" was completed in February of this year, and it was immediately put through very strenuous tests in order to remove the "bugs." As in every aircraft, there were some of these and such things as shifting the pilot slightly, changing the nose shape, altering the dihedral and the empennage, were found necessary before series production was undertaken. The type being in the acrobatic category, it was thoroughly tested in loops, rolls, and inverted flight. It was dived up to 160 miles per hour and finally underwent a 42-turn spin (6,300-foot height loss in 2 minutes 25 seconds). Thus, although a new type, the "Rhönsperber", can be considered to be thoroughly developed and is by no means experimental. For a gross weight of 500 pounds this aircraft has a minimum sinking speed of 2.35 feet per second and a maximum angle of glide of 1:20. An interesting point about the "Rhönsperber" is the use of spoilers, one on each wing about midway along the semispan consisting of flat plates normally flush with the wing about 2 feet by 4 inches in size, which are raised when it is desired to steepen the glide at landing.

Nine "Rhönsperber" gliders were entered for the competitions at the Wasserkuppe this year, the other two types best represented being the "Condor" (thirteen) (fig. 13) and the "Rhönadler" (twenty-one) (fig. 17). The two latter types were developed nearly simultaneously about three years ago, the "Condor" by Kramer and Dittmar, and the "Rhönadler" by Jacobs.

The "Condor" is to all appearances a cross between the "Wien" and the "Fafnir", having a braced high wing of gull form with considerable incidence decrease toward the tips. The characteristics of the "Condor" are a relatively large size and wing area giving a low sinking speed. These characteristics give good soaring qualities in upcurrents of low strength, but the glider is handicapped when it comes to high-speed work. In an attempt to over-come this handicap, the "Condor II" was developed. Both versions of the type possess good maneuverability, the all-moving tailplane helping considerably in this direction. The "Condor II", which appeared for the first time this year, has refined details and a thinner wing of reduced camber. The success of the alterations was demonstrated by the fact that on a flight during the competitions Dittmar was able to maintain a speed of 70 miles per hour for two hours.

General arrangement drawings of the "Condor" are given in figure 13.

The "Rhönadler" is a slightly different and simpler solution of the same problem as that faced by the "Condor", the wing being a straight tapered twisted cantilever without the gull-wing form. The wing, springing as it does from a narrow neck or cabane into which the pilot's cockpit cover is faired (fig. 18) follows closely the Darmstadt traditions. Again, possessing an all-moving tailplane and due to the twisted wing, the maneuverability of the glider is good while, like the "Condor", the high-speed performance leaves something to be desired. It was, in fact, to improve the range that the smaller wing and higher wing loading were adopted in the "Rhönsperber" as previously mentioned. This increase of "cruising speed" at a given L/D naturally results in a higher sinking speed, but this loss is considered outweighed by the gain in the other directions. It was noticeable, however, that during thermal soaring in this year's competitions the "Rhönsperbers", with the exception of those flown by pilots of outstanding skill, were outclassed by other types.

Apart from the three "standard" high-performance types, there were a number of others singly represented, as well as several "Rhonbussards", medium-performance gliders. The "Moazagotl" (W. Hirth) (fig. 19), and its smaller development, the "Göppingen 3" (fig. 20), were of special interest. The "Moazagotl" was notable for the exaggerated gull-wing, large size (20-meter span), and cleanness of detail design. Thus it was the only glider competing in which aileron control horns were not in evidence, but on the other hand, the reduction in chord at the center section, which the plan of the wing possesses, probably offsets any gain from this refinement.

The "Göppingen 3" is a cantilever version of the "Moazagotl", the smaller span allowing the departure from the semicantilever arrangement of the larger aircraft. It was obvious that this development is running on lines parallel to the "Rhonsperber".

The D.B.10 should be mentioned since it was one of the four gliders to break the world's distance record in simultaneous flights to Brünn in Czechoslovakia. Although possessing a fuselage of rectangular section, its wing and wing-root junction are aerodynamically well designed, and the aircraft showed up well in heavy weather. In passing, it should be noted here that the other three record breakers were "Condor", "Rhönadler", and "Rhönsperber", respectively.

