TECHNICAL NOTES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 38

MEASUREMENTS OF RUDDER MOMENTS ON AN AIRPLANE DURING FLIGHT.

By

Ing. v. Heidelberg.

Translated from
"Zeitschrift für Flugtechnik und Motorluftschiffahrt,"
Volumes Nos. 21 and 22,
Paris Office, N.A.C.A.

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The following report on the Measurements of Rudder Moments taken on an Airplane in Flight, is a translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," Volumes Nos. 21 and 22. The translation was prepared by the Paris Office of the National Advisory Committee for Aeronautics.

The urgent need for the highest possible number of utilizable machines, turned out in the shortest possible time, gave rise to such a demand on the airplane industry during the War, and there was such constant need for innovations in the airplanes themselves, that the manufacturers had to depend on their own common sense and experience rather than on scientifically acquired knowledge in the early years of the War. The results obtained were uncommonly successful, in spite of there being no spare time for developing aerodynamical theories and utilizing them as foundation to work upon. The method suited the times, but such an empirical mode of testing new types, constructed on unsure bases, could not be continued later on. The future of aircraft design will have to be entrusted to technically trained engineers who are specialists in their own line of work.

The creation of systematically scientific bases for the further development of airplanes will be specially sought after; their construction, their utilization and their efficiency will be studied, and strength calculations will be established by means of model tests, not only by static tests of breaking loads on costly finished airplanes, as heretofore. Much had been done along these lines before the War, and a great deal more has been achieved within the last few years. Wind tunnel model tests have been adopted extensively, but few practical tests have been made on airplanes during flight. The first utilizable tests carried out at the German Testing Laboratory* were cut short by the War. There is urgent need for such tests, for it is by their means alone that the value of model tests, obtained under simplified conditions, can be proved in respect of their application to actual airplanes. Wind tunnel measurements of large models and high velocities have occasionally produced astonishing results. This shows that it is only by means of a large number of practical tests that the requisite accuracy can be attained in aerodynamical calculations. Flight conditions, in their actual succession, can certainly never be realized by means of model tests, as such conditions depend upon the pilot, and are maneuvers which cannot be reproduced in testing models. All the conditions of non-steady flight and of the working of the propeller can certainly be obtained in model tests, but such tests can only be carried out with grest difficulty.

Up to the present time, there have been but few results of pracitcal flight tests, it being difficult to reduce the art of aviation to the limits of regular and systematic tests. The airplane requires so many constructional alterations, when its proportions are reduced to the dimensions of the model, that the effect of such modifications cannot always be foreseen and flight tests on actual airplanes are still dangerous, though less so than in former years, when less experience had been gained and there was less excess of engine power.

The rational starting point of all flight tests is steady horizontal flight. Measurements of swinging and steering conditions in curved flight should be postponed until horizontal flight has been brought to the standard of our present scientific knowledge. All the theoretical investigations and model tests made as yet deal with it alone.

There are two main points to be determined in investigating steady horizontal flight: they are the estimation of the forces and of the MOMENTS. The scope of the forces is important in its influence on the climbing capacity, speed and gliding capacity; that is, for the efficiency of the airplane. The equilibration of the moments is absolutely essential to its safety, stability, and controllability, - that is, as regards its flight qualities. The difficulties encountered in determining these two points are different in character: in measuring force, the functioning qualities of the engine and of the propeller are of such importance for the total efficiency of the airplane, that its aerodynamical qualities are of relatively minor importance and

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* See "Zeitschrift für Flugtechnik und Motorluftschiffahrt," No. V, 1914, pp. 3, 17, and 149; also "Technische Berichte der Flugzeugmeisterei," Vol. I, p.61.

slight alterations in the distribution of force may easily disguise aerodynamical influences quite effectively. It is essential, for these reasons, that particularly sensitive instruments should be used in measuring forces on airplanes, and a thorough acquaintance with the airflow conditions is equally necessary. It is, indeed, only when the propeller efficiency, decrease of power with atmospheric pressure, etc. has been thoroughly grounded that such measurements can be taken at all. When measurements of moments are taken, propeller and angine are, on the contrary, of small importance. Here we have to deal with the compensation of aerodynamical forces only, in the first case, and they can be measured with less delicate apparatus. The difficulties here encountered are of a purely technical nature, as the measurements of moments necessitate derangements of the equilibrium through unbalanced loads or by one-sided bracing of the cellule, and the pilot is therefore obliged to fly in an unbalanced airplane. These drawbacks may, however, be met by controlling devices and by experience on the part of the pilot.

We now propose to deal with such measurements of moments, giving the results of the action of the rudder on the position of the airplane as on the equilibrium of the moments. The measurement of moments is preceded by measurements of the dimensions of the moments produced by the steering of the rudder in their relation to the angle of attack. Calibrated rudder curves are obtained by such measurements, in the present instance for the rudder and the elevator. This theoretical data is closely connected with the direct and practical study of the influence of bracing on moments, and consequently on the equilibrium of the airplane and its safety in flight. Mention will also be made of the means by which errors in position can be corrected. A simple method of bracing is thus arrived at, and its direct utilization is shown in the test results given below.

Data on rudder efforts and the resultant moments has so far been obtainable from the controlling measurements taken in the Göttingen Model Testing Laboratory alone.* Such tests can only be carried out under simplified conditions, and they can only be applied to an airplane after it has been practically tested in flight. The Göttingen measurements take no account of the effect of the slip stream on the controls, although the rudder and fins are sensibly affected by the slip stream, as shown by the various positions taken up by an airplane when the engine is running, and in gliding flight. In the Göttingen measurements, the angle of attack has been successively increased by 5°, whereas such great differences never occur in the angle of attack in

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* Compare "Technische Berichte," Vol. I, No. 5, p.168.

actual flight, or at least not under the influence of the elevator. If the model tests are finally to be applied to that part of the control situated in the wake of the propeller wind, some further preliminary tests are needed, as ordinary plates were used in testing the control models, while the lateral controlling mechanism is always to be regarded as an extension of the wing ribs; also because such measurements apply to rudders having a depth of 1/5, 2/5, 3/5, and 4/5, whereas in actual airplanes such depth amounts to about 2/7.

During the War, the present writer took measurements of moments and rudder forces while flying on a DfwCV airplane (see Figs. 1 to 3), with a 200 H.P. Benz engine, at the German Testing Laboratory at Adlershof. The results of the tests are collectively stated below, as compared to those of the Göttingen Laboratory. The exact measurements of the airplane are to be found in Table 1 and Fig.1.

Table 1.

Measurements of the Dfw C V Airplane.

Wings mm.	upper	lower
Total Span	13 100	11 940
ti	1 750	1 750
ta	1 750	1 570

Total surface F = 41.26 sq.m.

Stagger β : 0°

Upper dihedral angle = 179°
Lower " " = 178°

Angle of the retreating upper wing ..180°
" " " retreating lower wing ..180°

Angle of attack:

Distance from the center	upper: right	upper: left	lower: right	lower: left
outer	2°	2°	4.5°	4.5°
inner	4°	4°	6.0°	6.0°
fixed part of tail plane			2.25°	2.25°

MEASUREMENTS OF LATERAL MOMENTS ON AN AIRPLANE.

There are two ways of producing unbalanced lateral moments in an airplane, apart from the steering moment:

1. By the application of weights on one side.
2. By unequalized bracing (unbalanced lifting force).

As the moment due to unbalanced lifting force can be compensated by the action of the aileron, and the location of the aileron at the moment in question therefore presents the possibility of equilibrating both the methods above referred to, and of establishing calibrated curves showing the force on the aileron in terms of the angle of attack.

Water weights are used in order to produce weight moments. A second manner of producing such moments is that of unequalized bracing below the spars (dissimilar angles of attack on the right and on the left). The measurements taken are for directional control and elevator control.

On the outer struts, water tanks of similar size and shape are built in between the wings in such a manner that the extra head resistance and the weight of the tanks are equal on both sides of the wings, and are therefore, equillibrated for the airplane (Figs. 2 & 3). The observer's cockpit contains a water tank of 30 liters capacity, located close to the pilot's seat in order to keep the extra weight as near as possible to the center of pressure. From this tank, a side-tank can be filled with water by means of a pressure pump b. The rubber tubing for that purpose is located in the bracing of the lower wing, so that it causes no derangement to the airstream. The volume of water pumped into the side-tank during flight can be read in liters on a benzine meter d specially calibrated for the purpose.

