Only Copy

TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 353

RECENT EXPERIMENTS WITH LARGE SEAPLANES

By Adolf Rohrbach

From "Berichte und Abhandlungen
der Wissenschaftlichen Gesellschaft für Luftfahrt,"
July, 1925

Washington
March, 1926

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 353.

RECENT EXPERIMENTS WITH LARGE SEAPLANES.*

By Adolf Rohrbach.

Two years ago I had the privilege of addressing you in Bremen on the advantages of large airplanes with a heavy wing-load. I am grateful to the "Wissenschaftliche Gesellschaft für Luftfahrt" for giving me the opportunity to tell you today what has been accomplished since the Bremen meeting, in both my companies, with the cooperation of my capable coworkers, in order to demonstrate practically the correctness of my views, on increasing the size of airplanes, by the construction of other large airplanes, after the 1000 HP. monoplane of the "Zeppelinwerke Staaken" (the only exponent at that time of the principle of heavy wing loading) had not been allowed by the "Interallied Control Commission" to complete its tests.

1. Advantages of heavy wing load.- Referring to the Bremen lecture, I would like to remind you, through this diagram (Fig. 1) of the principal advantages of large airplanes with heavy wing loading. This diagram shows, for large airplanes of the old type (in which the wing load per unit area is the same as for small airplanes) how the pay load increases with the size of the airplane only up to a total weight of

* From "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," July, 1925.

about 9000 kg (19,842 lb.)* and how it falls off beyond this point with constantly increasing rapidity. The case is different for large airplanes in which the specific wing load increases with the size of the airplane according to the law of similitude of naval architecture. As a result of the great reduction thus produced in the external dimensions of the airplane, the relative weight of the wings increases much slower, with the increasing size of the airplane, and the pay load consequently reaches its maximum value at a full load of about 16,000 kg (35,274 lb.). The speed of large airplanes with lighter wing loading is not greater than the speed of corresponding smaller airplanes but, on the contrary, as shown by the diagram, the speed of the large airplanes, having a heavy specific wing load, increases considerably with the size of the airplane.

In our flight tests with the first airplane, we attained a wing load of 88 kg/m² (18.02 lb./sq.ft.). In these tests the D. V. L. (Deutsche Versuchsanstalt für Luftfahrt) found our mean flight speed with full load to be about 174 km (108 miles) per hour. The propeller efficiency was only about 56%. Dr. Koppe will explain in his lecture** how the propeller efficiency was determined from observations made during flight.

I will improve this opportunity to speak briefly of the

* On the assumptions published in "Beiheft 10" of the "Zeitschrift für Flugtechnik und Motorluftschiffahrt," 1923.

** Heinrich Koppe, "Messungen an Luftfahrzeugen," Jahrbuch der W.G.L. (Wissenschaftlichen Gesellschaft für Luftfahrt,") 1924, pp. 38-47. Also N.A.C.A. Technical Memorandum No. 355.

great difficulties we had with the propellers. Due to the very favorable experience we had always had previously in the agreement of wind-tunnel experiments with the reality, in using propeller-experiment results published by the National Advisory Committee for Aeronautics, we did not take into account a number of factors. We knew, of course, that the working conditions for a propeller in a free air stream, as in wind-tunnel experiments, are fundamentally different from the working conditions of a propeller in front of a radiator, engine cockpit and wings, as on an airplane. In order to come as close as possible to the reality, we had the effect of the propeller slip stream on the model of our airplane determined and we found in the behavior of the airplane no disagreement with the results of these experiments. Since the Göttingen Institute, however, had no device for determining the reaction of the airplane on sufficiently large propeller models and since the production of such a device would have taken too long, we had to be contented with estimating the decrease in the propeller efficiency on the basis of previous Göttingen experiments. In this connection we assumed that different propellers were equally affected, so that the propeller which, according to the American experiments, was best adapted to the conditions existing with our airplane, must really be the best propeller. The test flights demonstrated, however, that this assumption was entirely wrong. Different propellers which, according to the

American experiments, could be expected to give almost identical results, actually gave extremely different results. We lost much time with these propeller problems. Now we are again making our propellers according to successfully applied practical formulas. It is to be hoped, however, that the Göttingen Institute will soon be equipped so that the results of propeller experiments, including the reaction between the propeller and airplane on the model, will agree with the reality, even in flight, as well as the stationary tests made at our request, with full-sized propellers, by the D. V. L. at Adlershof.

The heavy wing loading, as shown by Fig. 2, affords the further advantage of a considerably better turning ability. The time required for flying through a complete circle with a light wing loading increases rapidly with the size of the airplane, while it only increases very slowly for large airplanes with a heavy wing loading. The time required to fly through a given curve is often decisive, especially in aerial fighting. The turning ability of an airplane is satisfactory, however, only when it can quickly assume any curve and can then fly quickly through that curve. After the ability to fly quickly through the curve had been assured by the heavy wing loading, I first employed the exceptionally large dihedral angle of 6°, as shown in Fig. 3. This large dihedral seemed at first somewhat hazardous since all the more recent airplanes had either very small dihedrals or none at all. The dihedral is very desirable on seaplanes, however, first with regard to seaworthiness, because it raises the wing tips higher above the water and also for anticipated improvement in maneuverability. It is known that an airplane steers well in the longitudinal direction, only when its longitudinal stability or instability is slight. The same principle applies to banking ability, i.e., the lateral stability or instability must be made as small as possible and the simplest way to accomplish this result is to give the wings a large dihedral angle. In order to reduce the risk as much as possible, a very comprehensive mathematical investigation was undertaken by Mr. Brandt under the supervision of Professor Fuchs. The purpose of this investigation was to determine how the motion of the airplane is affected by increasing the dihedral angle.

A general solution of the problem is very difficult, since the functions under consideration are very complicated and not explicitly given, some of them never having been thoroughly investigated. The solution is given here in a simplified form, as a stability investigation by the method of small oscillations, the train of thought being as follows:

First, the general motion equations of the airplane are set down. These are simplified in so far as only small deviations from stationary flight and also from rectilinear flight are investigated. The motion equations are developed according to the small deviations and only members of the first order are considered. Then the differential equations are integrated on the assumption of definite rudder deflections and definite initial conditions. Thus the course of the airplane motion is obtained under the influence of the rudder deflections and indeed of the lateral angle, lateral inclination and angular velocity about the vertical axis, as a function of the time. This was accomplished with the Fuchs-Hopf formulas (Fuchs-Hopf "Aerodynamik," p. 403 ff), as follows.

The motion equations yield the power equations (Fig. 4):

$$x = \text{axis: } \frac{G}{g}\,\frac{dv}{dt} = -\,G\sin\varphi + S\cos\tau\,\cos\alpha - c_w\,q\,F \qquad (1)$$

$$Y_1 = \text{axis: } 0 = \frac{G}{g}\,v\left(\omega_y\sin\mu - \frac{d\varphi}{dt}\cos\mu\right) -$$

$$-\,G\cos\varphi\,\cos\mu + S\cos\tau\,\sin\alpha + c_a\,q\,F \qquad (2)$$

$$Z_1 = \text{axis: } 0 = \frac{G}{g}\,v\left(\omega_y\cos\mu + \frac{d\varphi}{dt}\sin\mu\right) +$$

$$+\,G\cos\varphi\,\sin\mu - S\sin\tau - c_Q\,q\,F \qquad (3)$$

Further for the moment equations:

$$J_X\,\frac{d\omega_X}{d\,t} - (J_Y - J_Z)\,\omega_Y\,\omega_Z = -\,K \qquad (4)$$

$$J_Y\,\frac{d\omega_Y}{d\,t} - (J_Z - J_X)\,\omega_Z\,\omega_X = -\,L \qquad (5)$$

$$J_Z\,\frac{d\omega_Z}{d\,t} - (J_X - J_Y)\,\omega_X\,\omega_Y = -\,M \qquad (6)$$

In these equations:

G = full load in kg,

g = gravity acceleration in m/s^2,

v = velocity in m/s,

φ = angle of flight-path (x direction) with horizontal plane,

S = propeller thrust in kg,

q = dynamic pressure in kg/m^2,

F = wing area in m^2,

ω = turning speed in degrees per second,

J = moment of inertia in $kg\text{-}m/s^2$,

K = rolling moment of air forces, including damping moments about the x axis,

L = yawing moment about the y axis in kg-m,

M = pitching moment about the z axis in kg-m,

x,y,z = flight-path axes.