Inspection of these aircraft revealed interesting points of a general nature as well as calling forth equally general criticisms. External finish of fuselages and wings was, as always had been the case in recent years, extremely smooth, but many of the external joints, strut-end fairings, control horns, and skid fairings, were often very crudely carried out. Other noticeable excrescences were the pitot and venturi heads near the nose of every fuselage (figs. 15, 19, and 20). It is hoped to incorporate these inside the fuselage in the future. Cabin tops were often amateurish in workmanship. Mass balances for elevators when present were not only of a crude form, but attached to the inboard ends of the control surfaces instead of at the tips (fig. 16).

From these remarks it will be realized that there is quite a large field for future improvement in detail design, but what of more fundamental and far-reaching alterations? Has finality come yet? The answer to this question may be found from an examination of the curve of performance against time (fig. 21). Although other factors influence this curve besides aerodynamic design, such as soaring technique, instruments, and even structural strength indirectly, it can be said without hesitation that finality has not been reached. The curve is still showing no signs of becoming asymptotic to the horizontal; in fact, just the reverse, for its slope is steadily increasing, and while that is the case, then improvement is obviously taking place steadily.

Increase in Loadings

In the search for better long-range performance, wing loadings will probably be yet more increased. This may involve difficulties in take-off and climbing in low-velocity air currents, in which case some artificial means of increasing lift temporarily may have to be sought. Wing flaps may come, and if they do, they will present no simple problem since drag must always be kept to a minimum.

Higher speeds coupled with the technique of continuous turning in the smaller currents may necessitate balancing ailerons, and this in turn will bring its attendant difficulties.

But perhaps the most obvious step to look forward to is the provision of such night-flying equipment as will remove the daylight limitation which prevented at least one of this year's record breakers from continuing his flight for perhaps many more miles.

Effect on Airplane Design

The writers of this account feel that they cannot end it without reference to the influence of the development of these gliders on German aircraft design in general. They were privileged by the courtesy of the German Air Ministry to visit a number of aircraft factories, and although details may not be published, the aerodynamic refinement which is characteristic of a number of types now in development has obviously resulted from the intensive study in the field of motorless flight.

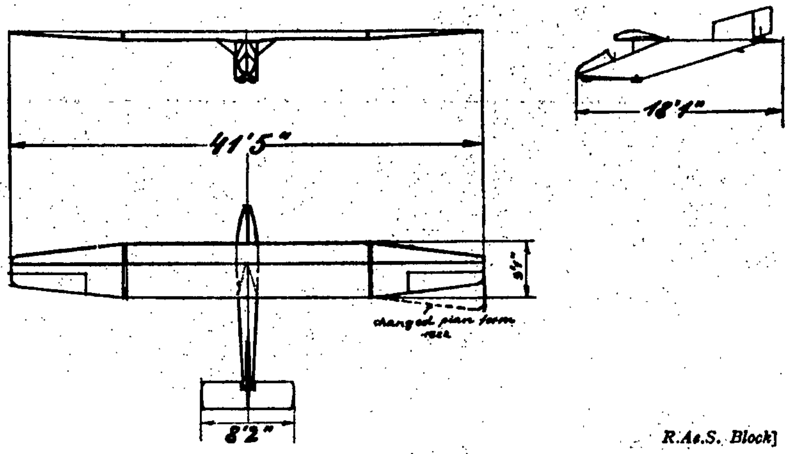

Fig. 1.—
Vampyr
(1921–22).
Tare wt.
287 *lb.*
Wing area
172 *sq. ft.*

R.Ae.S. Block]