The aileron is at a distance of 5 m. from the center line of the body. The angles of attack are measured on the lower wings below each rib by means of a water-level, and determined as angles of the corresponding wing chord in relation to the engine shaft. If the angles of attack of a wing need alteration, the cables of the front bearing surface are left as they are, the cables and counter-cables of the rear bearing surface alone being altered. The turnbuckles are thoroughly loosened before bracing, and then tightened until the relative positions of the upper wings and the lower wings (stagger 0 being measured with a plumbline) are equal. In this way, the dihedral angle remains unchanged, the fore main struts and the front loads are not eccentrically loaded, and there is not too high a stress on the turnbuckles. The differences in the angles are the differences in the chord angles of the right and left lower wings at the ribs which are marked as being adjustable, on the outer or inner strut. On account of the construction of the interior of the wing, the adjoining ribs take up the positions shown in Table 2 after such adjustment. The fourth ribs, left and right, counting from the outside, bear the mark 4.5° angle of attack. A difference of 1° is, for instance, thus obtained in the angle of attack on the outer strut (test series b), when the fourth right rib is reduced by 1°, so that its chord is inclined towards the engine shaft at an angle of 5.5°, while the left rib is inclined to the engine shaft at an angle of 4.5°. This is the process adopted in equipping airplanes at the factories. Differences of 1° in the angle of attack, at the rear outer strut, are visible to the naked eye by reason of the notable camber of the upper surface. With the aid of a cup anemometer located beyond the sweep of the slip stream, on the right inner strut, a uniform flight velocity is maintained during the entire series of tests, when flying either at full intake or in gliding flight. In flight against the wind, readings are taken at an altitude of 2000 to 2200 m., so that approximately equal flying conditions may be attained even when the flights take place on different days.

Table 2.

Bracing of the Test Airplane in Test-series a) to d).

Test Series	Angle of Attack in Degrees.															
	Right Wing (number of ribs):															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
a)	2.5	3.0	4.0	4.5	5.1	5.3	5.3	5.5	5.7	6.0	6.0	6.0	6.0	6.0	5.9	5.9
b)	2.8	4.3	5.1	5.5	5.5	5.7	5.8	5.9	6.0	6.0	6.0	6.0	6.0	6.0	5.9	5.9
c)	2.5	3.5	4.3	5.0	5.2	5.5	5.5	5.7	5.9	6.0	6.0	6.0	6.0	6.0	5.9	5.9
d)	2.8	4.3	5.1	5.5	5.5	5.7	5.8	5.9	6.0	6.0	6.0	6.0	6.0	6.0	5.9	5.9

Table 2 (Cont'd)

Bracing of the Test Airplane in Test-Series a) to d).

Test Series	Angle of Attack in Degrees																	
	Left Wing (number of ribs).																Diff. of Angle	Dihedral.
	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1		
a)	5.9	5.9	6.0	6.0	6.0	6.0	6.0	5.7	5.5	5.3	5.3	5.1	4.5	4.0	3.0	2.5	0.0°	+2°
b)	5.9	5.9	6.0	6.0	6.0	6.0	6.0	5.7	5.5	5.3	5.3	5.1	4.5	4.0	3.0	2.5	1.0°	+2°
c)	5.9	5.9	6.0	6.0	6.0	6.0	5.7	5.5	5.0	5.0	4.8	4.2	3.5	3.1	2.3	1.3	1.5°	+2°
d)	5.9	5.9	6.0	6.0	6.0	6.0	5.7	5.5	5.0	5.0	4.8	4.2	3.5	3.1	2.3	1.3	2.0°	+2°

Table 3

Results of Test-series a) to d)

Test Series	Diff. in Angle of attack rt. and left	Speed km/h	Altitude in m.	Kind of Flight	Elevator	Rudder	Aileron	Water Weight kg.	Moment m/k
a)	0.0°	110	2000 to 2200 and 2200 to	Engine running	5.5°	4.5°	0.0°		
				Gliding flight	-1.0°	4.5°	0.5°	–	–
				Engine running	4.5°	4.5°	0.5°	10	50
				Gliding flight	-1.5°	4.5°	1.25°		
				Engine running	4.5°	4.5°	1.5°	15	75
				Gliding flight	-1.5°	4.5°	2.0°		
				Engine running	4.5°	4.5°	2.25°	20	
				Gliding flight	-2.0°	4.5°	2.75°		
				Engine running	4.5°	4.5°	2.8°		
				Gliding flight	-3.0°	4.5°	3.3°	30	150
b)	1.0°	110	2000 to 2200 and 2200 to 2000	Engine running	5.0°	3.5°	-1.5°	–	–
				Gliding flight	0.0°	3.5°	-1.0°		
				Engine running	5.0°	3.5°	-0,75°	10	50
				Gliding flight	-0.5°	3.5°	-0.25°		
				Engine running	4.5°	3.5°	0.0°	15	75
				Gliding flight	-1.5°	3.5°	0.5°		
				Engine running	4.0°	3.5°	0.75°	20	100
				Gliding flight	-2.0o	3.5°	1.25°		
				Engine running	4.0°	3.5°	1.3°	30	150
				Gliding flight	-2.5°	3.5°	1.8°		

Table 3 (Cont'd)

Results of Test-series a) to d).

Test Series	Diff. in Angle of Attack rt. and left	Speed km/h	Altitude in m.	Kind of Flight	Elevator	Rudder	Aileron	Water Weight kg.	Moment m/k
c)	1.5°	110	2000 to 2200 and 2200 to 2000	Engine running	5.0°	2.5°	-3.0°	–	–
				Gliding flight	-1.0°	2.5°	-2.0°		
				Engine running	5.0°	2.5°	-1.95°	10	50
				Gliding flight	-1.5°	2.5°	-1.45°		
				Engine running	5.0°	2.5°	-1.0°	15	75
				Gliding flight	-1.5°	2.5°	-0.5°		
				Engine running	4.5°	2.5°	-0.45°	20	100
				Gliding flight	-2.0°	2.5°	0.05°		
				Engine flight	4.0°	2.5°	0.1°	30	150
				Gliding flight	-3.0°	2.5°	0.6°		
d)	2.0°	110	2000 to 2200 and 2200 to 2000	Engine running	5.5°	2.5°	-4.0°	–	–
				Gliding flight	1.0°	2.5°	-3.5°		
				Engine running	5.0°	2.5°	-3.25°	10	50
				Gliding flight	1.0°	2.5°	-2.75°		
				Engine running	5.0°	2.5°	-2.5°	15	75
				Gliding flight	0.5°	2.5°	-2.0°		
				Engine running	5.0°	2.5°	-1.75°	20	100
				Gliding flight	-0.5°	2.5°	-1.25°		
				Engine running	4.5°	2.5°	-1.0°	30	150
				Gliding flight	-1.5°	2.5°	-0.5°		

The position of the elevator and of the lateral control may be read on graduated sectors with movable fingers; these sectors are installed in the observer's cockpit, in connection with the corresponding wires, and the position of the right aileron is determined in a similar manner, (see Fig.5). As these flights were extended over a period of ten days, so that they took place under approximately similar conditions of temperature and altitude, in relation to the surrounding atmosphere, and at a similar time and speed, the static pressure may justly be said to be approximately constant in the different groups of tests. No measurements were taken at the time.

The tests were carried out in the following manner:

a) With the airplane normally braced (Compare Table 2, test a), the pilot climbed to an altitude of 2000 m. In flying from 2000 m. to 2200 m. with the engine running, a speed of 110 km/h was studiously maintained, according to the anemometer, in horizontal flight against the wind. The positions of the elevator, the rudder and the aileron were read during the time. Then came a descent from 2200 to 2000 m. in gliding flight (throttle closed), the velocity of 110 k/m being maintained and readings again taken in all three positions. Ten liters of water were pumped into the right-hand side-tank by the observer while the airplane dropped to 1900 m. and climbed again to an altitude of 2000 m. Readings were again taken during flight with the engine running, from 2000 m. to 2200 m., and also in the succeeding gliding flight from 2200 m. to 2000 m., and similar measurements were taken with 15, 20 and 30 liters of water in the side-tank.

The entire series of tests was repeated three times, as follows:

b) With a difference of 1° in the angle of the attack on the right and left sides, produced by lowering the right outer rear strut (the fourth rib below the strut being marked for the angle of attack).

c) With a difference of 1.5° in the right and left angles of attack, caused by raising the left outer rear strut by 1/2°, and by lowering the right outer rear strut by 1°.

d) With a difference of 2° in the right and left angles of attack, produced by lowering the right outer rear strut, and raising the left one, in each case by 1°.