X,Y,Z = airplane axes.

The principal forces may fall directly on the axes x,y,z, so that there will be no centrifugal moments to be considered. K,L,M are the moments of the air forces on all the airplane parts. They also contain the damping moments, which are produced on the airplane parts, farther removed from the center of gravity, by the rotation about the assumed airplane axes.

In the above six equations, the quantities v, ω, φ, μ, α, τ, ω_x, ω_y and ω_z are unknown, while c_a, c_w and c_q are dependent on α and τ. The air-force moments depend on all six variables. ω_x, ω_y and ω_z must be put in relation with the six variables. We thus obtain with respect to the path-fixed system of coordinates

$$\omega_x = \omega \sin\varphi \tag{7}$$

$$\omega_y = \omega \cos\varphi \tag{8}$$

$$\omega_z = \frac{d\varphi}{dt} \tag{9}$$

For the airplane-fixed system of coordinates, we obtain

$$\omega_X = \left[\left(\omega \cos\varphi \cos\mu + \frac{d\varphi}{dt}\sin\mu\right)\sin\alpha + \left(\omega \sin\varphi + \frac{d\mu}{dt}\right)\cos\alpha\right]\cos\tau - \left[\omega\cos\varphi\sin\mu + \frac{d\varphi}{dt}\cos\mu + \frac{d\alpha}{dt}\right]\sin\tau \tag{10}$$

$$\omega_Y = \left(\omega\cos\varphi\cos\mu + \frac{d\varphi}{dt}\sin\mu\right)\cos\alpha - \left(\omega\sin\varphi + \frac{d\mu}{dt}\right)\sin\alpha + \frac{d\tau}{dt} \tag{11}$$

$$\omega_Z = \left[\left(\omega\cos\varphi\cos\mu + \frac{d\varphi}{dt}\sin\mu\right)\sin\alpha + \left(\omega\sin\varphi + \frac{d\mu}{dt}\right)\cos\alpha\right]\sin\tau + \left[-\omega\cos\varphi\sin\mu + \frac{d\varphi}{dt}\cos\mu + \frac{d\alpha}{dt}\right]\cos\tau \tag{12}$$

With respect to only steady motion and only slight deviations from rectilinear flight, equations (10) to (12) become

$$\omega_X = \omega\sin(\varphi_o + \alpha_o) + \frac{d\mu}{dt}\cos\alpha_o \tag{13}$$

$$\omega_Y = \omega \cos(\varphi_0 + \alpha_0) - \frac{d\mu}{dt} \sin \alpha_0 + \frac{d\tau}{dt} \tag{14}$$

$$\omega_Z = \frac{d(\varphi_0 + \alpha_0)}{d\,t} \tag{15}$$

in which v_0, α_0 and φ_0 are steady-flight values.

After equations (1) to (6) have been treated in the same way, i.e., if only steady motion and small deviations from rectilinear flight are considered, the first system of equations (1) to (6) breaks up into two groups of three equations each, one group representing the longitudinal and the other the lateral motion. The three latter equations read, after the air forces have also been developed according to the variables

$$\begin{aligned} 0 = &\left[- \frac{S}{qF} - c_s' \frac{F_s}{F} - \frac{\Phi'}{F} - \right. \\ &\left. - \left(c_s' \frac{F_s}{F} \frac{s}{b} \cos\alpha - c_s' \frac{F_s}{F} \frac{h}{b} \sin\alpha \right) \frac{d}{dt} \right] \tau + \\ &+ \left[G_n \cos\varphi - c_s' \frac{F_s}{F} \frac{s}{b} \cos\varphi - \right. \\ &\left. - c_s' \frac{F_s}{F} \frac{h}{b} \sin\varphi \right] \overline{\omega} + \\ &+ \left[c_a - c_s' \frac{F_s}{F} \frac{h}{b} \frac{d}{dt} \right] \mu \end{aligned} \tag{16}$$

$$0 = \left[+ \frac{1}{4} c_n' \, |\nu| + c_s' \, \frac{F_s}{F} \, \frac{h}{b} + \right.$$

$$\left. + \left(\frac{1}{6} c_n \cos\alpha - \frac{1}{12} c_n' \, \sin\alpha \right) \frac{d}{d\bar{t}} \right] \tau +$$

$$+ \left[\bar{J}_X \sin(\varphi + \alpha) \frac{d}{d\bar{t}} + \frac{1}{6} c_n \cos\varphi + \right.$$

$$\left. + \frac{1}{12} c_n' \, \sin\varphi \right] \bar{\omega} + \left[\bar{J}_X \cos\alpha \frac{d^2}{d\bar{t}^2} + \right.$$

$$\left. + \frac{1}{12} c_n' \, \frac{d}{d\bar{t}} \right] \mu - i_s \tag{17}$$

$$0 = \left[+ \frac{1}{4} c_t' \, |\nu| + c_s' \, \frac{F_s}{F} \, \frac{s}{b} + \bar{J}_Y \frac{d^2}{d\bar{t}^2} \right.$$

$$\left. + \left(c_s' \, \frac{F_s}{F} \, \frac{s^2}{b^2} \cos\alpha - \frac{1}{12} c_t' \, \sin\alpha \right) \frac{d}{d\bar{t}} \right] \tau +$$

$$+ \left[\bar{J}_Y \cos(\varphi + \alpha) \frac{d}{d\bar{t}} + c_s' \, \frac{F_s}{F} \, \frac{s^2}{b^2} \cos\varphi + \right.$$

$$\left. + \frac{1}{12} c_t' \, \sin\varphi \right] \bar{\omega} + \left[- \bar{J}_Y \sin\alpha \frac{d^2}{d\bar{t}^2} + \right.$$

$$\left. + \frac{1}{12} c_t' \, \frac{d}{d\bar{t}} \right] \mu + l_s \tag{18}$$

in which

S = propeller thrust in kg,

q = dynamic pressure in kg/m²,

F = wing area in m²,

c_s' = deduction of normal power coefficient on the vertical tail planes according to the angle of attack (non-dimensional),

F_s = area of vertical tail planes in m²,

Φ' = deduction of harmful area of airplane (without wings and tail, in a lateral wind according to the angle of attack) in m²,

s = length of tail in m,

b = span of wing in m,

α = angle of attack of wing in degrees,

h = height of vertical tail planes above center of gravity in m,

$G_n = \frac{Gv^2}{gqFb}$ = weight, as non-dimensional factor,

φ = angle of flight path in degrees,

ν = dihedral angle in degrees,

$\bar{t} = \frac{v}{bt}$ = time, as a non-dimensional variable,

$\bar{\omega} = \frac{b\omega}{v}$ = turning speed, as a non-dimensional variable,

μ = lateral inclination in degrees,

τ = direction of lateral wind in degrees,

l_s = rudder moment (non-dimensional),

k_s = banking moment (non-dimensional).

$$\left.\begin{array}{l} \bar{J}_X = G_n \times \dfrac{i_X^2}{b^2} \\[2ex] \bar{J}_Y = G_n \times \dfrac{i_Y^2}{b^2} \end{array}\right\}$$ non-dimensional inertia moments, in which k = radius of inertia.

