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REPORT No. 112

CONTROL IN CIRCLING FLIGHT

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REPORT No. 112

CONTROL IN CIRCLING FLIGHT

BY

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CONTROL IN CIRCLING FLIGHT.

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SUMMARY.

This investigation was undertaken by the National Advisory Committee for Aeronautics at the Langley Memorial Aeronautical Laboratory for the purpose of developing instruments that would record the forces and positions of all three controls, and to obtain data on the behavior of an airplane in turns. All the work was done on a standard rigged JN4H (machine No. 2 of N. A. C. A., Report No. 70). It was found that the machine was longitudinally unstable and nose heavy; that it was laterally unstable, probably due to too little dihedral; and that it was directionally unstable, due to insufficient fin area, this last being very serious, for in case of a loss of rudder control the machine immediately whips into a spin from which there is no way of getting it out. On the other hand, it was found possible to fly quite satisfactorily with the rudder locked, and safely, though not so well, with the ailerons locked. The value of Y_v was obtained in free flight, and when the effect of the propeller was subtracted, the agreement with the model test was excellent, but with the propeller revolving at 1350 the value of Y_v was nearly doubled. The value of L_v and N_v were little affected by the slipstream, but their values do not agree with the model test.

GENERAL STABILITY AND CONTROLLABILITY.

It has been attempted to present this report from the standpoint of the engineer and pilot as well as from that of the physicist, for the more time that is spent on practical stability, the less important seems the theory of small oscillations as compared with the other phases of the problem. When one of the most used and well liked training planes is normally unbalanced and statically unstable with free controls in every particular, it would seem that the dynamical stability is at present of secondary importance. There are, of course, airplanes that are much more stable than the machine used in these tests, but the point that should be emphasized is that, generally speaking, a pilot does not know a stable from an unstable machine, and if the forces on the controls are small he is just as well satisfied with the unstable one as with the other. It seems to be the general impression among nonflyers that piloting an unstable plane is analogous to walking a tight rope, requiring constant vigilance and great dexterity, but the beginner learns to fly as quickly in an unstable machine as in a stable one. It is not intended to give the impression that stability is of no value, for this is certainly not the case; for a machine stable with free controls could be brought down safely if a control wire broke and it would be less tiring to the pilot in long flights.

The subject of stability and control is still in a very confused state for the reason that little has been done to bring together the work of mathematicians and physicists on one hand and engineers and pilots on the other. The former class is apt to theorize on conditions that do not actually exist in flight and the latter have no definite means of expressing control or stability quantitatively. However, the subject of stability and controllability may be logically divided into four parts.

The first is balance, that is, there should be no force on the controls when in the normal flying condition, for without the fulfilment of this requirement stability would have no significance. For example, a machine may be nose heavy and if left to itself dive under onto its back, yet if the pull on the stick were balanced by a spring the machine might be stable. This condition of course applies only to free controls.

The second division is what is commonly called static stability, and is present if forces are produced when the machine is displaced from its equilibrium position, which tend to return it to that position. This applies both with free and locked controls.

The third part is what is called dynamic stability, and can have significance only when the machine is in balance and is statically stable. A machine is said to be dynamically stable when any oscillation set up tends to damp out. This condition is easy to observe on almost any airplane by locking the elevators in the machine's stable region, which can be found by trial. If the throttle is closed for an instant until the nose starts to drop, and then opened to its former setting, the nose will soon rise, overshooting the equilibrium angle, and will continue to rise and fall regularly with a period of from 15 to 30 seconds. If stable, the amplitude of these oscillations will decrease; if unstable, they will increase. The same thing can be observed when making banked turns, but the stability characteristics are different under these conditions. Oscillations in roll and yaw are more difficult to observe, probably because a sufficient degree of static lateral stability has not been obtained. It may be said in general that dynamic stability is of the least importance compared with the other divisions of the subject, for if the machine is not statically stable it has no meaning, and if the machine is made statically stable it is practically always also dynamically stable.

The fourth part is lightness of control, especially in acrobatics; that is, a small force on, and a small movement of the controls should be required to produce large angular accelerations. Lightness of control is intimately connected with static stability, especially as regards longitudinal motions. There has been no satisfactory method of measuring this quality and its degree has been determined heretofore by the statements of pilots. By using three synchronized instruments recording respectively the control forces, the control positions, and the angular attitude of the machine, it should be possible to obtain a definite measure of controlability. This is a primary aim of the National Advisory Committee for Aeronautics in studying the subject.

APPARATUS AND METHODS.

The general method of recording the forces on the controls is shown in figure 1. An auxiliary rudder bar is connected to the regular bar by special springs (22). The rudder wires (24) are connected to this secondary bar, so that the relative movement between the two bars is a measure of the force applied. In the same way the relative motion between the handle and the top of the control column will measure the elevator and aileron forces. These forces can be read directly on the rudder scale (21) and the aileron and elevator scale (19), but in most cases the forces were transmitted to the recording instrument (23). In figure 2 is shown a detail view of the control head. The upper part with the handle is connected to the lower collar through the cantilever springs (18) and the relative motion is transmitted by the two bell cranks (16 and 17) mutually at right angles to the wires (20) running to the recording instrument.