Test series a) to d) were thus accurately carried out with a view to obtaining a reliable calibration curve by means of numerous readings. The results of this test series are collectively given in Table 3. Figs. 6 to 9 show the effect of unequalized bracing of the outer struts on the aileron action, with the engine running and in gliding flight. The sheaf of curves follows the same general direction, converging only by 5°. It may therefore be concluded that the wing tips are no longer under the influence of the slip stream. If the current had been disturbed by the slip stream, there would also have been consequent alterations in the form of the curve sheaf. It follows that only one calibrated curve is valid for the aileron (Fig. 10), both when the engine is running and in gliding flight. It also follows that the measurements of control models, taken at the Göttingen Laboratory for the calculation of ailerons, may be applied to flying airplanes if the conditions be duly considered, because the currents prevailing at the ailerons, directly they are beyond the influence of the propeller wind, are similar to those encountered in the wind tunnel. The conditions differ only in so far as that certain vortices and divergences of the air-stream occur at the tips of the wings, being due to the influence of the edges, during flight, whereas such derangements do not occur to the same extent in the wind tunnel.

The sweep of the curves of the values of C_n* found in the Göttingen Report and reproduced in Figs. 11 and 12 is quite similar to that of the calibrated curve in Fig. 10. It gives the impression that the point of inflection is dependent on the ratio of the rudder area to the total area. In some of the curves, a further point of inflection is shown for larger angles of attack. The Göttingen measurements do not show whether there is also a point of inflection between 0 and 5°, as they were carried out only at intervals of 5°. To judge by the sweep of the curves, however, there is every reason to believe that it is possible.

The Göttingen values of moment cannot be compared with those obtained at Adlershof on account of the comparatively large angle of attack in the Göttingen tests. It must also be remembered that the Göttingen ratio between rudder surface and total surface is 1/5: 2/5, whereas it is only 2/7 in the tests in question. If mean values were found for the two Göttingen models, they would approximately correspond to the ratio of 2/7. If the value of 2° be interpolated, the scale of dimensions of the resulting values of moment is similar to that of the values found at Adlershof; it is only 10% lower. If we take a point of retrogression between 0 and 5° in the Göttingen curves, as was done for the Adlershof calibrated curve, higher moments are obtained, and the Göttingen curves correspond even more exactly to calibrated curve No. 10.

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* See "Technische Berichte" Vol. 1, No.5, Tables CLXIII and CLXIV.

With linear interpolation, the following model values are obtained from the Göttingen curves for the aspect ratio 2 : 7:

Angle of attack:	-12°	-9°	-6°	-3°	0°	3°	6°	9°	12°
Moment:	71	84	76	84	82	71	69	55	46m/kg,

as compared to 90 m/kg. for the Adlershof calibrated curve with 2° rudder position. Values of about 10% higher than the Göttingen measurements were anticipated, the two vortexes alone being bound to reduce the lift in measuring the rudders - unlimited and free as they were on both sides - more strongly than the single vortex on the outer side of the aileron. They may therefore be considered to correspond satisfactorily.

The effect of the decrease in the torque of the engine at an altitude of 2000 m., when passing from flight with the engine running to gliding flight, is made evident by the displacement of the curve sheaf, in flight with the engine running, by a difference of 0.5° in the position of the aileron as compared to its position in gliding flight (See Fig.13).

According to the calibrated curve shown in Fig. 10, the difference of 0.5° in the aileron position corresponds to a clock-wise transverse moment of the 200 HP Benz engine at an altitude of 2000 m. The only conclusion that can be drawn is that the total influence of engine and propeller is such that a moment of 40 kg/m should be added on the right side, in order to keep the airplane in a favorable position when passing from flight with the engine running to gliding flight.

It is important to note that considerable transverse moments can be brought to bear upon the airplane (See Fig.10) by making comparatively small alterations in the position of the aileron, while extremely high unequalized moments may, on the other hand, easily be compensated by altering the position of the aileron. Even for the highest transverse moment of 150 kg/h, an alteration of 2.8° in the aileron position (applied to one aileron) is sufficient. Protracted flight with such a high unequalized moment is certainly fatiguing to the pilot, particularly when the airplane has a joy stick. He must also avoid curves at the side on which a moment of more than 100 m/kg. arises, as he would find it difficult to get out of such curves. If we apply this result to the two-strut C airplane, the span of which is about the same when the aspect ratios are practically stationary and with equally large surface loads, and which shows little difference in the position of the perpendicular struts, the following conclusions may be deduced:

In the case of night-bombing airplanes, in which part of the bomb load is suspended under the lifting surface on both sides of the fuselage, 100 kg. may safely be suspended within 2 m. of the center of the fuselage because the airplane runs no risk, and can continue to fly, in spite of the unequalized weight and even if the bomb releasing device should get out of gear on one side. It is, therefore, not absolutely essential that the bomb-release should act simultaneously on both sides. By means of the arrangement above described, they can be alternately dropped. It might be advisable, however, that such aircraft should be equipped with reversible or semi-reversible aileron controls, that is, with wheel gearing, so that the pilot may not be over fatigued by the unequalized loading of the airplane.

The fact that the calibrated curve is flatter in the center is probably due to certain effects of the air current produced by the portion of the wing in front of the aileron. In case of extremely large angles (over 12° according to Göttingen measurements), the inversion of the steep upward portion of the curve may be anticipated, though that portion of the curve lies beyond the range of possible measurements.

A further series of tests was carried out as a sequel to those above mentioned, the differences on the right and on the left of the angles of attack being represented, by way of comparison, as unequalized displacements of the inner struts. The results of this series of tests, e , are shown in Table 4. In Figs. 14 and 15, a comparison is drawn between this method and the inner strut displacement applied to the first series of tests, as regards their influence on the position of the aileron in flight with the engine running and in gliding flight.

This comparison shows that unequalized transverse moments or the drag of an airplane - which amounts to the same thing - may be more effectively corrected by a right and left displacement of the angle of attack below the outer struts. A bracing under the outer struts thus has greater influence on the transverse position of the airplane than bracing of the same dimension under the inner struts, in spite of the decrease of lift towards the wing tips.

The actual difference in the angles of attack, from right to left, is at most 1° from the central position, though it may amount to 2° in tests. This displacement causes a strong torsion of the surfaces, plainly visible to the naked eye. Even with a displacement of 1° under the inner or outer struts, the differences affecting the aileron are not inconsiderable, as the transverse moment amounts to 75 kg/m. in the first instance, and to 56 kg/m. in the second

Table 4.

Results of Tests with Alterations in the Position of the Inner Struts (Test-series e)

Test Series	Diff. in angle of attack rt.& left	Speed km/h	Altitude in m.	Kind of Flight	Elevator	Rudder	Aileron	Water Weight kg.	Moment in m/kg.
e)	0.0°	110	2000 to 2200 2200 to 2000	Engine running	5.5°	4.5°	0.0°	–	–
				Gliding flight	0.0°	2.5°	-0.5°		
	1.0°			Engine running	5.5°	4.5°	-1.0°	–	–
				Gliding flight	0.0°	2.5°	-1.5°		
	1.5°			Engine running	5.5°	4.5°	-2.0°	–	–
				Gliding flight	0.0°	2.5°	-2.5°		
	2.0°			Engine running	5.5°	4.5°	-3.0°	–	–
				Gliding flight	0.0°	2.5°	-3.5°		

instance. The following rules may therefore be applied to bracing:

The side-slip of an airplane may be corrected by altering the angle of attack on one side, under the inner or outer strut. The latter method is the more effective.

On the basis of test results obtained in series a to d,. Fig. 16 further shows how the position of the directional control is altered by transverse moments produced either by adding weights or by altering the angle of attack on one side. This figure clearly shows that purely transverse moments produced by weights have no influence whatever on the position of the directional rudder when the engine is running or in gliding flight. The frequently expressed opinion that a side-slip accompanies transverse moments causing rotation of the airplane thus fails to hold good when such rotation is the result of moments due to weights, and is equilibrated by altering the position of the aileron. This action of the aileron may be traced to the simultaneous action of both. (In the case of moments that make the airplane tilt laterally, there is no simultaneous rotation of the cellule if the airplane be disequilibrated.)

With the aileron position formerly in general use, one side only came into play, while the opposite side remained inert and rotation was the obvious result of the unequalized resistance.

In Fig. 17, a comparison is again drawn between the displacement of the outer strut in tests a to d and the displacement of the inner strut in series e , as regards their influence on the position of the aileron. We know that an unequalized alteration of the angle of attack below the inner strut has no effect on the position of the aileron, though side-slip as well as rotation results from such alteration below the outer struts, the position of the aileron and the directional control being thereby affected.