The general solution of the equations reads:

$$\tau = A_0 + A_1\, e^{\lambda_1 t} + A_2\, e^{\lambda_2 t} + A_3\, e^{\lambda_3 t} + A_4\, e^{\lambda_4 t} \qquad (19)$$

$$\omega = B_0 + B_1 \; e^{\lambda_1 t} + B_2 \; e^{\lambda_2 t} + B_3 \; e^{\lambda_3 t} + B_4 \; e^{\lambda_4 t} \qquad (20)$$

$$\mu = C_0 + C_1 \; e^{\lambda_1 t} + C \quad e^{\lambda_2 t} + C \quad e^{\lambda_3 t} + C \quad e^{\lambda_4 t} \qquad (21)$$

The exponents λ are determined from an equation of the fourth degree, which is derived from equations (16) to (18). The determination of the values of τ, ω and μ yields the following curve for the horizontal flight of the airplane type Ro II at an altitude of 2000 m (6562 ft.) and for a given rudder and aileron deflection (Fig. 5). A 6° dihedral is found to be far too great for entering quickly "into the curve." The calculation was also made for climbing flight, the result proving similar to the one for horizontal flight.

The numerical calculations showed that, for μ and ω in equations (19) to (21), the members with the indices 0 and 2 are essentially definitive. The oscillation members 3 and 4 exert an especially great influence on τ. This is due to the fact that the oscillations consist simply of a so-called wind-vane motion which does not affect the flight path and revolution speed. Instead of the general solution, we have, according to these proofs of the surpassing importance of the indices 0 and 2 and after all but the members of the first degree have been discarded:

$$\mu = - 6 \frac{v^2}{g\ b} \frac{|i_s|}{c_n} \left(1 - e^{\frac{2gc_\mu}{vc_n'} t}\right) +$$

$$+ 3 \frac{v}{b} \nu\ t \left[6\ |i_s|\ \frac{s}{b} \frac{1}{c_a} + l_s \frac{1}{c_s' \ \frac{F_s}{F} \frac{s}{b}} \right] + \mu_o \tag{22}$$

$$\omega = + 6 \frac{|i_s|}{c_n} \left(1 - e^{\frac{2gc_n}{vc_n'} t}\right) -$$

$$- 3 \frac{g}{v} \nu\ t \left[6\ |i_s|\ \frac{s}{b} \frac{1}{c_a} + l_s \frac{1}{c_s' \ \frac{F_s}{F} \frac{s}{b}} \right] + \omega_o \tag{23}$$

These relatively simple equations can be recommended for all airplanes of similar design.

The following is a discussion of equations (22) and (23) without taking the initial conditions into consideration.

$$\mu = - 6 \frac{v^2}{g\ b} \frac{|i_s|}{c_n} \left(1 - e^{\frac{2gc_n}{vc_n'} t}\right) +$$

$$+ 3 \frac{v}{b} \nu\ t \left[6\ |i_s|\ \frac{s}{b} \frac{1}{c_a} + l_s \frac{1}{c_s' \ \frac{F_s}{F} \frac{s}{b}} \right] \tag{22}$$

Here

μ = lateral inclination in degrees,

v = velocity in m/s,

g = gravity acceleration in m/s²,

b = wing span in m,

i_s = aileron moment, nondimensional through division by wing area and wing chord,

c_n = normal-power coefficient (nondimensional),

c_n' = its deduction according to the angle of attack (nondimensional),

t = time in seconds,

ν = dihedral angle in degrees,

s = length of tail in m,

c_a = lift coefficient (nondimensional),

l_s = rudder moment (nondimensional, like k_s),

c_s' = normal power coefficient on the vertical tail planes, deduced according to the angle of attack (nondimensional),

F_s = area of the vertical tail planes in m²,

F = area of wings in m².

The greatest possible increase in μ, with increasing time t, is desirable for the turning ability of an airplane. For this purpose, it is necessary to consider which of the two expressions increases faster, since they have opposite signs.

In the first expression, t stands in an exponent. If the exponent increases much, then the bracketed expression becomes more negative, the left expression always more strongly positive and strengthens the growth of the right member. Both members thus work in the same desired direction.

Only the second of the two expressions contains the factor of the dihedral angle. With otherwise equal constants, since ν is added as a multiplier, an airplane with a larger dihedral surpasses one with a smaller dihedral, as regards its turning ability with reference to its longitudinal axis.

$$-\omega = -6\,\frac{|i_s|}{c_n}\left(1 - e^{\frac{2gc_n}{vc_n'}t}\right) + $$

$$+ 3\,\frac{g}{v}\,\nu\,t\left[6\,|i_s|\,\frac{s}{b}\,\frac{1}{c_a} + l_s\,\frac{1}{c_s'\,\frac{F_s}{F}\,\frac{s}{b}}\right] \qquad (23)$$

ω is the turning speed, in degrees, about the vertical axis of the airplane.

The same principle which holds good for ω in comparing the two members, also applies here for ω, but with the difference that, on account of the system of coordinates chosen, ω is negative. But even here, with increasing t, the turning speed becomes constantly more negative and still more so for a greater dihedral angle. The bracketed quantities are the same in equations (22) and (23), only the preceding factors differing. These factors show whether the dihedral has a more favorable effect on the rapid increase of the lateral inclination or on the turning speed about the vertical axis. In order to settle this point, an evaluation of the order of magnitude of the values in equations (22) and (23) is necessary.

$$\frac{2\,g\,c_n}{v\,c_n'}\,t$$

lies somewhere within the limits 0 and 0.5, when it is considered that only small values of t are concerned. Hence

$$e^{\frac{2\, g\, c_n}{v\, c_n'} t}$$

lies somewhere within the limits 1 and 1.6 and

$$\frac{v^2}{g\, b}$$

is chosen at about 10.

Then the first expression increases from zero to about 0.7 and the second expression increases about the same, even for a large dihedral. In equation (23) the first member increases approximately from 0 to 0.07 and the second member increases approximately from 0 to 0.1 for a large dihedral angle.

Thus it is demonstrated that a larger dihedral angle is especially favorable for the turning ability about the vertical axis of the airplane, because in equation (23), the member with ν increases more rapidly with a greater ν than the first without ν, while in equation (22), the members have the same value.

The whole investigation holds good only for small ν, the relations being different for large ν. An airplane, of the type for which the investigation was made, is stable laterally for a dihedral of about 10°. The effect of the ailerons is thus considerably diminished, showing that an excessive dihedral should be avoided.

In fact the airplane has excellent turning ability, in agreement with the computed results. It is brought very easily into the curve, simply by means of the rudder, and can likewise be easily brought back again into rectilinear flight by the same means.