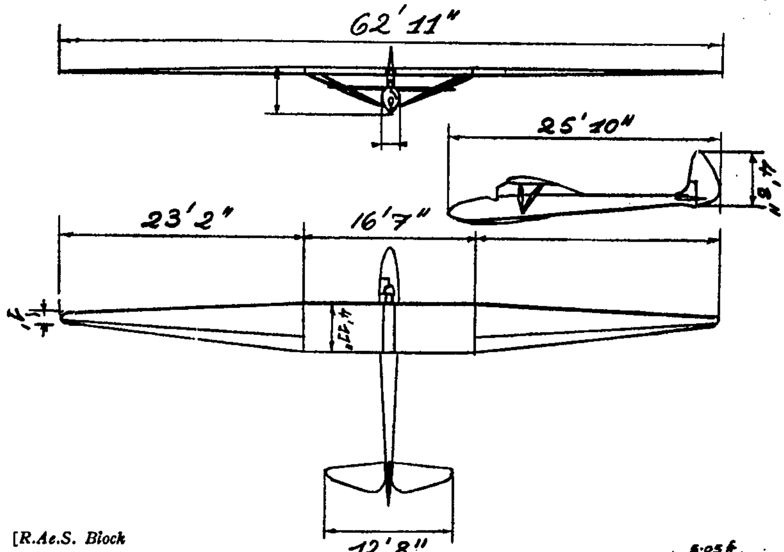

Fig. 2.—
Wien.
Tare wt.
353 *lb.*
Aspect-ratio
20

[R.Ae.S. Block

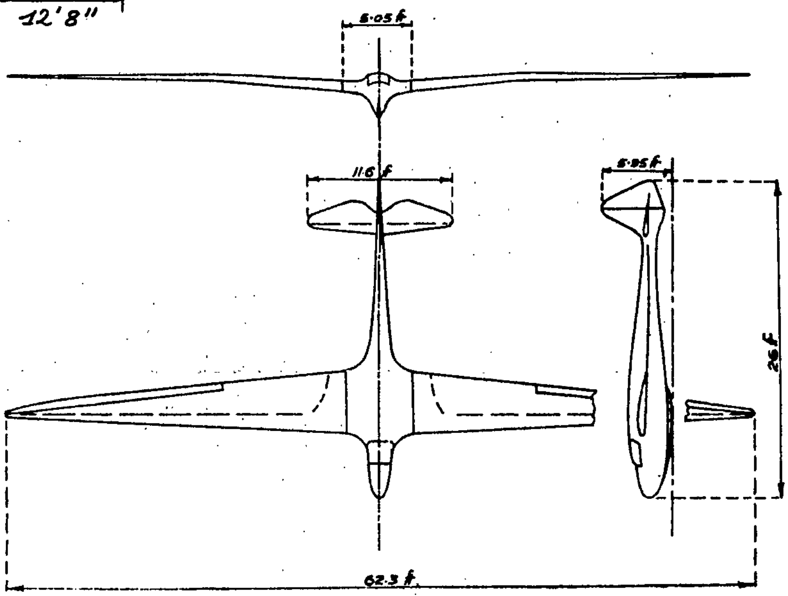

Fig. 5.—
Fafnir II
Sao Paulo

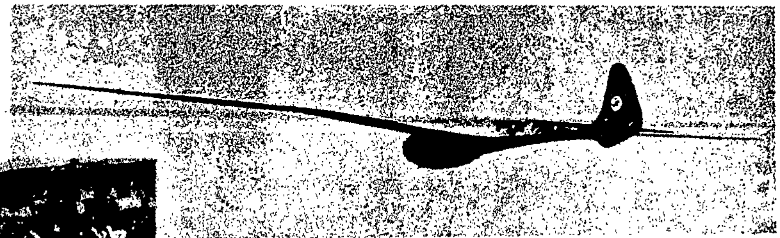

FIG. 6—*Fafnir II in flight*

FIG. 3.—*Fafnir I. Original condition*

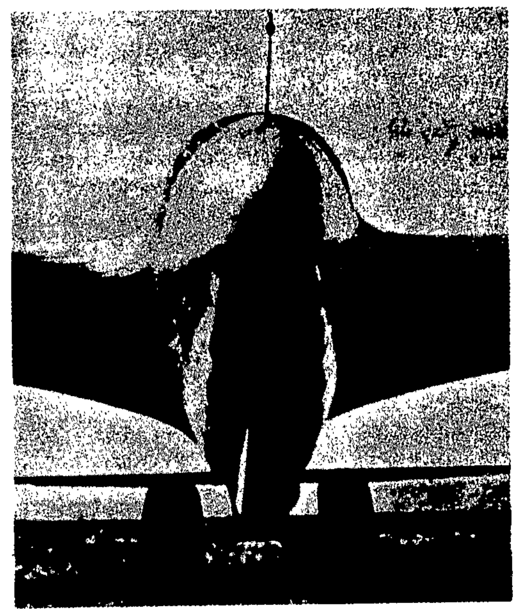