The following principles may therefore be adopted in practice:

The rotation of an airplane can only be corrected by altering the angle of attack below the inner struts. There is no need to fear a consequent recurrence of side-slip. The alteration of the angle of attack below the outer struts is certainly a more efficacious means of correcting rotation, but it causes side-slip of the airplane after bracing.

Fig. 17 further shows that the directional control takes up various positions in flight with the engine running and in gliding flight, in consequence of the action of the propeller. This may be ascribed to the influence of the slip stream on the rudder.

In the case of an engine running with full load, the moment exerted on the fixed part of the rudder by the slip stream causes an anti-clockwise action of the rudder. This necessitates the production of a counter-moment by clockwise steering with the directional rudder. Observations taken at the propeller lead to the supposition that the right-handed sweep of the slip stream trails off to the right at the back, when the engine is at full intake, like the wash behind a rotary ship's propeller when it is stationary in the water.

MEASUREMENTS OF LONGITUDINAL MOMENTS ON AN AIRPLANE.

Close beside the tail-skid, a tank is built into the rear end of the fuselage. This tank can be filled by pumping from the observer's cockpit during flight. When the tests were being carried out in November and December, 1917, water could not be utilized on account of frost, and the "Allweil" pump would have been stopped up by the addition of kitchen salt to the water. The tank was therefore filled with gasoline of 0.720 specific weight. The distance between the center of the tail and the c.g. of the airplane is taken as the lever arm of the longitudinal moments, and the migration of the total c.g. towards the rear, due to increase of weight in the rear tank, is also taken into consideration. Including the empty tank, the installation weighs 5.2 kg., and the calibrated curves of the elevator consequently run from that point. The quantity of fuel carried during the tests being always the same, the total weight of the airplane and the position of the c.g. remain constant.

Contrary to the method followed in the preceding tests, the angles of attack of the wings are altered to the same degree on both sides of the airplane (the setting of the wings being left unaltered), that is, the wings are drawn up just so much on the trailing edges, below the outer struts, as they are lowered below the inner struts. The position of the wings relative to the engine shaft depends upon the wing chord adjustment prescribed by the manufacturer. Increased incidence is marked with a minus, decreased incidence with a plus.

The tests were carried out like the earlier series with the sole difference that a flight velocity of 120 km/h was maintained in the present instance. The results are collectively given in Table 6. If we compare, by means of this table, the influence of the various positions of the wing chords, as affecting the engine shaft, on the position of the elevator when flying with the engine running and in gliding flight (See Figs. 18 and 19) there is a noticeable difference in the sweep of the curves. Contrary to the results of previous tests (Figs. 6 to 9), the curve sheaves do not deviate in parallel directions, but in different directions. This confirms the belief that it is not only the deviation of the air current behind the wings, and the lift of the fixed part of the stabilizer that act as air forces on the controlling part of the fuselage, but that the position of the elevator is also considerably influenced by the propeller wash. As the measurements were made with the engine running and in gliding flight, at the same altitude, on the same day, and at the same flight velocity, - that is, with the same impact pressure, the deviation of the air current of the wings was the same for both methods of flight. The difference in the curve is therefore due to the fact that the characteristic values of the lift of the fixed plane are different in gliding flight from those in flight with the engine running, on account of the unequalized angle of attack and the air eddy of the propeller. The impact pressure, $\left(\frac{1}{2}\frac{\rho}{gv^2}\right)$ during the tests, amounted to 68 kg/sq.m. The angle of attack, in flight with the engine running and in gliding flight, could not be successfully measured, the apparatus specially designed for the purpose proving defective at the first test. In spite of this, it could be seen that there is little variation in the angles of attack with the engine running and in gliding flight, so the alteration in the first approximation may be stated as null.

The calibrated curves of the elevator (Fig. 20), which are taken from the test results, comprise the influence of all three kinds of air forces on the controlling devices and on the position of the elevator. The possibility of calculating, from the Göttingen measurements, a calibrated curve taking no account of the influence of the propeller wind, provides an opportunity of checking the curves in question by comparison with the Göttingen measurements and determining, at the same time, to what extent a calibrated curve based partly on theory and partly on measurements taken in the wind tunnel can be applied in practice.

For the calculation of the calibrated curve, similar angles of attack were presumed for flight with the engine running and for gliding flight. In the present instance we get the following values:

Impact pressure $q = 68$ kg/sq.m.

Angle of attack $\alpha =$ constant.

Distance of the axis of rotation of the elevator from the c.g. a ...... = 5 m.

Surface of the fixed plane f ..... = 4.13 sq.m.

Longitudinal moment due to the additional weight ....M_Z = 19.4 m/kg.

Angle of the elevator .... = $+5.75^\circ$

The controlling moment M_L is algebraically composed of the moment M_Z of the additional weight and the wing moment M_F. To obtain equilibrium, we must have the following solution:

$$M_F = M_L - M_Z.$$

Now $$M_L = C_n \,.\, q \,.\, f \,.\, a.$$

The normal air force symbol C_n for the controlling action is also dependent on the angle of attack α of the control and on the angle θ of the elevator. According to Göttingen measurements, it is as follows:

$$C_n = C_{no}(\alpha) + 2.4\ \theta,$$

$$M_L = M_F + M_Z = M_F(\alpha) + C_{no}(\alpha) \,.\, a \,.\, f \,.\, q + 2.4\, a\, f\, q\, \theta$$

The test shows that an additional moment of 19.4 m.kg. with a wing angle of -1.0° relative to the normal corresponds to a rudder angle of 5.75° (See Fig. 20). From the equation:

$$M_L = \text{constant} = 34.2\ \theta,$$

we get the following supplementary moments for the additional angles,

$\theta =$ 0.5	1.0	1.5	2.0	2.5	3.0
$M_L =$ 17.1	34.2	51.3	68.4	85.2	102.6

calculated from the normal trim of 5.75° downwards.

Table 5.

Bracing of the Test Airplane in Test-Series f) to k).

Test Series	Angle of Attack in Degrees.															
	Right Wing (Number of Ribs).															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
f)	4.0	4.5	5.0	5.5	5.8	6.2	6.5	6.8	7.0	7.0	7.0	7.0	7.0	6.8	6.6	6.3
g)	2.5	3.5	4.3	5.0	5.3	5.5	5.8	6.2	6.3	6.5	6.5	6.5	6.5	6.4	6.3	6.2
h)	2.5	3.0	4.0	4.5	5.1	5.3	5.3	5.5	5.7	6.0	6.0	6.0	6.0	6.0	5.9	5.9
i)	2.3	2.8	3.8	3.9	4.0	4.4	4.6	4.8	4.9	5.3	5.4	5.5	5.7	5.7	5.7	5.7
k)	1.3	2.3	3.1	3.5	3.8	4.3	4.3	4.3	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Table 5 (Conclusion).

Bracing of the Test Airplane in Test-Series f) to k).

Test Series	Angle of Attack in Degrees.																Diff. of Angle	Dihedral
	Left Wing (Number of ribs).																	
	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1		
f	6.3	6.6	6.8	7.0	7.0	7.0	7.0	7.0	6.8	6.5	6.2	5.8	5.5	5.0	4.5	4.0	1.0°	2°
g	6.2	6.3	6.4	6.5	6.5	6.5	6.5	6.3	6.2	5.8	5.5	5.3	5.0	4.3	3.5	2.5	0.5°	2°
h	5.9	5.9	6.0	6.0	6.0	6.0	6.0	5.7	5.5	5.3	5.3	5.1	4.5	4.0	3.0	2.5	0.0°	2°
i	5.7	5.7	5.7	5.7	5.5	5.4	5.3	4.9	4.8	4.6	4.4	4.0	3.9	3.8	2.8	2.3	-0.6°	2°
k	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.9	4.3	4.3	4.3	3.8	3.5	3.1	2.3	1.3	-1.0°	2°

Table 6.

Results of Test-series f) to k).