The power plant.- A compromise was adopted in installing the engines, with regard to good maneuverability on the water, on the one hand, and good flying with only one engine, on the other hand. The two Rolls-Royce Eagle IX engines are therefore mounted on supporting frames of streamlined struts above the wings, in order to have the propellers high enough above the water. This arrangement has been found satisfactory in every respect. The large radiator stands between the engine and propeller on a prolongation of the engine supports. The radiators can be entirely closed by means of vertical adjustable shutters operated from the pilot's seat. Behind the engine and separated from it by a fire wall, there is a gravity tank (for 20 minutes) and an oil tank supported by a backward extension of the engine supports. It was originally planned to place the main fuel tanks (capable of holding enough fuel for 6.5 hours with throttle wide open) in the hull. Since this arrangement is, however, prohibited in England, on account of the fire danger, we hung the tanks for the first test flights provisionally under the wings, following the example of many English airplanes. They are now placed in the wings, being given the exact shape of the latter. The fuel is forced from the main tank into the gravity tank by means of a pump geared to the propeller shaft.

The side-by-side arrangement of the engines has, for water maneuvers, the advantage that when only one engine is run, it is always sufficiently cooled and that, moreover, by operating only one engine, a very great turning moment can be developed, without giving the airplane so great a speed as would be necessary for the obtention of a like turning ability, if the engines were in tandem. With the engines abreast, the seaplane therefore requires considerably less room for turning on the water, than if the engines were in tandem. Due to the lower speed, it ships much less water in maneuvering in a heavy sea.

Maneuvering on the water is greatly facilitated by the adjustable tail unit (Fig. 6), which can be rotated (on two bearings, in five seconds, up to a deflection of 12°, by means of a crank within reach of the pilot's seat) about a duralumin tower firmly secured to the rear end of the hull (Fig. 7). This adjustability of the tail unit was originally designed simply to offset the one-sided propeller thrust, when flying with only one engine running, which purpose it very successfully served. A deflection of only a few degrees suffices for rectilinear flight, even with the rudder in its central position, so that the seaplane, with only one engine running, can be brought, by means of the rudder alone, into either a right or left curve as easily as in normal flight, with both engines running, or in gliding flight.

This facilitating of the operation of the rudder also considerably improves the actual flying ability with one engine, since the rudder is so effective on this airplane, even at low speed, that all gusts can be directly counteracted. When, however, the rudder (as is the case with airplanes not having an adjustable tail unit) must be deflected very far, in order to offset the one-sided pull of the single engine, it is generally no longer effective enough, at the lowest possible flight speed, to prevent easily a deviation of the airplane from the desired course in gusty weather. The pilot should, therefore, in gusty weather, maintain a rather high speed, in order to make the rudder more effective. The result is that such an airplane loses altitude more rapidly than would be necessary with reference to the actual flying ability of the airplane.

The adjustability of the tail unit is, however, as already mentioned, also very useful on the water. With the normal position of the rudder and ailerons and with completely throttled engines, the seaplane runs about two points (22.5°) out of the wind. By the operation of the rudder and ailerons, the seaplane can be turned about four points (45°) out of the wind. If, furthermore, the whole tail unit is shifted, the seaplane can then turn as much as six points (67.5°) out of the wind. Thus the pilot still has at his disposal the total turning moment generated on an engine by opening out the throttle and can therefore turn the seaplane safely, even in a very strong wind. With a wind velocity of 14 m (46 ft.) per second and a tide of 3 m (nearly 10 ft.) per second, with very short choppy waves, all possible evolutions were made on the water without the least difficulty. The seaplane turned very quickly and easily out of the wind. The tail unit was shifted in a wind of 15 m (49 ft.) per second and then, with only the engine on the weather side running at 700-800 R.P.M., a distance of several miles was taxied obliquely to the wind.

Floats.- The use of relatively large lateral floats, at a short distance from the hull, contributed greatly to the success of this seaplane, since one of the greatest disadvantages of many boat seaplanes is the lack of sufficient lateral stability. Hence, floats were installed under the wing tips or wing stubs and were attached to the sides of the hull. A two-float seaplane offers more resistance to the air than a corresponding boat seaplane, but the former has good lateral stability, although it often has barely enough longitudinal stability. A float seaplane is driven off its course by seas striking it on one side, more easily than a boat seaplane. In a rough sea, the wing floats throw a seaplane very easily off its course.

Due to the large lateral floats, the advantages of boat seaplanes, as they have hitherto been known, are to a certain extent combined with the advantages of ordinary float seaplanes.

A boat seaplane, with large floats near the hull, has great longitudinal and lateral stability, in spite of the small air resistance, and, due to the central position of all three floating bodies, is not so readily thrown off its course in a rough sea, as an ordinary two-float seaplane.

Since the lateral floats contribute but little to the longitudinal stability of a boat seaplane, their rear and forward ends can be extended in long sharp points, in order to lessen the air resistance and to cut smoothly through the waves.

Each float has six water-tight compartments. This extensive division, as compared with the volume of a water-tight compartment of the hull, is provided, notwithstanding the additional weight and cost involved, because leakage is not so easily discovered in the completely inclosed floats, as in the hull. Thus a little leakage into one of the floats would not interfere with the take-off.

The floats are each secured by two horizontal steel tubes to the hull and by four vertical steel struts to the wing above (Fig. 12). The bottoms of the floats are somewhat higher than the bottom of the hull. Hence the dynamic lift of the floats helps to support the seaplane only during the low speed at the start. Above about 60 km (37 miles) per hour, the floats are entirely clear, so that the seaplane glides only on the bottom of the hull.

Hull.- Theoretically the hull should be very slender in order to diminish the air resistance (drag) and the weight of the bottom braces. By means of a very large number of towing experiments, we succeeded in giving the two-step hull a shape with which the small resistance, requisite for a short start, was obtained with the original width of 1.25 m (49.2 in.). This width corresponds, as follows from Table I, to a very large step loading in comparison with what has hitherto been considered allowable.

Table I. Comparison of Step Loadings.

Airplane type	Full load kg lb.	Step length m / ft. Hull alone	Step length m / ft. With floats	Load in kg / " " lb. Per m step length / Per ft. step length Hull alone	Load in kg / " " lb. Per m step length / Per ft. step length With floats	Load in kg / " " lb. Per $(\text{step length})^2$ Metric / Per $(\text{step length})^2$ English Hull alone	Load in kg / " " lb. Per $(\text{step length})^2$ Metric / Per $(\text{step length})^2$ English With floats
Brandenburg KWD	1065 2348	--	1.22 4.00	--	875 587	--	716 147
Brandenburg GW	3740 8245	--	2.22 7.28	--	1760 1133	--	833 156
Brandenburg GNW	1650 3638	--	1.80 5.91	--	917 616	--	509 104
Brandenburg W29	1463 3225	--	1.45 4.76	--	1010 678	--	697 142
Lohner flying boat	1700 3748	1.16 3.81	--	1462 984	1465 984	1260 258	1260 258
Oertz flying boat	2640 5820	2.50 8.20	--	1050 710	1050 710	421 87	421 87
Gotha WD 7	1920 4233	--	1.60 5.25	1200 806	1200 806	--	750 150
Rumpler 6 B 1	1130 2491	--	1.20 3.94	942 632	940 632	--	785 160
Sablatnig SF5	1600 3527	--	1.80 5.91	889 597	890 597	--	495 101
Albatros W 4	1030 2381	--	1.22 4.00	885 595	885 595	--	725 149
Staaken L	11800 26015	--	3.30 10.83	3576 2402	3580 2402	--	1085 222
Dornier Wal	4850 10692	2.50 8.20	6.00 19.68	1940 1304	809 543	776 159	135 28
Ro II	6200 13669	1.25 4.10	2.95 9.68	4960 3334	2100 1412	3960 813	713 146

Table I. Comparison of Step Loadings (Cont.)