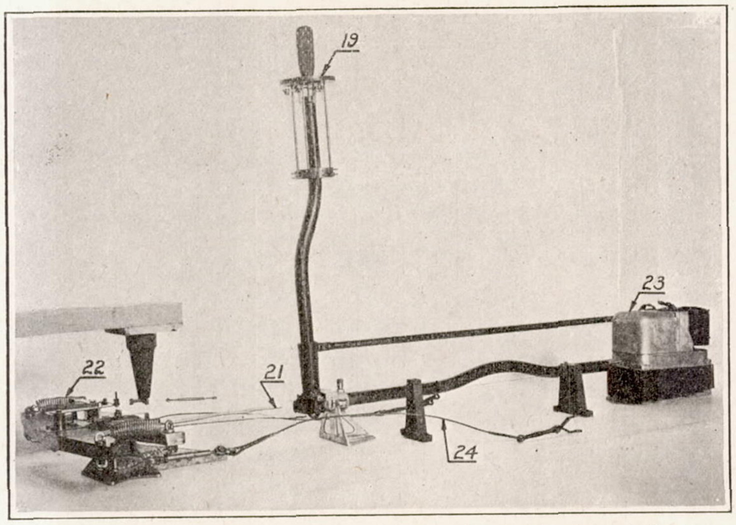


FIG. 1.—General assembly of apparatus for recording forces on the controls.

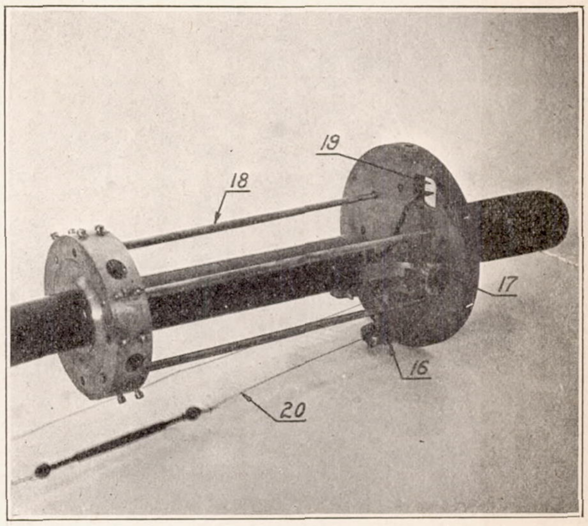


FIG. 2.—Head of force recording stick.

Figure 3 shows the interior of the instrument for recording the control forces; (6) is an electric motor to give a constant speed, but the governor in this case was removed, as the speed was of no importance in this work; (7) is a light holder, containing a special flash-light bulb and an adjustable prism to reflect the beam through the lens (9) onto the three mirrors (8) from which it is reflected to the photographic film. In order to distinguish between the three records a sectored disk (10) driven from the lower shaft by a belt (15) revolves slowly before the mirrors, making dotted lines on two of the records. The drum for holding the film is shown in figures 5 and 6 and is constructed like a plate holder, so that the shutter (25) is automatically opened by the pin (14) when the drum is placed on the instrument. At the same time the clutch (12) is engaged to rotate the drum. The film is held on the inner drum (fig. 6) by the rollers (27) and the amount the drum has turned can be seen on the dial (28) through a red glass window. The underside of the instrument is shown in figure 7 with the bottom cover plate removed; (3) is the lower part of the motor frame, (2) is the drive shaft, (1) is the gear for rotating the film drum, and (4) are the springs to take up any backlash in transmission.

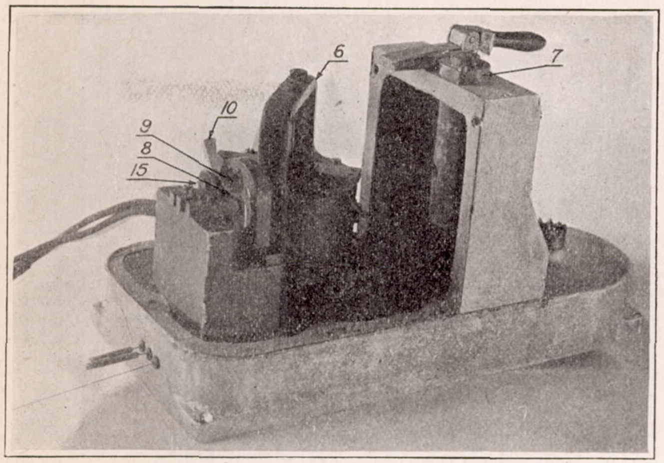


FIG. 3.—Instrument for recording forces.