Test Series	Diff. in angle of attack, right and left	Speed km/h	Altitude in m.	Kind of Flight	Elevator	Rudder	Aileron	Water Weight kg.	Moment m/kg.
f)	±1.0°	120	2000 to 2200 and 2200 to 2000	Engine running	7.55°	4.5°	0.0°	5.2	19.4
				Gliding flight	6.20°	2.5°	0.5°		
				Engine running	8.50°	4.5°	0.0°	12.4	46.0
				Gliding flight	7.00°	2.5°	0.5°		
				Engine running	8.70°	4.5°	0.0°	16.0	59.2
				Gliding flight	7.50°	2.5°	0.5°		
				Engine running	9.00°	4.5°	0.0°	19.6	72.3
				Gliding flight	8.00°	2.5°	0.5°		
				Engine running	9.40°	4.5°	0.0°	26.8	98.3
				Gliding flight	9.00°	2.5°	0.5°		
g)	±0.5°	120	2000 to 2200 and 2200 to 2000	Engine running	6.95°	4.5°	0.0°	5.2	19.4
				Gliding flight	6.00°	2.5°	0.5°		
				Engine running	7.75°	4.5°	0.0°	12.4	46.0
				Gliding flight	6.90°	2.5°	0.5°		
				Engine running	8.00°	4.5°	0.0°	16.0	59.2
				Gliding flight	7.30°	2.5°	0.5°		
				Engine running	8.25°	4.5°	0.0°	19.6	72.3
				Gliding flight	7.80°	2.5°	0.5°		
				Engine running	8.70°	4.5°	0.0°	26.8	98.3
				Gliding flight	8.80°	2.5°	0.5°		
h)	0.0°	120	2000 to 2200 and 2200 to 2000	Engine running	6.00°	4.5°	0.0°	5.2	19.4
				Gliding flight	4.70°	2.5°	0.5°		
				Engine running	6.90°	4.5°	0.0°	12.4	46.0
				Gliding flight	5.50°	2.5°	0.5°		
				Engine running	7.20°	4.5°	0.0°	16.0	59.2
				Gliding flight	6.00°	2.5°	0.5°		
				Engine flight	7.55°	4.5°	0.0°	19.6	72.3
				Gliding flight	6.50°	2.5°	0.5°		
				Engine running	7.90°	4.5°	0.0°	26.8	98.3
				Gliding flight	7.50°	2.5°	0.5°		

Table 6 (Cont'd)

Results of Test-series f) to k).

Test Series	Diff. in angle of attack rigth & left	Speed km/h	Altitude in m.	Kind of Flight	Elevator	Rudder	Aileron	Water Weight kg.	Moment m/kg/
i)	-0.6°	120	2000 to 2200 and 2200 to 2000	Engine running	5.80°	4.5°	0.0°	5.2	19.4
				Gliding flight	3.80°	2.5°	0.5°		
				Engine running	6.50°	4.5°	0.0°	12.4	46.0
				Gliding flight	4.50°	2.5°	0.5°		
				Engine running	6.85°	4.5°	0.0°	16.0	59.2
				Gliding flight	5.00°	2.5°	0.5°		
				Engine running	7.10°	4.5°	0.0°	19.6	72.3
				Gliding flight	5.50°	2.5°	0.5°		
				Engine running	7.50°	4.5°	0.0°	26.8	98.3
				Gliding flight	6.50°	2.5°	0.5°		
k)	-1.0°	120	2000 to 2200 and 2200 to 2000	Engine running	5.75°	4.5°	0.0°	5.2	19.4
				Gliding flight	3.20°	2.5°	0.5°		
				Engine running	6.50°	4.5°	0.0°	12.4	46.0
				Gliding flight	4.00°	2.5°	0.5°		
				Engine running	6.80°	4.5°	4.5°	16.0	59.2
				Gliding flight	4.50°	2.5°	0.5°		
				Engine running	7.00°	4.5°	0.0°	19.6	72.3
				Gliding flight	5.00°	2.5°	0.5°		
				Engine running	7.50°	4.5°	0.0°	26.8	98.3
				Gliding flight	6.00°	2.5°	0.5°		

These moments, with the initial moment 19.4 m/kg. are marked in dotted lines in Fig. 20; the calibrated curve runs in a straight line midway between the curves for flight with the engine running for gliding flight, and this leads to the conclusion that the Göttingen tests coincide remarkably with the tests during flight, carried out quite independently. The difference between the curves calculated without including the influence of the propeller wash on the controlling devices, and the curves found in actual tests, constitutes a direct standard measurement for the influence of the propeller on the controlling device both in flight with the engine running and in gliding flight.

Figs. 21 and 22 show that the lines of longitudinal moment climb more steeply in flight with the engine running than in gliding flight. From this and from the calibrated curves, it may further be seen that the elevator is more effective in flight with the engine running than in gliding flight. It follows that if the airplane cannot be righted in a steep nose-dive, even when the elevator is at its largest angle, it may possibly be done by putting the engine at full throttle. At the same time, the flight velocity is also increased and the lifting force of the wings augmented. Flight with the engine running is less suitable for testing longitudinal stability and steering capacity of an airplane type than gliding flight. If the elevating control has been incorrectly measured, the airplane will only crash when it is gliding at a steep angle; the larger the angle of the elevator in a steep glide, the greater is the difference between the longitudinal moments produced by the rudder (lifting moments) in gliding flight and in flight with the engine running. The airplane can therefore be steered in flight with the engine running at an angle that would not be possible for gliding flight, as the moment produced would be insufficient.

It is further shown, in Figs. 21 and 22, that when the angle of attack of the wings is increased, the longitudinal moments corresponding to the angle of the elevator increase with the same velocity. As a result, the curves in Fig. 22 are flatter than those in Fig. 21, in gliding flight more noticeably than in flight with the engine running. With the same angle of attack and at the same velocity, the angle of the elevator is larger in flight with the engine running than in gliding flight; that is, the airplane is nose-heavy within altitudes of less than 4000 m. - which is the test limit - if it has been equilibrated for flight with the engine running. When it is equilibrated for gliding flight, it is tail-heavy in flight with the engine running. With a view to overcoming these differences in the flight of an airplane under the two flight conditions, the fixed part of the stabilizer has been so disposed as to be adjustable from the pilot's seat, by means of a self-locking hand-wheel. This system has been chiefly adopted in England. The airplane can thus be equilibrated under any known condition of flight - with the engine running or in gliding flight - at a given altitude, with a given angle of attack and with a given velocity. No effort is required on the part of the pilot, because the elevator is not called into action. No sooner does one of these factors undergo an alteration, however, than the equilibrium is again disturbed and can only be restored by the readjustment of the fixed plane or by the action of the elevator. If an alteration takes place in all the above-named influences, brusquely as in the case of steep gliding with the engine stopped, it may sometimes happen that the increase in the elevator angle no longer suffices for the adjustable fixed planes. On this account, there is some objection to adjustable fixed planes; to begin with, the pilot can compensate his airplane for only one flight condition, at high altitudes, through altering the position of the fixed part. This derangement of the equilibrium when passing to another condition of working may be dangerous in the case with airplanes with extremely marked variations of position and speed, such as fighting monoplanes, for instance, especially when the c.g. is located high up on account of the position of the pilot's seat and the machine-gun, as in German fighting monoplanes with a stationary engine.

The adjustable tail plane is favorable for airplanes in which the c.g. varies considerably during flight (as, for instance, through the weight of bombs applied in front of or behind the resultant of the air-forces in night-bombing or giant airplanes) as the pilot can considerably lighten the elevator, after bombs have been dropped, by readjusting the fixed plane. In airplanes of the newest types, the adjustment of the fixed part scarcely needs to be taken into account, there being no marked alterations in the flight conditions. The same may be said of large size or giant airplanes.

SUMMARY OF THE TEST RESULTS.

1. C airplanes with two struts are extremely susceptible to aileron maneuvers, slight alterations of the aileron sufficing to compensate great unequalized moments.

2. Great unequalized moments can be produced or neutralized by the unequalized alteration of the angle of attack below the outer or inner struts. Adjustment below the outer strut is the more effective method of the two. Contrary to the effect of alterations in the angle of attack below the outer struts, moments resulting from weights and alterations in the position of the inner struts cause no side-slip in the airplane.

3. When a load of bombs is suspended beyond the center of the airplane, below the wings, the bombs need not be dropped on both sides simultaneously.

4. The propeller wash of a wide open engine has considerable influence on the position and working of the elevator. The elevator is more susceptible in flight with the engine running than in gliding flight.

5. Adjustable tail planes are not advisable for D airplanes, nor for the C type, but they are, on the other hand, to be recommended for large size and giant airplanes in which the c.g. changes during flight.

6. The aileron values obtained by wind-tunnel measurements are about 10% too low, though otherwise applicable. For the elevator, the results of such measurements should be taken as mean values between flight with the engine running and gliding flight.