FIG. 8.—*Fafnir II. (The wheels are part of the handling trolley)*

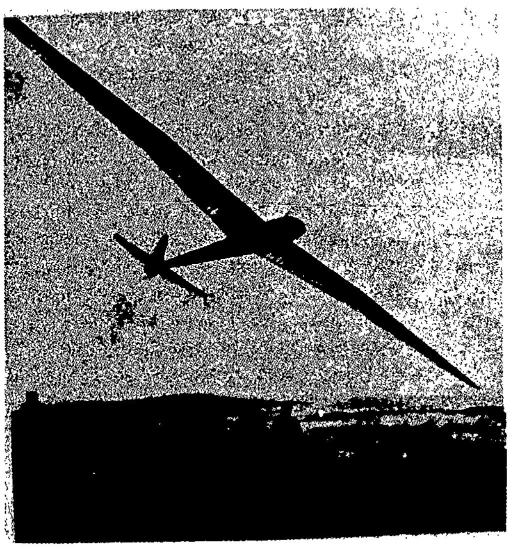

FIG. 4.—*Fafnir I in flight*

FIG. 10.—*Rhönsperber in flight*

FIG. 11.—*Rhönsperber showing form of cabin top and fairing for wing attachment-bolts*

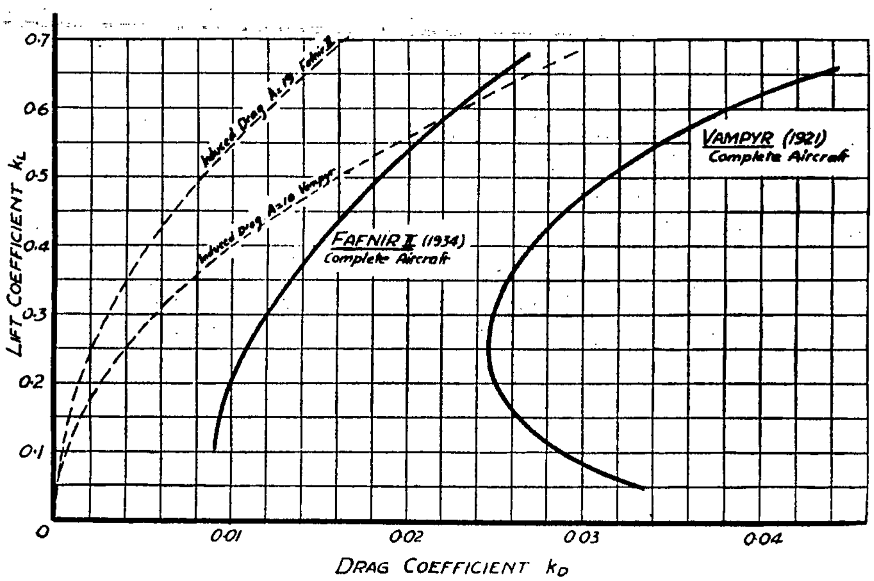

Fig. 7.— *Advance in glider design as indicated by polar curves for Fafnir II and Vampyr*