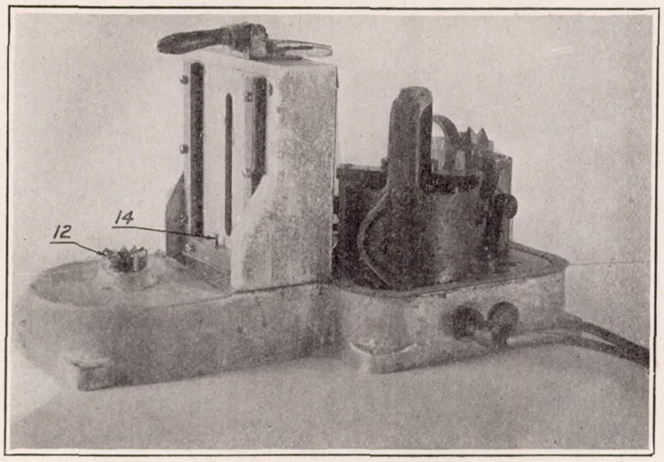


FIG. 4.—Another view of instrument for recording forces.

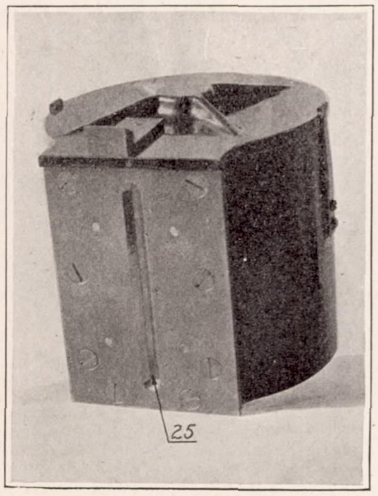


FIG. 5.—Film drum holder.

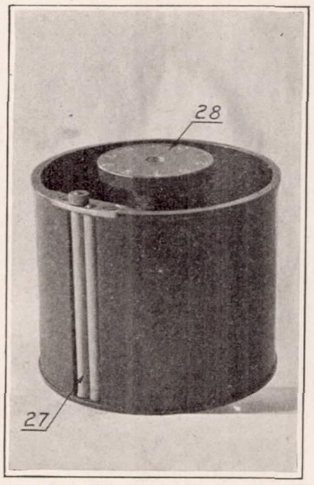


FIG. 6.—Film drum showing rollers for tightening film.

An identical instrument is being constructed to record the position of the controls, but as it could not be completed in time for these tests the scales shown in figure 8 were used and were read by the observer. The movement was transmitted from the control by throttle wire and a spring was placed in the system to take up the backlash. Each scale was carefully calibrated after it was in place.

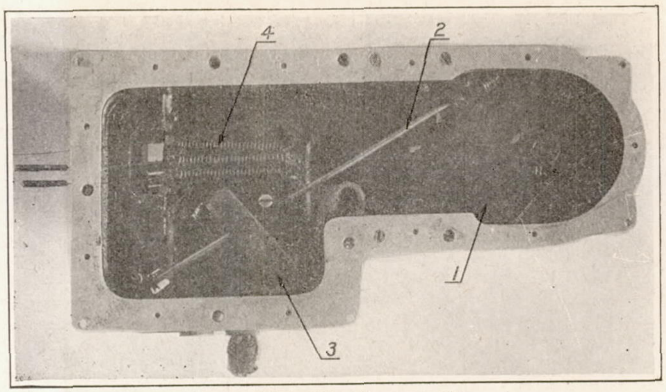


FIG. 7.—Underside of force recorder.

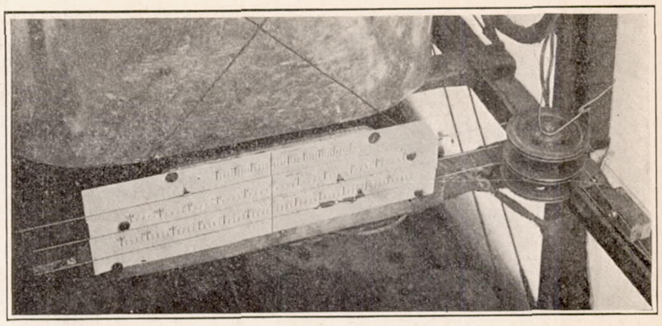


FIG. 8.—Scales for indicating the position of the controls.

The air speed was determined by the usual pitot-venturi instrument, and the error in bank by an especially sensitive bubble inclinometer. It was attempted to measure the yaw by the British type of yawmeter using slack diaphragms (fig. 9). This instrument, however, was found very unreliable, the scale being crowded together on one side of the zero and very open on the other and the readings varying with the speed of the airplane. The method finally adopted consists of a simple U tube half filled with alcohol and the free ends connected to the sides of a yaw head. In addition to this a graduated vane pivoted on a vertical axis was placed low down and ahead of the wings at the inner strut so that it could be read by the pilot. The method of procedure consisted in flying at the desired speed and yaw by means of the vane and then setting a movable pointer at the level of the liquid in the U tube and using this to fly by. Although this method seems a little indirect, it gave very satisfactory results.