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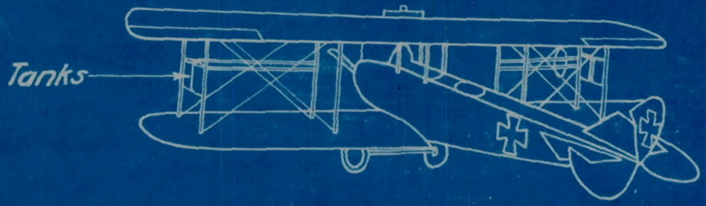
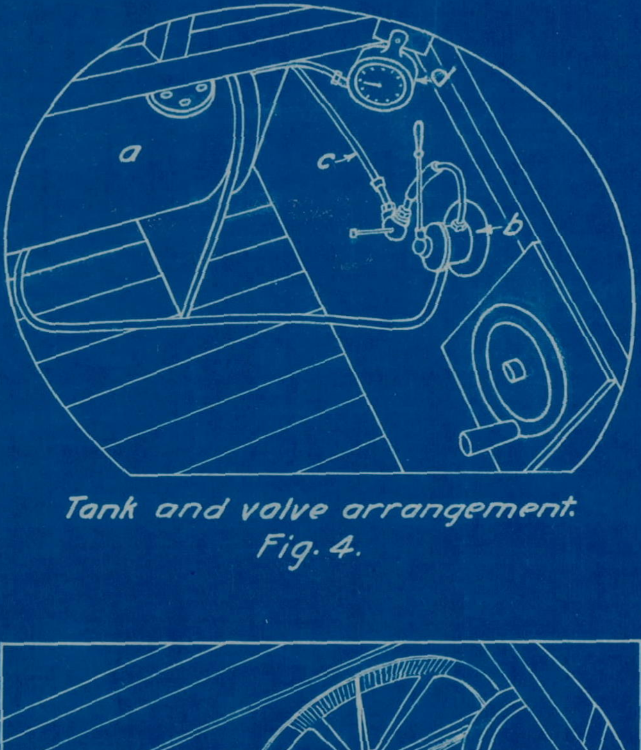
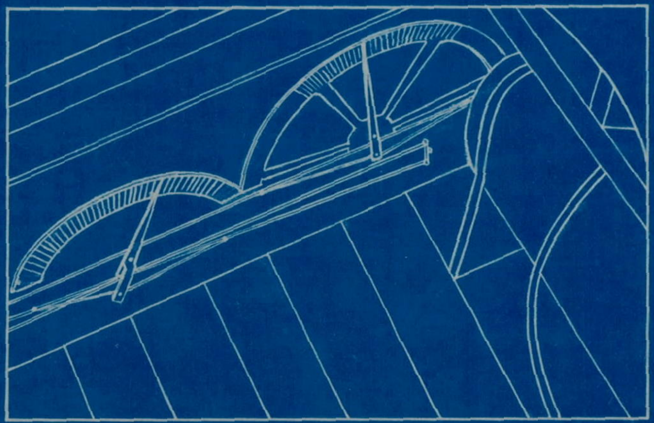


Airplane showing position of tanks.
Fig. 2 and 3.



Tank and valve arrangement.
Fig. 4.



Indicators for controls.
Fig. 5.

2

V.HEIDELBERG MEASUREMENTS OF RUDDER MOMENT TAKEN ON AN AIRPLANE DURING FLIGHT

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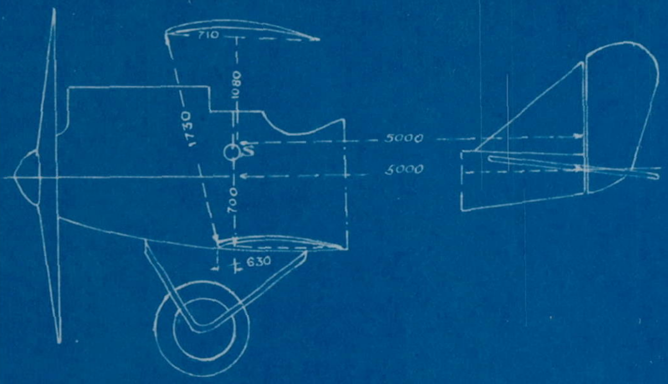

FIG. 1 _ *Dimension of the DfwCV*

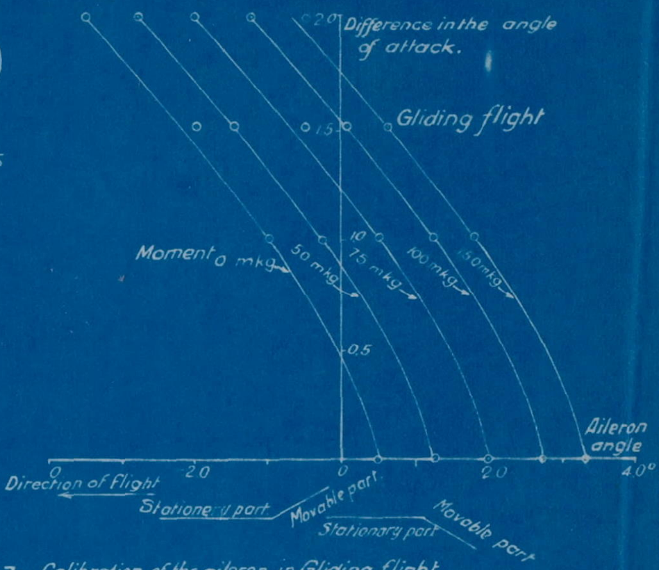

FIG 7 _ *Calibration of the aileron in Gliding flight.*

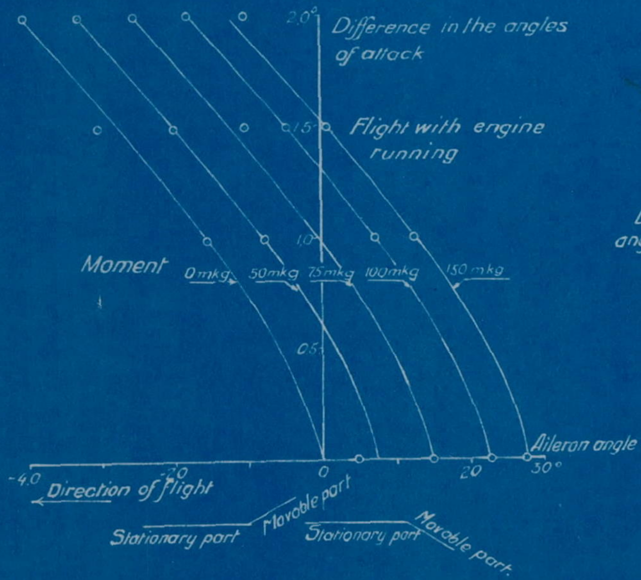

FIG 6 _ *Calibration of the aileron in flight with the engine running.*

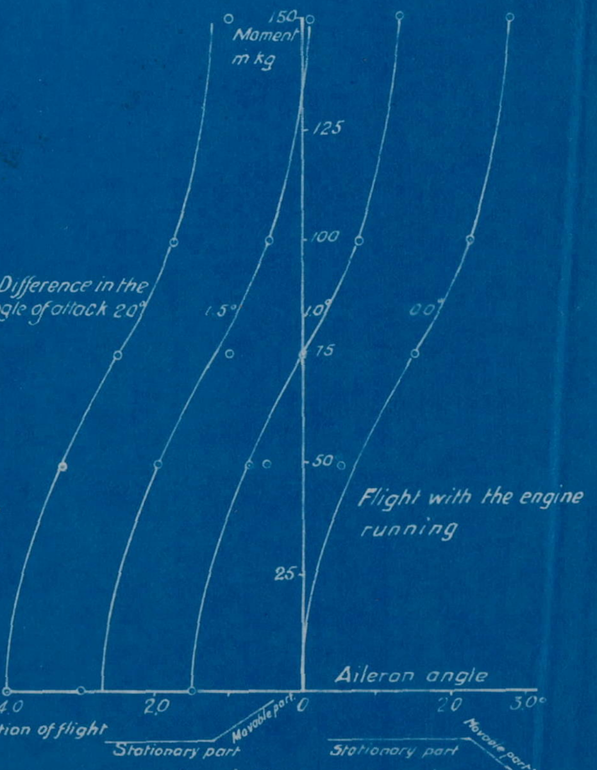

FIG 8 _ *Calibration of the aileron in flight with the engine running*

V. HEIDELBERG_ MEASUREMENTS OF RUDDER MOMENT TAKEN ON AN AIRPLANE DURING FLIGHT

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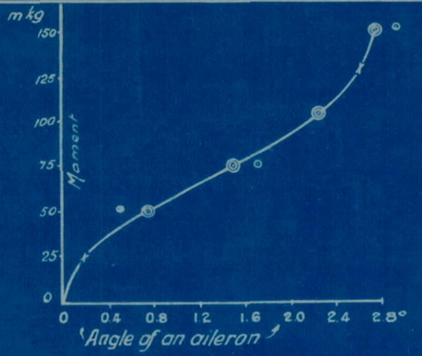