Airplane type	Full load kg lb.	Step length m ft. Hull alone	Step length m ft. With floats	Load in kg " " lb. Per m step length Per ft. step length Hull alone	Load in kg " " lb. Per m step length Per ft. step length With floats	Load in kg " " lb. Per (step length)^2 Metric Per (step length)^2 English Hull alone	Load in kg " " lb. Per (step length)^2 Metric Per (step length)^2 English With floats
English F 5	6000 13228	3.05 10.01	--	1970 1321	1970 1321	645 132	645 132
English P 5/3	5700 12566	2.35 7.71	--	2420 1630	2420 1630	1030 211	1030 211
English N4 (Atalanta) (Titania)	14500 31967	2.75 9.02	--	5280 3544	5280 3544	1920 393	1920 393
English PSB (Fury)	14500 31967	3.80 12.47	--	3820 2564	3820 2564	1000 206	1000 206

The narrowness of the hull denotes considerable saving in the weight of the bottom braces, especially for a seaplane with heavy wing loading, in which the bottom stresses from the water pressure are unusually high, due to the high take-off speed. With a broad hull, the weight of all the parts, dimensioned with reference to the water stresses, would be so great as to lose again most of the weight saved by the heavy wing loading. I find here a sort of repetition of what was illustrated by the Staaken monoplane with its heavy wing loading. For the latter, an exceptionally flexible landing gear had to be developed, in order to avoid an increase in weight with respect to the landing stresses. Here an exceptionally favorable shape of hull had to be found, in order to enable a short start at high speed, in spite of the heavy step loading necessary for avoiding a too great weight of the hull.

The structural design of the hull is very simple (Fig. 8). The outer covering is so strengthened everywhere by inner riveted members, that it can transmit all the stresses to these members. In this way, strong corner flanges are formed on all four longitudinal edges. Strong transverse frames, five of which are water-tight bulkheads, maintain the cross-sectional shape of the hull. The bulkheads assure complete floatability, without danger of capsizing, even if any two of the main compartments should spring aleak simultaneously. The hull covering is everywhere accessible.

Wing Structure

Maximum strength with minimum weight.- The all-aluminum wings each consist of three main parts, the box girder (Fig. 9), which receives all the stresses, and the extremely light leading-edge section and trailing-edge section (Fig. 11) for giving the desired shape. These structures are usually stiffened by formers and covered with thin sheet metal.

The structure of the box girder is shown in Fig. 10. Two openwork longitudinal members connect the upper and lower wing coverings. Cross-ribs, riveted to the lower and upper wing covering impart the correct cross-sectional shape to the whole girder. The longitudinal members are so cut out or built up that they contain only the necessary diagonals and uprights. The sheet metal covering is protected from local buckling by being riveted to the ribs. I would like to designate the outer covering of the box girder, which is subjected to every kind of stress and contributes in a large degree to both the torsional and bending strength of the wing, as "full supporting," in order to distinguish it from the very thin metal covering of the Junkers and Dornier wings, which is often referred to as "supporting," although it really adds but little to the torsional strength of the wings.

Many experiments have shown us how the stresses caused by the bending and twisting of such box spars can be computed in advance. I hope that all patent questions will soon be so far settled, that we can publish these experimental results and the computation method. The results of such strength calculations now agree very well with the experimental results. Hence each small part can be made of just the right strength. Accordingly, the thickness of the sheet-metal covering and the cross-section of the corner flange, as likewise the diagonal braces and bulkheads, gradually decrease toward the outside. At the same time, the adaptation of the thickness of the material to the stress can be much more perfect than is the case in other methods of wing construction since, in them, the strength of a flange or other member running in the direction of the span cannot be changed every one or two meters, as in our method. Since, moreover, this box girder is more rigid than any other form of wing spar, it is obvious, without any further formulas or mathematical demonstrations, that the wings can be very light, so light in fact that they can be made entirely overhanging with an aspect ratio of 10 and as strong as required for looping and taxying. The wing has not shown the least tendency to whip or even to tremble in any of its parts, although we have given it very severe tests in gliding and curving flight.

Since the question of weight is extremely important, I would gladly have had, for my own purposes and for your information, an accurate weight comparison between our metal wing and other metal and wooden wings of correspondingly favorable air-resisting properties. Unfortunately, I have not succeeded in obtaining any such comparative figures for wooden wings and can, therefore, only make the following statements. The weight of our airplane is exactly the same as that of the English boat-seaplane F 5. The safety factor of the latter (3.75 in case A) is so small that, for this reason alone, neither looping nor taxying is possible. In our seaplane, the safety factor is sufficient for both looping and taxying, since it is still 2.5 times the maximum stress in the sharpest curving flight (See "Bausicherheit und Kurvenflug," "Zeitschrift für Flugtechnik und Motorluftschiffahrt," 1922, p.1). Of course these figures afford no direct comparison of the wing weights. It is manifest, however, that, on the other structural parts, such as the hull and tail unit, which are throughout of lighter construction than the wings, only such small weight savings can be made, that the smaller weight, in comparison with the F seaplane, must be accounted for by the wings.

Safety in the event of injury of important parts.- A wing should not break from being hit by gunfire nor from material defects, when any one of its structural members is injured. No local injury, either to a leading- or to a trailing-edge section can endanger the safety of the wing.

It is also obvious that the upper and lower sheet-metal covering of the box girder must be very seriously and extensively injured before the wing breaks. After the complete rupture of one of the diagonal or vertical bracing strips, the transverse stress would be transmitted by the neighboring transverse wall to the other members, though with a diminished safety factor. When the flange of a longitudinal member is injured, the stress, previously borne by it, is transmitted through the upper and lower covering, to the other longitudinal member. The wing is, therefore, statically indeterminate in each section and cannot be brought to the breaking point by injury to only one of its structural components.

Safety against weathering and corrosion.- A metal covering is indispensable for making an airplane independent of the weather. Something more is required, however, to protect it fully against corrosion. Unprotected duralumin is generally but little affected by the atmosphere. Whenever it is joined to other metals, however, a galvanic cell is formed which corrodes either the duralumin or the other metal, according to the sign of the electrical tension. For instance, duralumin is very rapidly corroded when joined to bronze or copper and, likewise, zinc is rapidly eaten away when in contact with duralumin and sea-water. Whenever different copper-containing duralumin alloys are joined, as, e.g., rivets containing more copper with sheets containing less copper, the alloy containing less copper will corrode.

Fortunately, ordinary steel and duralumin generally give rise to very slight electric action. On the contrary, steel containing much chromium or nickel can be used only with great caution. Duralumin is very rapidly destroyed by many good steels, including, among others, Krupp's non-rusting rich nickel-steel. In order to avoid failures, every kind of steel must therefore be tested with reference to the electric tension it develops in contact with duralumin. Moreover, the use of other metals, even steel, in conjunction with duralumin, should be avoided as much as possible. An all-duralumin wing, in which only the main fittings, for attaching it to the airplane, are steel, is less endangered by corrosion than any other kind of wing.

For perfect protection against corrosion, all parts must be well painted, both inside and outside. Every individual part of the finished wing of our seaplane can be inspected and painted on all sides, due to the removability of the leading- and trailing-edge sections.

Easy accessibility of every structural part.- The leading- and trailing-edge sections of the wing can be very easily removed by simply loosening a few external nuts. In order to increase the advantages connected with the removability of the leading- and trailing-edge sections, the latter are divided into equal, independent portions.