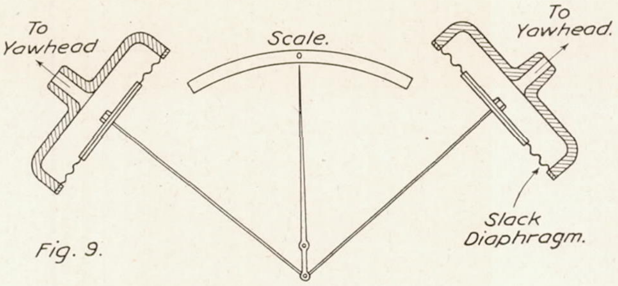
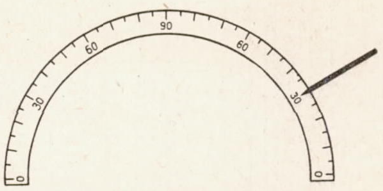


Fig. 9.

YAWMETER



Scale placed over cowling in front of pilot to determine angle of bank. Fig. 10.

The angle of bank was determined by a movable pointer on the cowling just astern of the motor, that could be set to any angle by a graduated circle (fig. 10).

The center of gravity of the machine was about 38 per cent back on the mean wing chord and was kept in one place by the addition of lead when a lighter observer went up.

A record of control forces obtained in turns is shown in figure 11, and it is evident that the records are quite distinguishable in this film. In figure 12 is shown a typical record of control forces in yaw, and in figure 13 a record of a short flight. In the latter record, as the air was quite bumpy, the illumination was not sufficient to give clear records. On this instrument only two dry cells were used on a 4-volt lamp, while to get the same illumination in the accelerometer four cells were necessary with this lamp. This is due to the shorter focal length of the lens and the larger mirrors in the force recorder.

The force recorded was calibrated by applying known forces on the stick and rudder bar by a pulley and weights, at the same time making a record on the film. The errors due to a movement of the controls were studied as well as the effect of one control acting on another, but in no case was the error greater than 1 pound, which was considered as close as any one set of readings could be duplicated. The angle scales were in some cases calibrated with various loads on the control surfaces, and in a few cases it was found necessary to make a small correction for deflection, so that the angle readings may be relied on to within one-half of a degree.

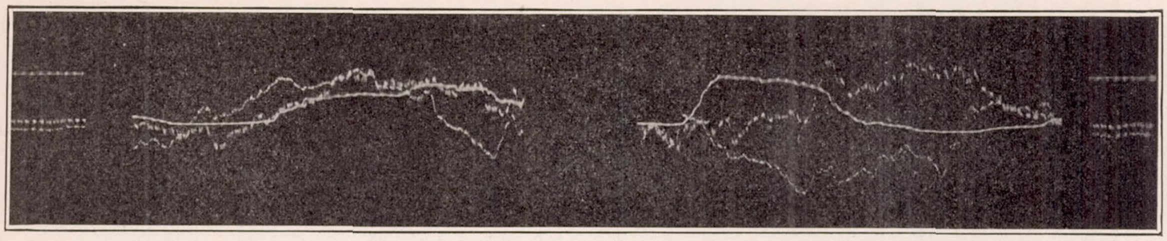


FIG. 11.—Control forces in a turn to the left and to the right.

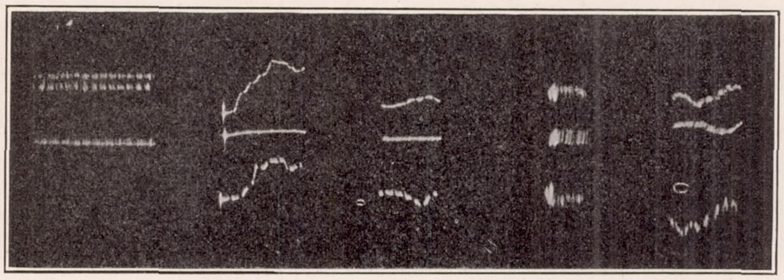


FIG. 12—Control forces in yaw.

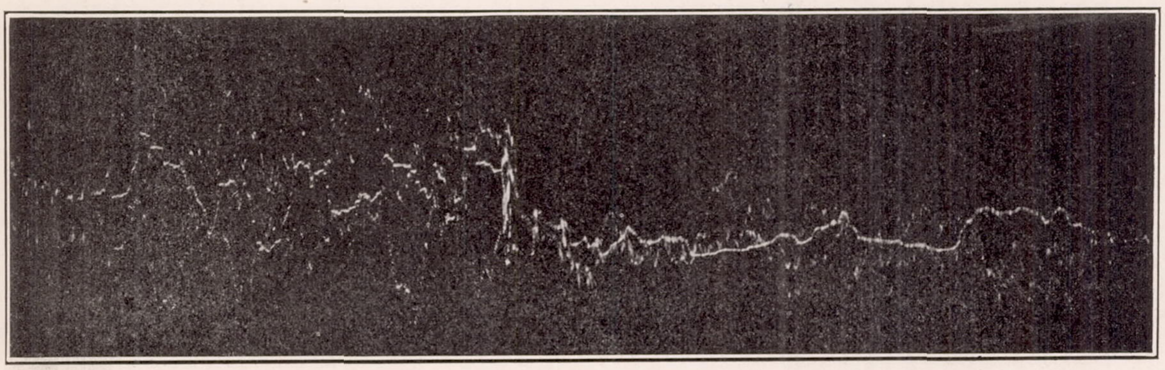


FIG.13.—Control forces in bumpy air.