FIG. 10 Result of the calibration of the aileron

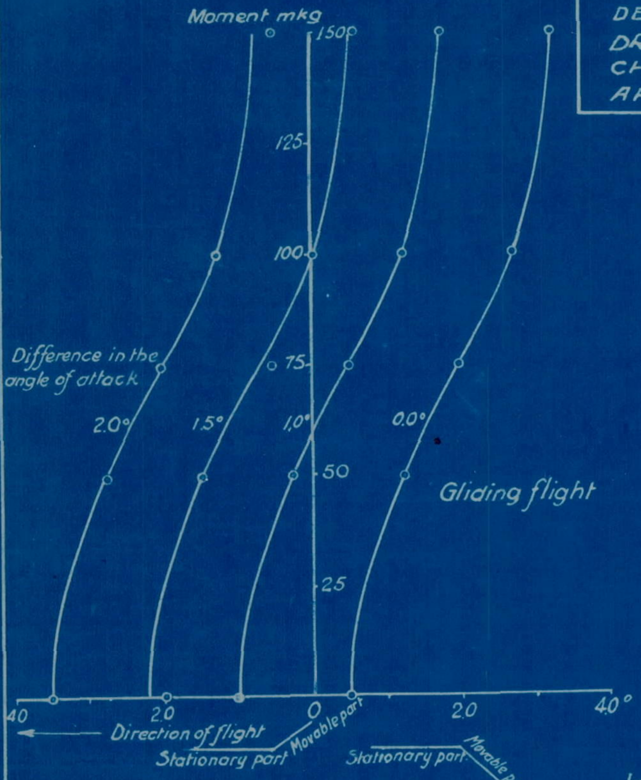

FIG. 9 Calibration of the aileron gliding flight

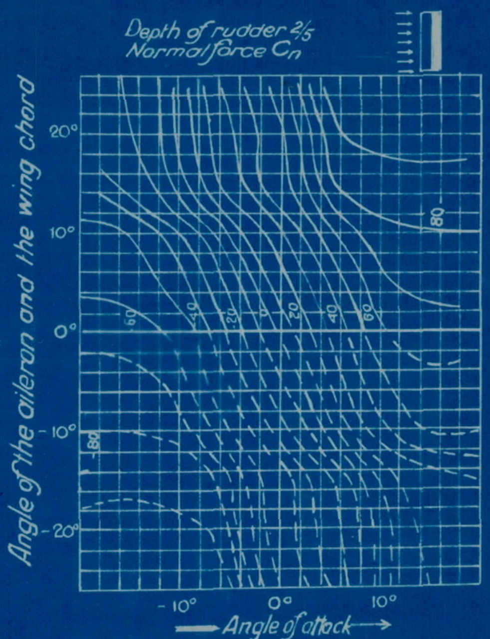

FIG. 12 »TB« I Tafel CLXIV

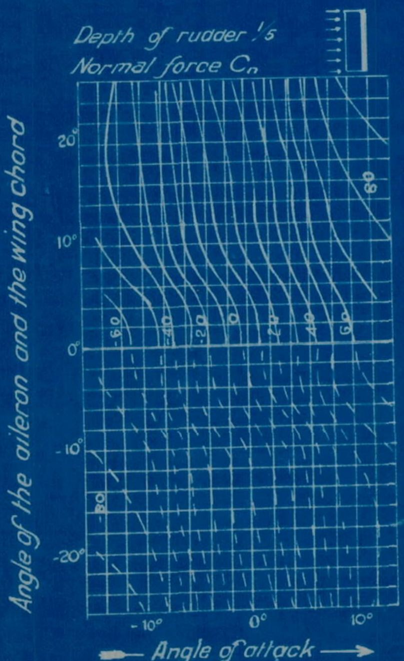

FIG 11. »TB« I Tafel CLXIV

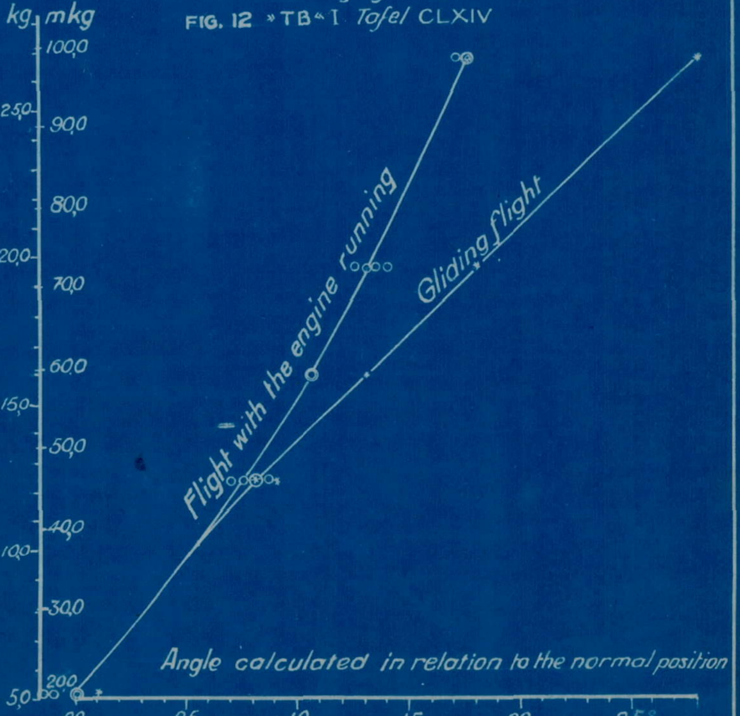

FIG. 13 Value of the rotary moment in flight with the engine running and in gliding flight.

V. HEIDELBERG - MEASUREMENTS OF RUDDER MOMENT TAKEN ON AN AIRPLANE DURING FLIGHT

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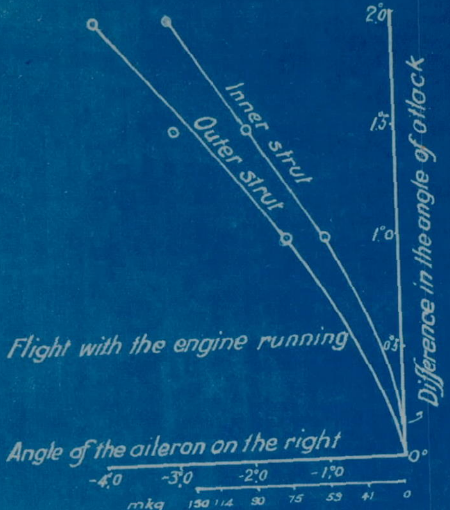

FIG.14. Angles of the aileron when the position of the struts is altered during flight with the engine running.

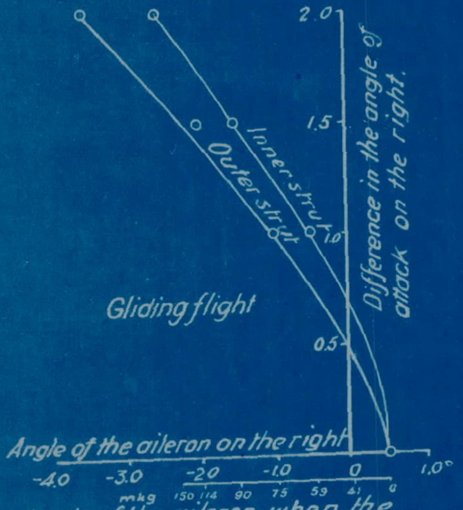

FIG.15 Angle of the aileron when the position of the struts is altered during gliding flight