The wing girders can be removed by loosening the bolts which fasten them to the stubs on both sides of the hull, or to the next wing section, when the wings are each divided into several sections. The connections consist entirely of steel. Each pair of fittings, secured by two bolts, serves to transmit the stresses in the upper and lower flanges, as likewise the shearing stresses. This method of attaching has proved very satisfactory. After a series of tests extending over eight months, during which more than 70 flights were made, the seaplane, when taken apart for transportation, still looked like new.

Inexpensive manufacture.- This assumes that only simple structural parts, such as smooth sheet-metal and stamped openwork parts, but no tubes and no hollow members are used. For cheap production, the wing profile and chord remain the same throughout the whole span. All roundings of the wing tips, etc., are avoided since, as found by experiment, they do not appreciably diminish the drag. The construction cost is most reduced by diminishing the work of assembling as much as possible, because by the factory performance of most of the work, so long as the individual parts are still separate, much space is saved, a much greater division of labor is possible, a much better control of the workmen and the quality of their work is possible and a much greater use of special tools can be made.

Ribs and some other parts can be made, even in small numbers, after a kind of quantity production by the use of special tools. Most of the work done in making a box girder consists in riveting together the parts of the longitudinal members and in riveting the flanges to the top and bottom metal sheets, wherever these parts are separate. They are then fastened in a simple manner to the box girder, without the work's being delayed by difficultly accessible riveting. As a result of this simple manufacturing method, the division of labor is already far advanced for the few seaplanes we have already built. In future, all the riveting will be done by special riveters who will do nothing else. The quality of the work has also been greatly improved by this division of labor.

Launching gears.- One of the most disagreeable obstacles was the shallowness of the Oresund, which was less than 1 meter (3.28 ft.) deep for a distance of more than 300 m (984 ft.) from the shore, the bottom being partly stony and partly muddy. Due to the great distance between the land and sufficiently deep water, the construction of a concrete runway or the dredging of a sufficiently wide channel would have cost more than the company could afford. We therefore built two launching gears, one for each side of the seaplane (Figs. 12 and 13). They support the seaplane by means of specially provided points of attachment on each wing. These launching gears keep the hull and floats from striking the very uneven bottom of the Oresund and thus protect them from injuries which might cause leaks. The size of the wheels was determined by experiments on the spot with variously loaded rolling disks.

For attaching and detaching the launching gears, a U-shaped float was employed, from which one could readily work. The launching gears can be detached in four minutes by two unskilled workmen, by loosening the turnbuckles on the bracing cables and removing the bolts from the wing fittings of the seaplane. The launching gears then float of themselves. It likewise takes four minutes to attach them. In order to prevent the supporting tower of the heavy launching gear, in rough water, from damaging the wing before it can be attached, the well-padded launching gear is first suspended from the wing by a cable which can be shortened by means of a hand winch secured to the launching gear, until the latter is lifted about 50 cm (20 in.) out of the water and its attachment fitting engages in the corresponding fitting on the wing, so that the pointed fastening-bolts can be inserted. As soon as (by the gradual emergence of the launching gear from the water) a portion of its weight is borne by the wing, it follows every motion of the seaplane, since the motion of the water can then no longer give it any motion of its own.

These launching gears have proved very satisfactory and will therefore find use in many similar cases where, as with us, it is necessary to economize.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

a, Pay load
b, Cost per person
c, Flight time
d, Pay load, unit 800 kg
e, Flight time, unit 4 hrs.
f, Cost per person, unit 400 gold marks

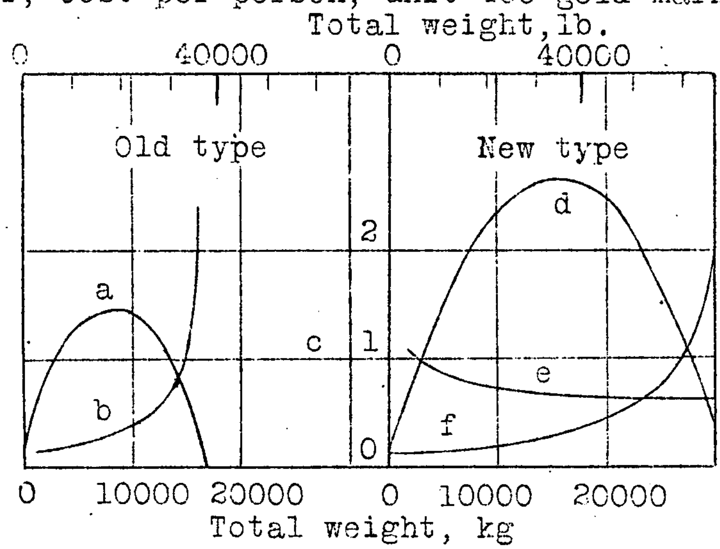


Fig.1

g, Turning time, unit 4 seconds

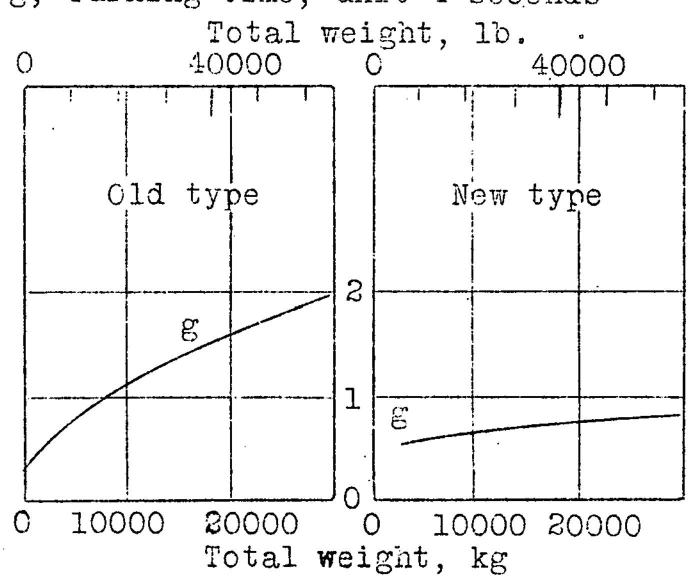
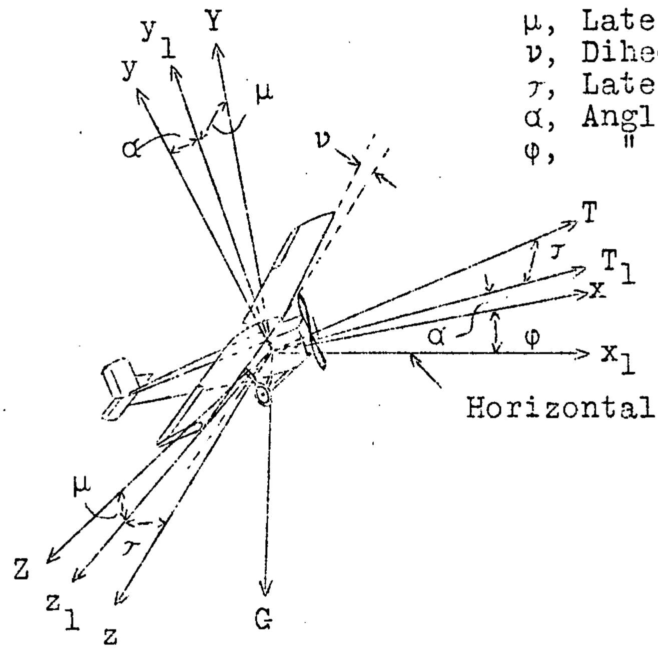