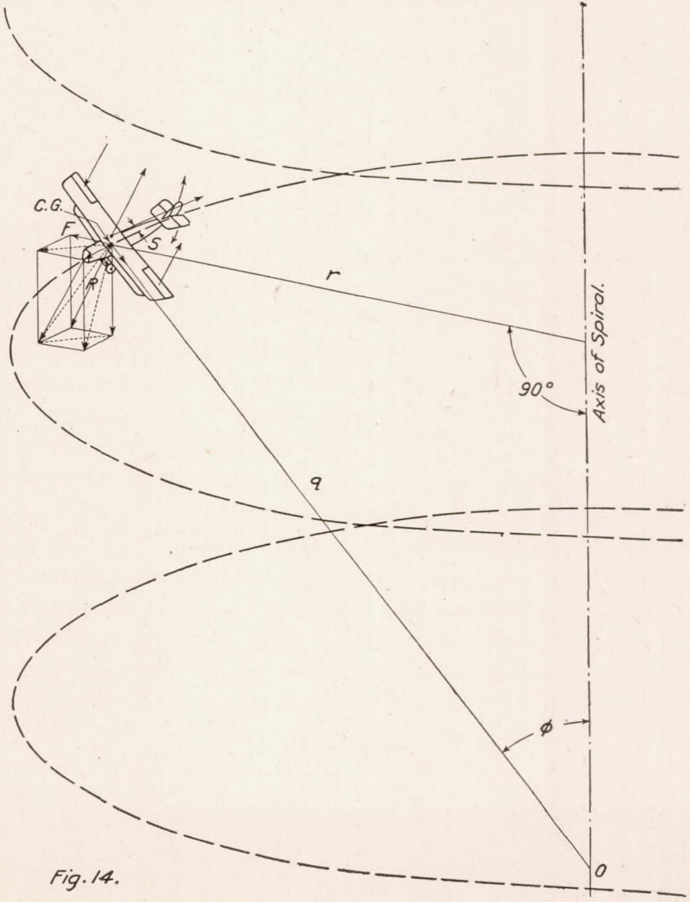


Fig. 14.

MOTION IN CIRCLING FLIGHT.

If m is the mass of the machine in slugs (weight in pounds divided by g or 32.2), ϕ the angle of bank from the horizontal, and F the centripetal force, we have:

$$F = mg \tan \phi = \frac{mv^2}{r}$$

or r, the radius of the circle $= \dfrac{v^2}{g \tan \phi}$

if V is the air speed in ft./sec.

R, the resultant force acting normal to the wing chord will be equal to $\dfrac{mg}{\cos \phi}$ as shown in figure 14, and the ratio of mg to R is given by $\dfrac{1}{\cos \phi}$, which is the acceleration experienced in a turn. In figure 15 is plotted this acceleration against angle of bank, as the acceleration should not vary with the air speed, so long as there is no skidding or side-slipping. In figure 16 are plotted the angle of attack of the airplane when flying at various speeds and banks taken from the full flight lift curves (the lift coefficient being computed from the known speed and load on the wings), and in figure 17 are plotted the theoretical radius of circles and the actual radii as obtained by taking the time for a complete circle. It is regretted that a camera obscura was not available to measure this distance accurately, but the results obtained check fairly well, and the discrepancy is probably due to the fact that the calibration of the air speed head is affected in banks. In all cases a true bank was held by means of the bubble inclinometer.

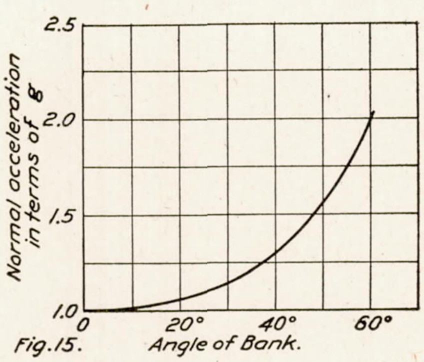


Fig. 15.

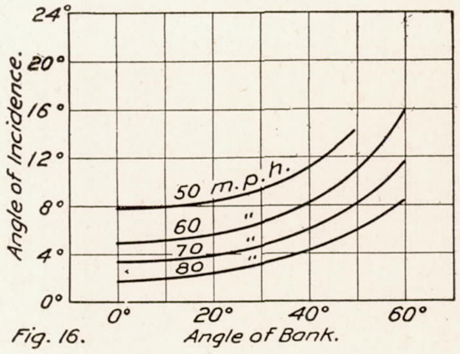


Fig. 16.

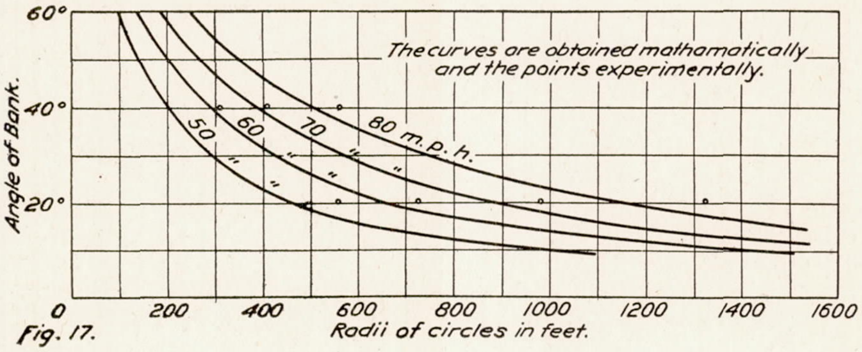


Fig. 17.