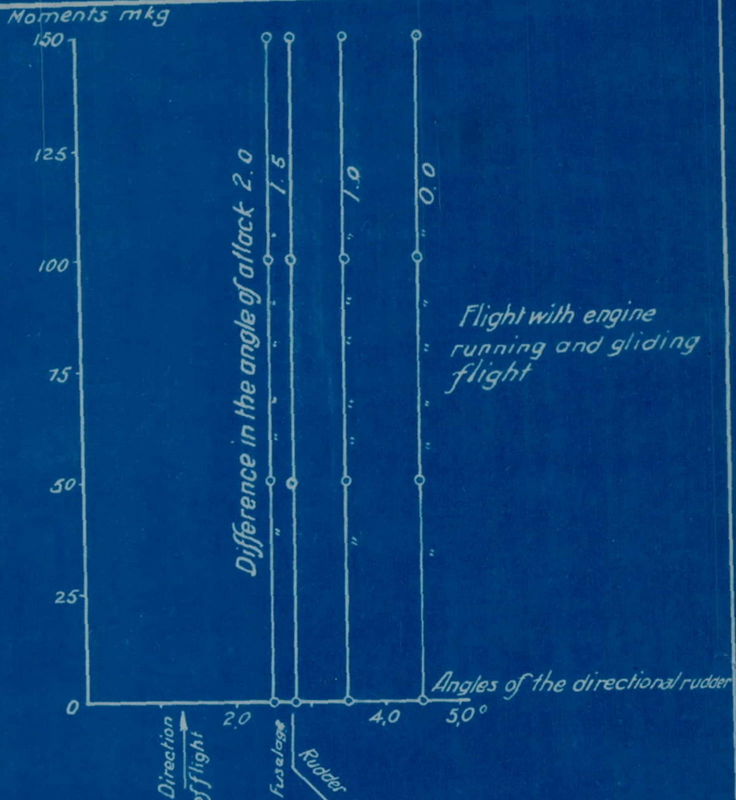

FIG.16 Variations in the position of the rudder caused by aileron moments

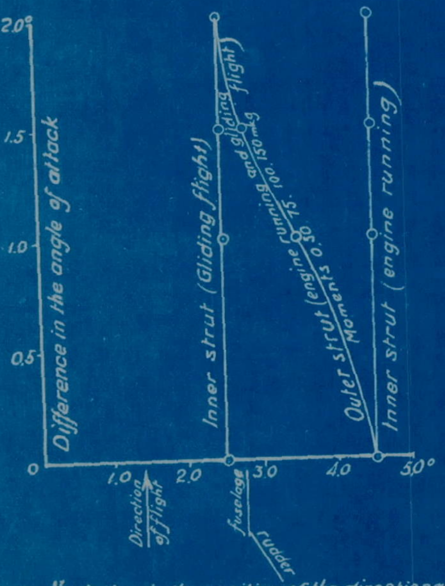

FIG.17 Variation in the position of the directional rudder in terms of the position of the struts

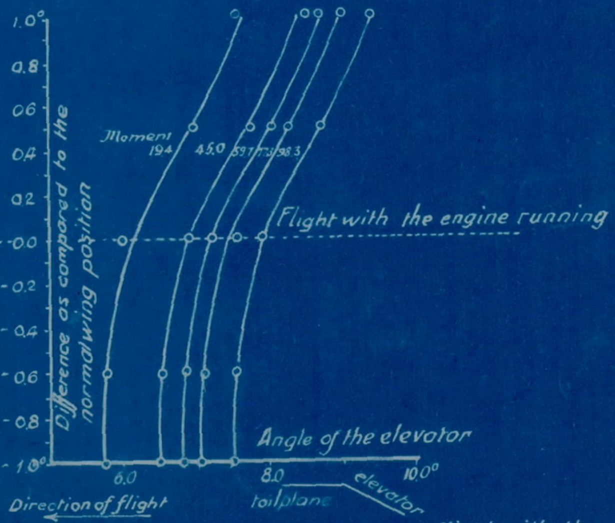

FIG.18 Calibration of the elevator in flight with the engine running

V. HEIDELBERG_ MEASUREMENTS OF RUDDER MOMENT TAKEN ON AN AIRPLANE DURING FLIGHT

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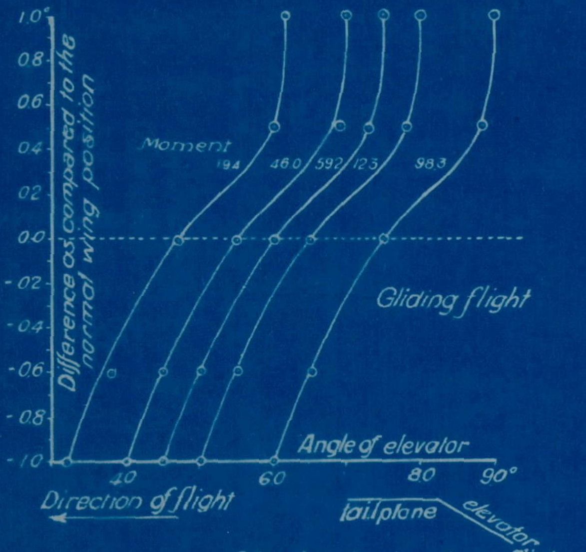

FIG. 19. Calibration of the elevator in gliding flight

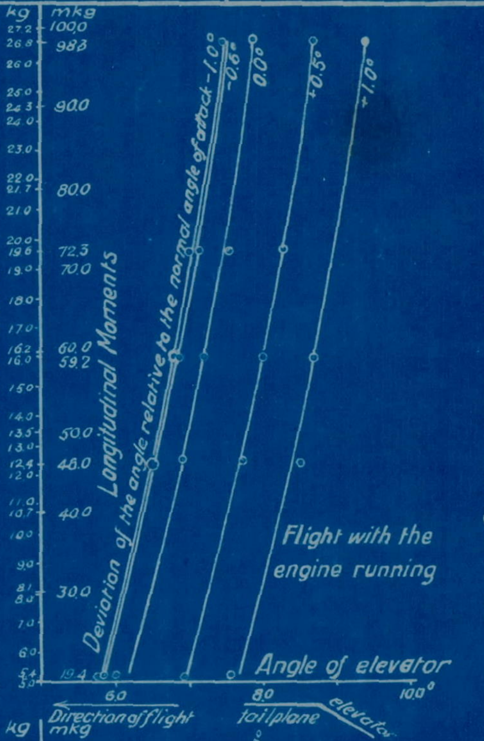

FIG. 21 Calibration of the elevator in flight with the engine running

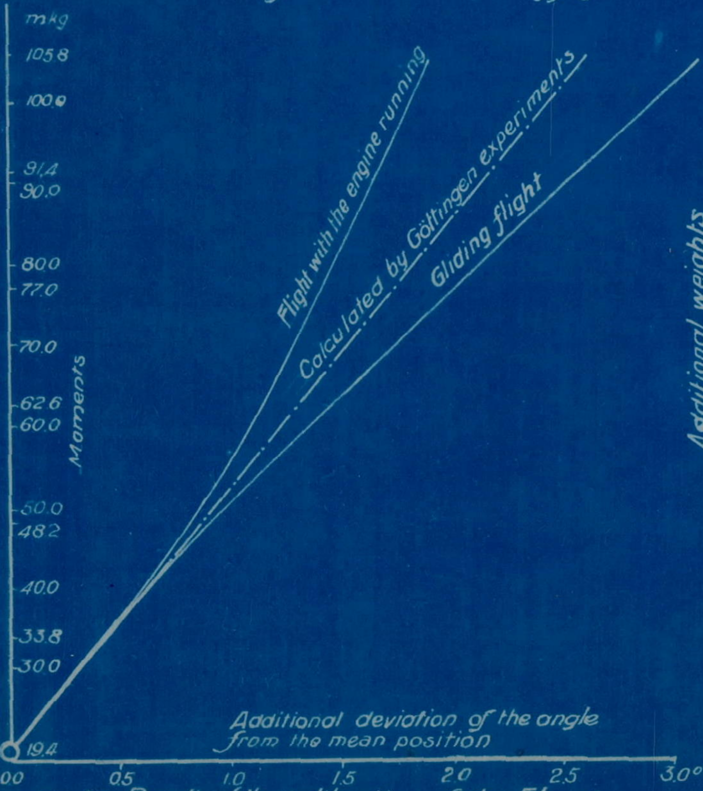

FIG. 20 Result of the calibration of the Elevator

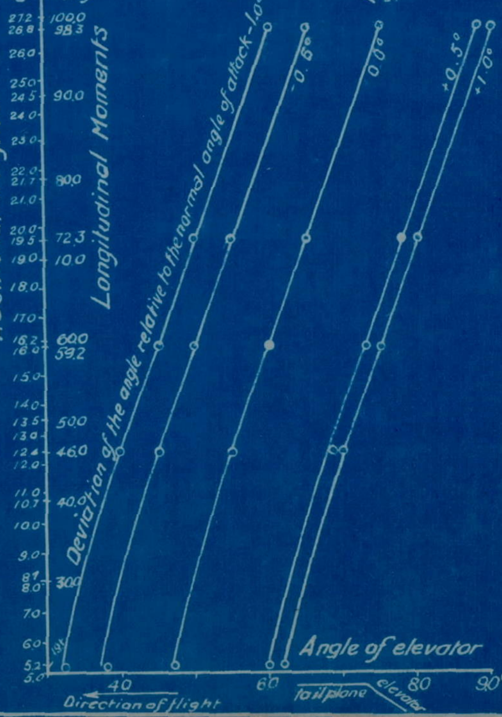

FIG. 22 Calibration of the elevator in gliding flight