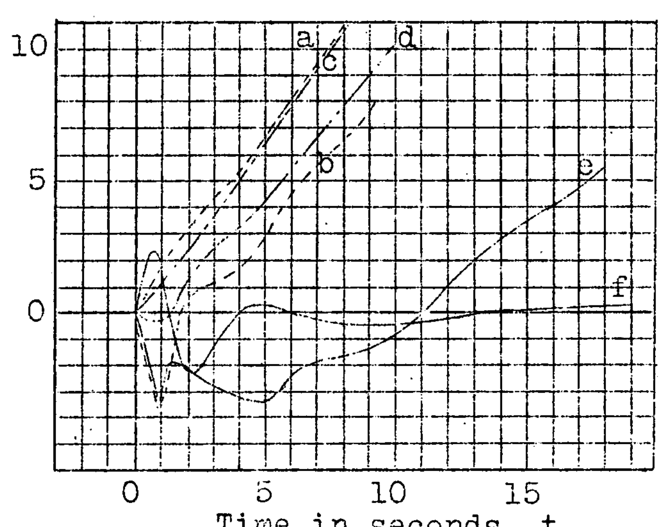
Fig.2



μ, Lateral inclination, degrees
ν, Dihedial angle, "
τ, Lateral " , "
α, Angle of attack, "
φ, " " flight path, "

Fig.4

↑-ω, Turning speed about vertical axis. 1 unit = 1° per sec.
↑ τ, Direction of lateral wind in degrees. 1 " = 10° " "
↑ μ, Lateral inclination in degrees. 1 " = 10° " "



a, -ω for 6°
b, -ω " 2°
c, μ " 6°
d, μ " 2°
e, τ " 6°
f, τ " 2°

Fig.5

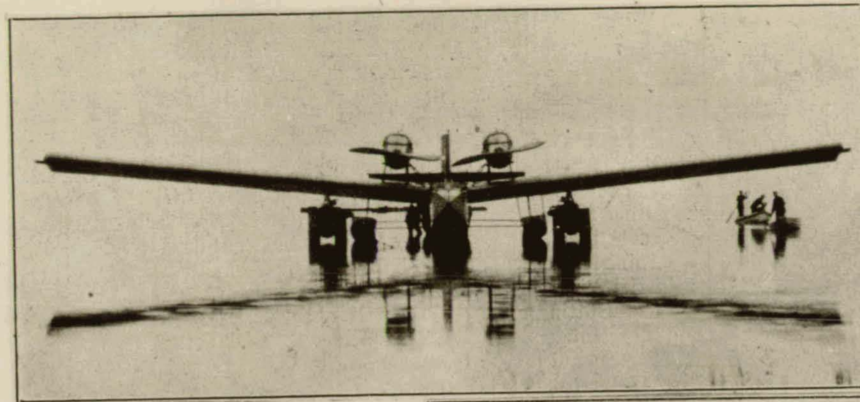


Fig.3

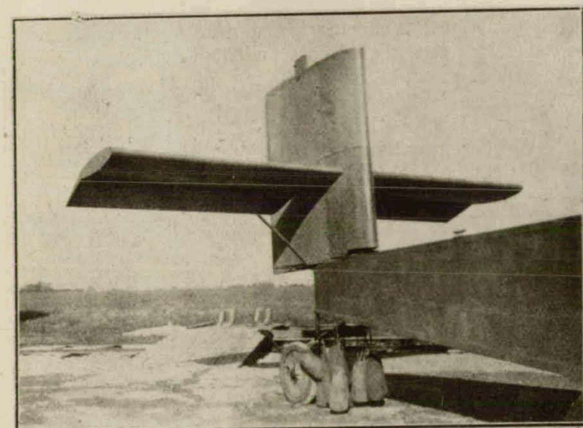


Fig.6

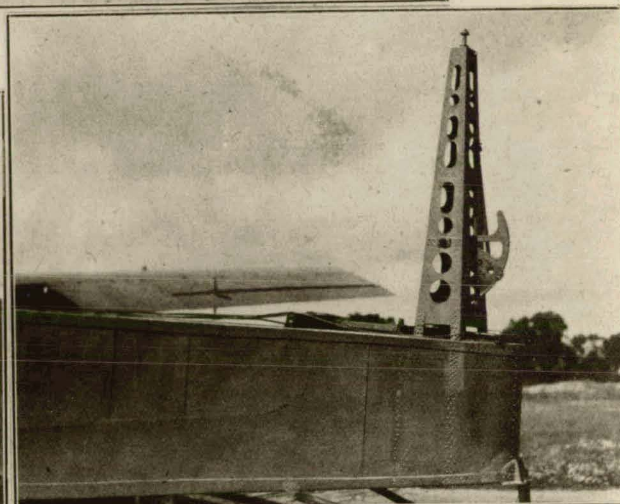


Fig.7

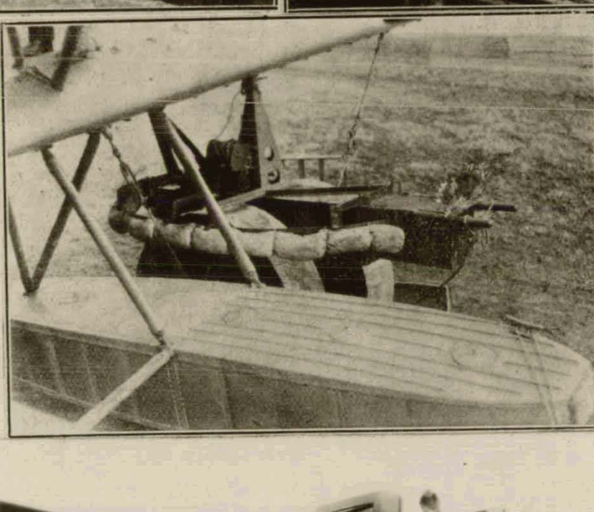
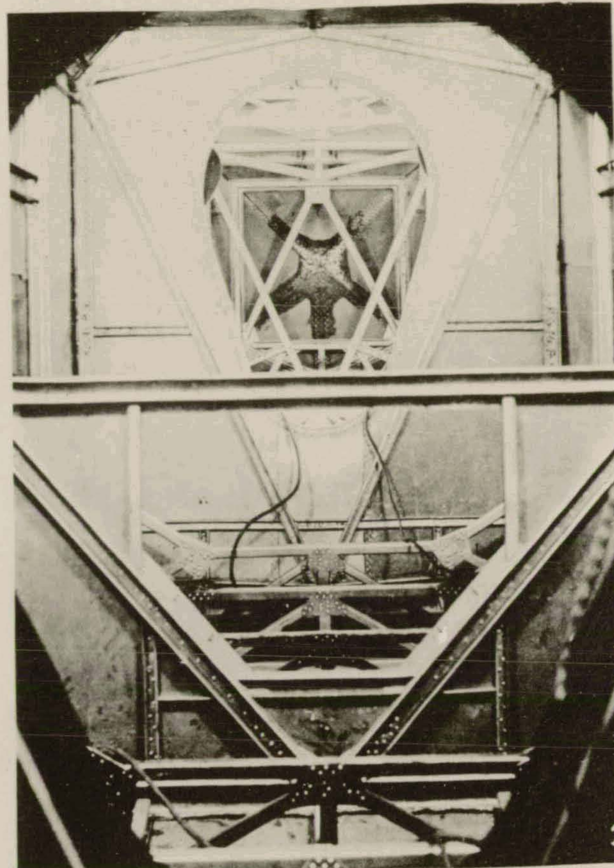