In a turn the outer wing has a higher velocity than the inner one, and its lift is therefore greater, producing a rolling moment which must be balanced by the moment of the ailerons. The outer wing will also have the higher resistance, and the resultant yawing moment is balanced by the rudder and in part, except at very small angles of attack, by the ailerons.

The distance S of the center of lift from the plane of symmetry (fig. 14) may be determined by an integration of the air forces.[1] As the velocity along the wing is proportional to its distance

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[1] Kann, Technische Berichte Band III Heft 7.

x from point O in the axis of the turn, and the lift at any point is proportional to V^2, introducing $q=\frac{r}{\sin\varphi}$ (see fig. 14), we have

$$(q+s)\int_{q-a}^{q+s} x^2dx=\int_{q-a}^{q+a} x^3dx$$

where a is the half span,
which gives

$$S=\frac{2qa^2}{3q^2+a^2}$$

Hence, substituting for q its value,

$$S=\frac{2ra^2\sin\Phi}{3r^2+a^2\sin^2\Phi}$$

as a^2 is usually small compared with r^2 the question reduces to:

$$S=\frac{2}{3}\frac{a^2\sin\Phi}{r}=\frac{2}{3}\frac{a^2g\sin^2\Phi}{v\cos\Phi}\frac{2}{3}\frac{a^2v^2}{r\sqrt{v^4+g^2r^2}}$$

The rolling moment is RS, where R is the total normal force on the wings. For turns at constant altitude and correct bank,

$$R=W\sec.\Phi$$

$$L=RS=\frac{2}{3}\frac{a^2W\tan\Phi}{r}$$

Eliminating r and Φ in turn by introducing the speed of flight,

$$L=\frac{2}{3}\frac{a^2Wg\tan^2\Phi}{v^2}=\frac{2}{3}\frac{a^2Wv^2}{gr^2}$$

The moment Rs must equal the aileron moment, and as this increases as the square of the span, it is evident that machines having large spans must have relatively more powerful ailerons for the same angles of bank than small machines. If it is assumed that the force exerted by the ailerons is proportional to their angle from the mean position this should then be inversely proportional to the square of the radius of the turn if the speed remains constant. An examination of the experimental curves shows that this is true for turns of large enough radius for the a^2 term to be neglected.

The wing drag may be integrated in the same way as the lift, but as the greater part of the total drag is structural and aileron resistance, little would be gained, as the structural resistance will vary with different machines. It may be stated, however, that the decreased drag of the inner wing is almost balanced by the greater aileron resistance on that side, leaving very little for the rudder to balance, as evidenced by the fact that turns may be made with the rudder locked in neutral and with little or no side-slipping or skidding.

NOMENCLATURE.

Throughout this report the following terms and signs will be used. All directions are taken from the viewpoint of the pilot. It should be noticed that No. 5 is the reverse of that previously used, being changed for consistency.

1. In right, or positive roll, the left wing is raised.
2. In right, or positive yaw, the wind strikes the pilot's left cheek.
3. Aileron is positive when the trailing edge of the left aileron is down.
4. Rudder is positive when the trailing edge moves to the right.
5. Elevator is positive when the trailing edge is pulled up.
6. Aileron force is positive when force on the stick tends to give right aileron.
7. Rudder force is positive when the push is with right foot.
8. Elevator force is positive when the stick is pulled toward the pilot.

The forces on the controls are given in all the curves, and if it is desired to find the moments about the control surface hinges, the following conversion factors must be used:

1. Subtract 8½ pounds (the static weight) from the stick force and multiply by 23.8 to obtain moments in inch pounds.
2. Multiply stick force by 56.0 to get aileron moments in inch pounds (sum of both ailerons).
3. Multiply rudder force by 10.5 to get moments in inch pounds.

CONTROL POSITIONS IN TRUE BANKS.

Before this work was commenced it was thought that there might be a considerable range of rudder and aileron position that would give equal flight properties to the airplane. While this was found to be true when flying without a lateral inclinometer in seemingly perfect banks, yet if the inclinometer was held exactly in the center the positions of the controls were uniquely determined. Due to the great difficulty in flying the machine at the correct bank and air speed at the same time that the readings were taken, it was found necessary to repeat each run several times. As the variation in control position is very slight, in many cases less than the error in reading, the points do not lie smoothly on a curve, but in all cases the curves obtained should be accurate to one degree. In order to investigate the effect of the slip stream, runs were made at 1,350 r. p. m. and 600 r. p. m., and the similarity in shape between the two sets is a check on the accuracy of the results.