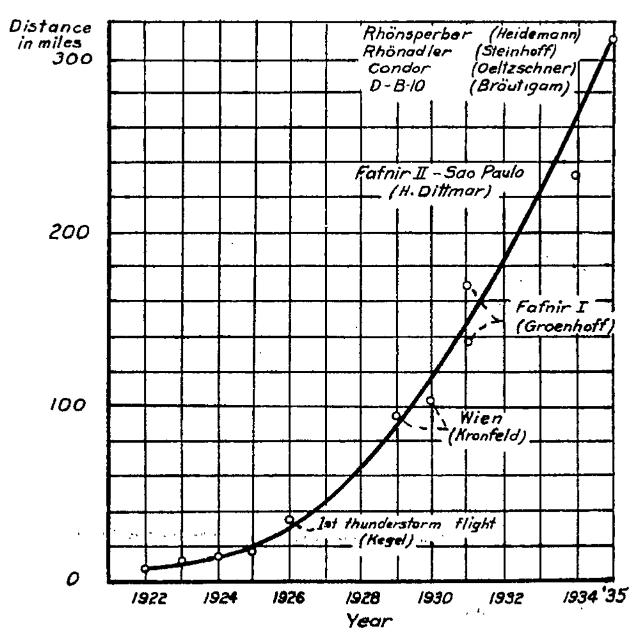

Fig. 21.— *Advance in glider performance as indicated by range*

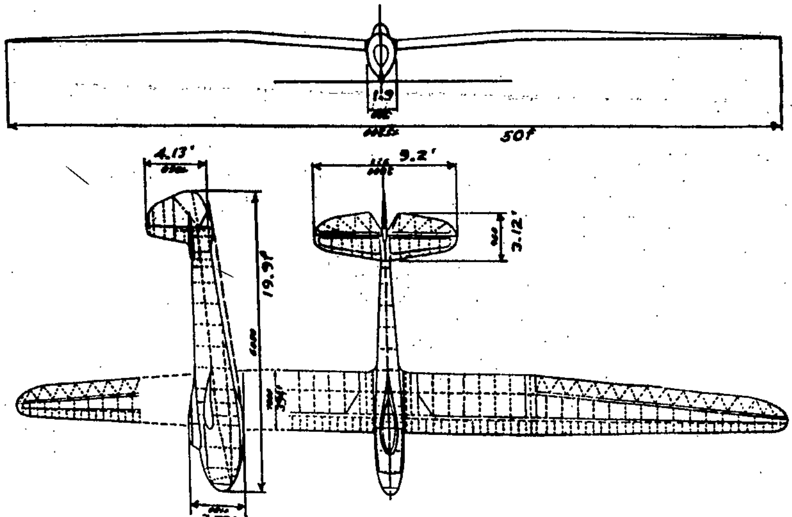

Fig. 9.—
Rhönsperber.
Tare wt. 330 *lb.*
Load 220 ,,
Gross wt. 550 ,,

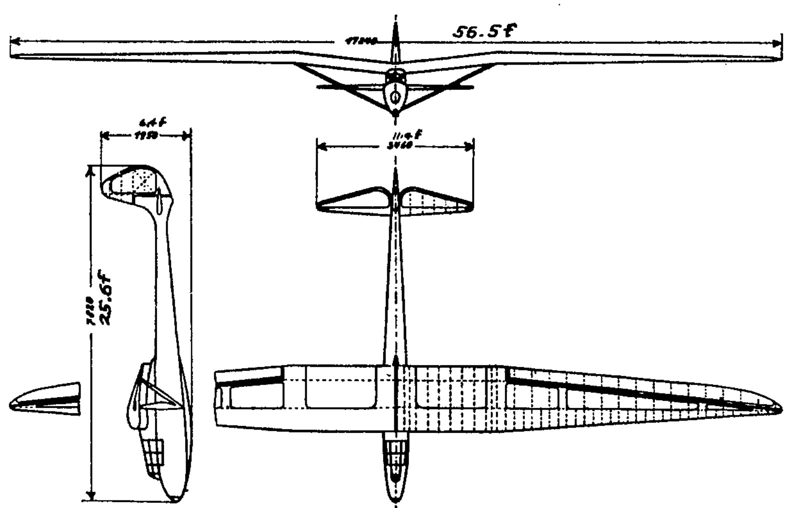

Fig. 13.—*Condor. Tare wt.* 340 *lb. Load* 210 *lb. Gross wt.* 550 *lb.*
Licensed for unlimited gliding and soaring. Auto towing up to 50 *m.p.h.*
Aeroplane towing up to 75 *m.p.h.*

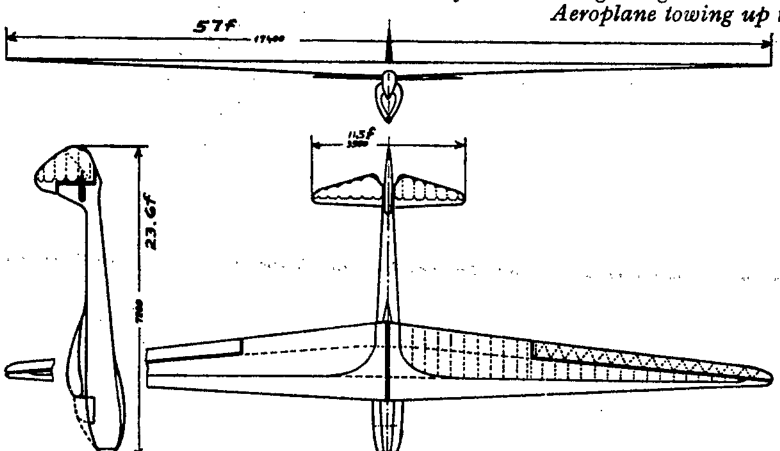