Fig.12

Fig.13

12296 A.S.



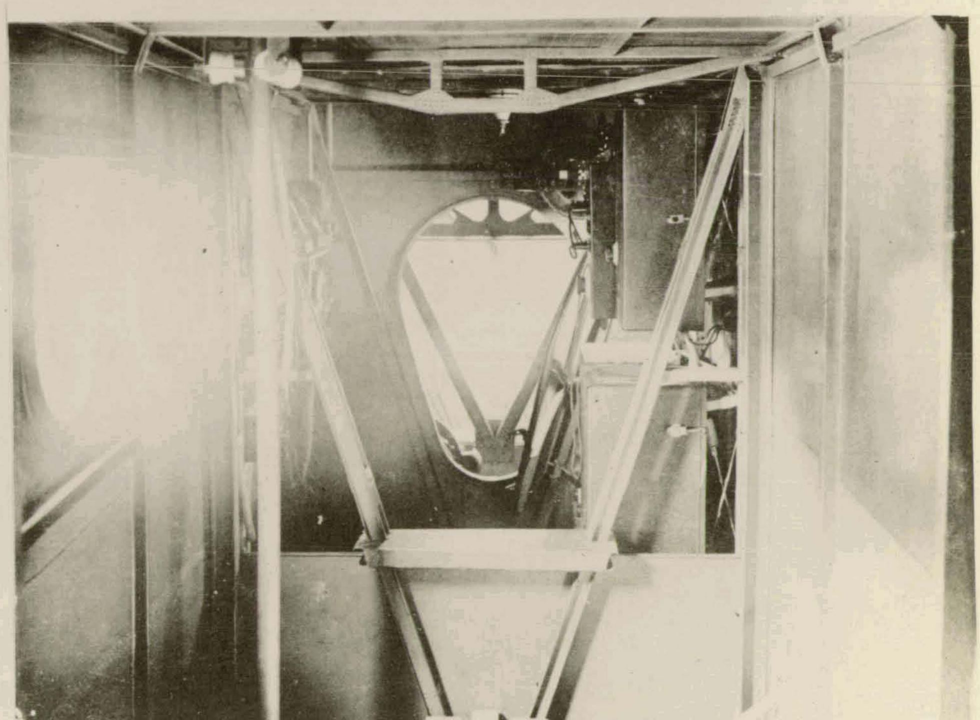


Fig.8

12297 A.S.

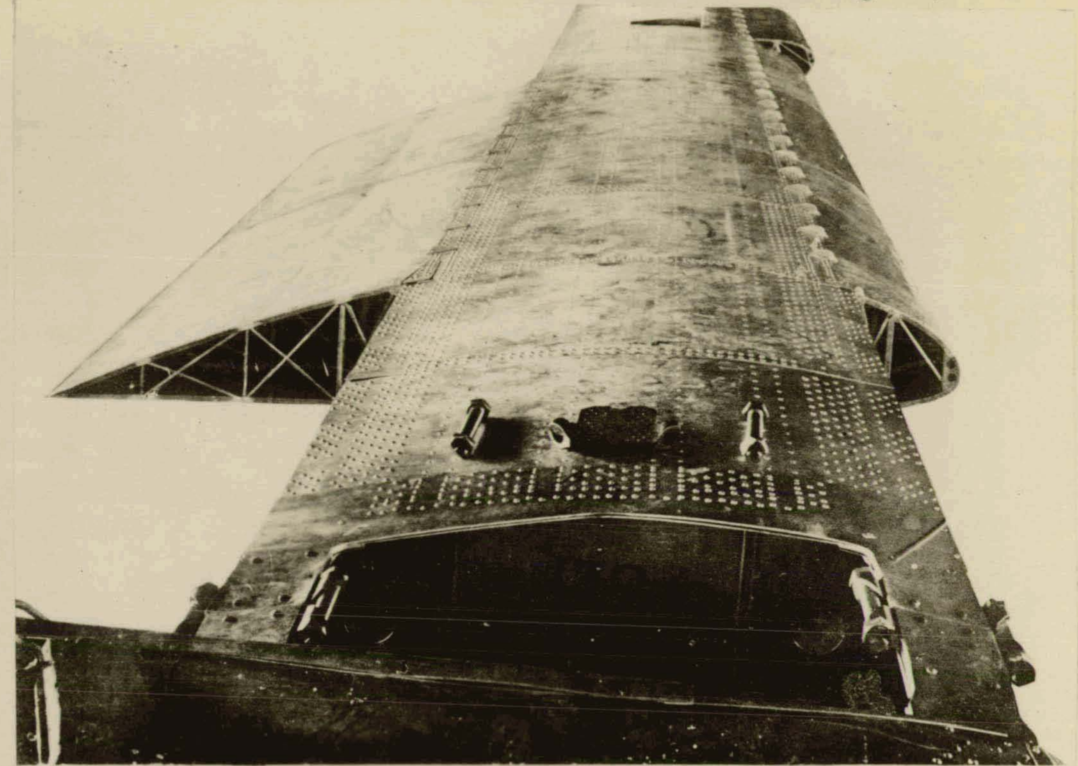


Fig.9

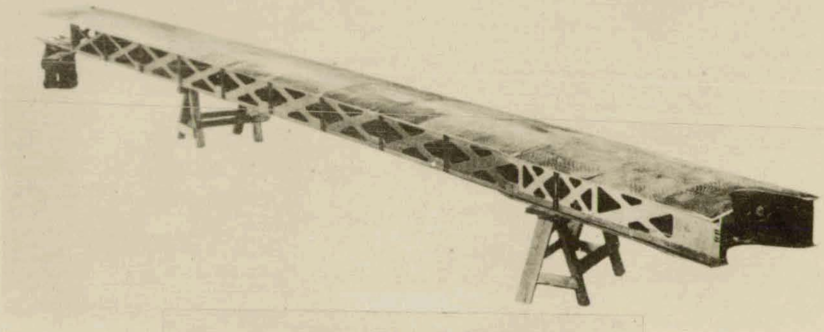


Fig.10

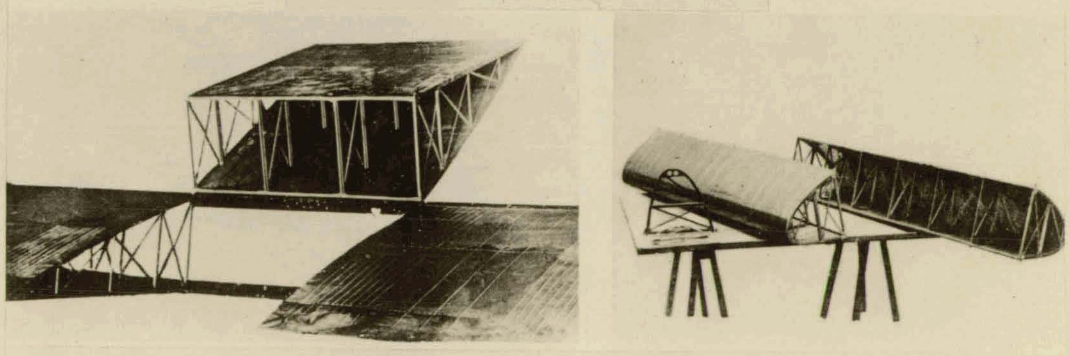


Fig.11

12298 A.S.