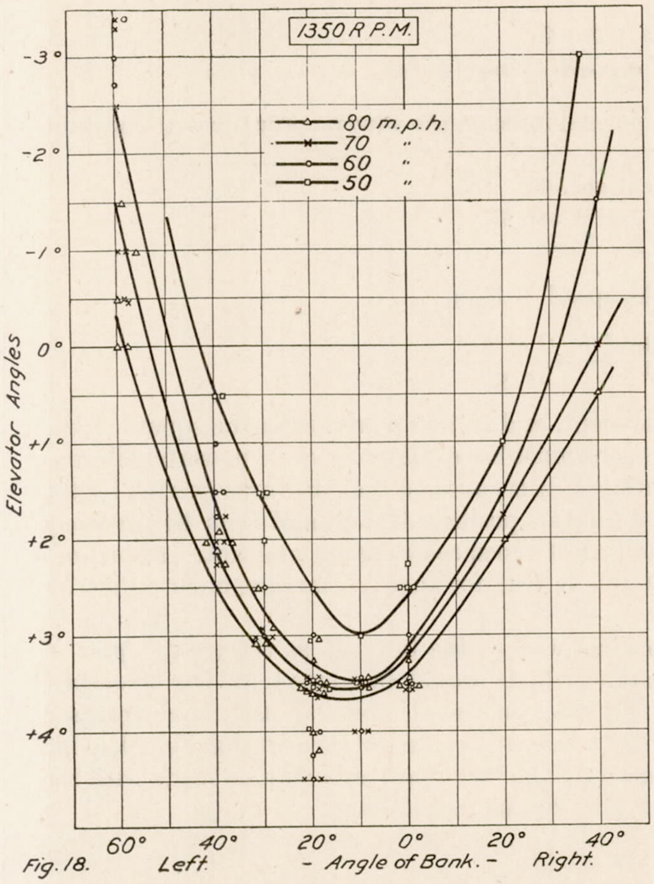

Fig. 18.

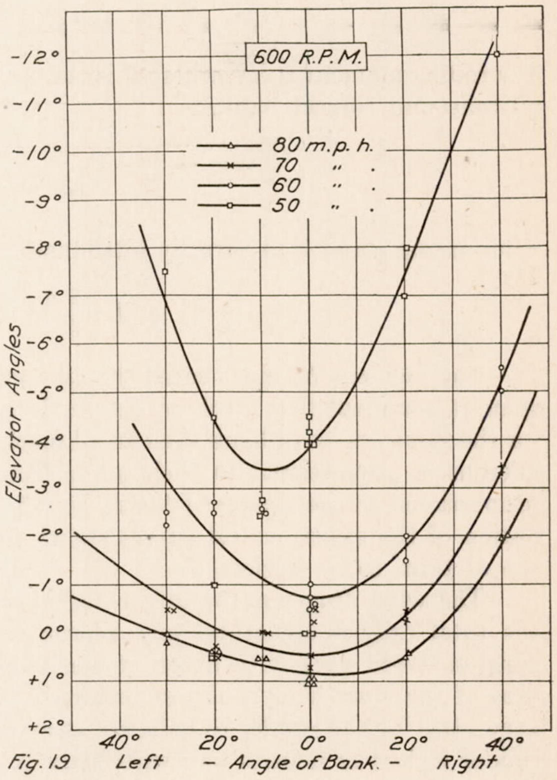

Fig. 19

The elevator is pulled back in any turn to keep the same flight speed, for the angle of attack is increased due to the greater apparent weight of the machine, and this must be balanced as in level flight by raising the elevator (figs. 18 and 19). The curves are nearly symmetrical about zero at 600 r. p. m., but at 1,350 r. p. m. more elevator is required in right banks than in left. The longitudinal, fixed control stability does not, however, seem to be otherwise affected, as the curves are very nearly parallel.

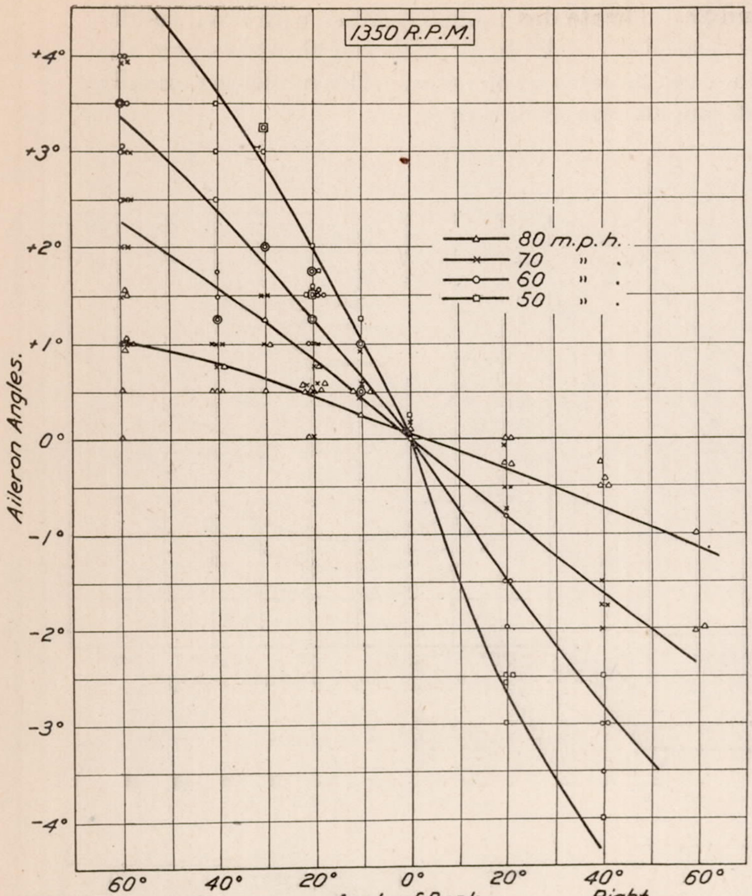

Fig. 20.