Fig. 17.—*Rhönadler. Tare wt.* 400 *lb. Load* 180 *lb. Gross wt.* 580 *lb.*

FIG. 12.—*Rhönsperber tail unit*

FIG. 14.—*Condor, showing aileron chord as large proportion of wing chord at tip*

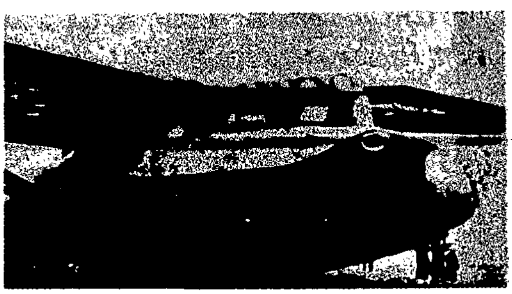

FIG. 15.—*Condor. A less refined cabin than that of the Rhönsperber*

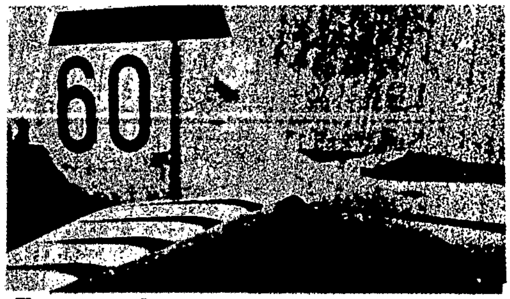

FIG. 16.—*Condor tail unit with all-moving elevator. Note mass balances*

FIG. 18.—*Rhönadler*

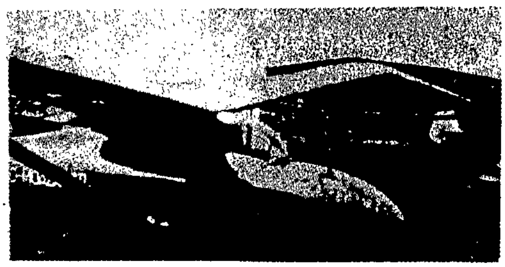

FIG. 19.—*Moazagotl. (Hirth)*

FIG. 20.—*Göppingen III*