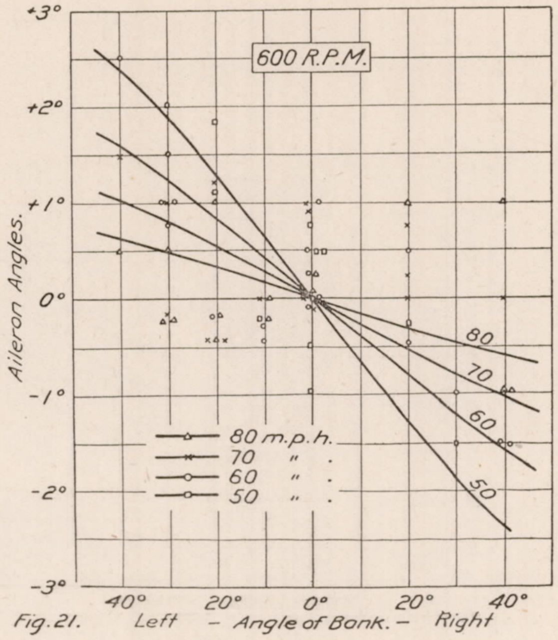

Fig. 21.

The aileron position curves (figs. 20 and 21) are nearly straight lines passing through zero angle at zero bank, and their slope increases inversely as the air speed; that is, the higher speeds require the smaller angles. The most important feature, however, is that opposite aileron is used to hold the bank from increasing; that is, the machine is laterally unstable with the fixed controls.

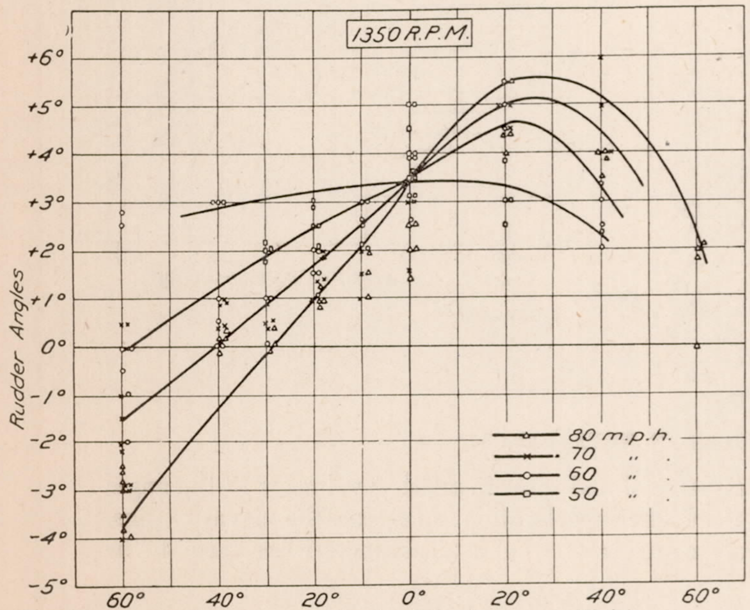

Fig. 22.

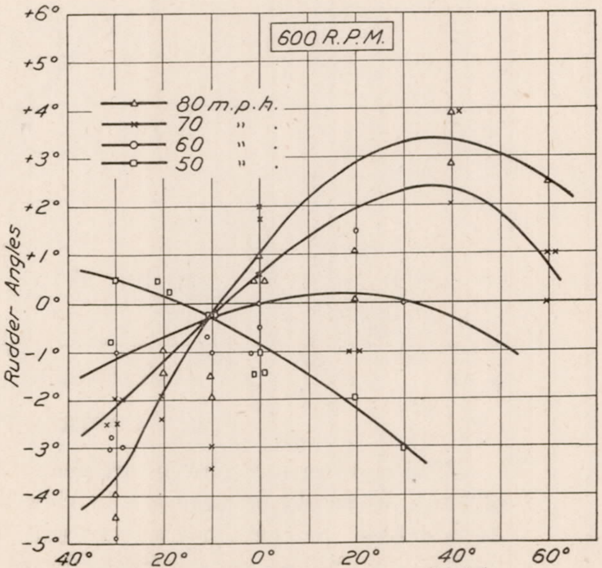

Fig. 23.

The rudder position curves (figs. 22 and 23) indicate directional stability with fixed rudder for small angles of bank. At high banks, especially right bank with the throttle open, the curves fall off rapidly as the rudder acts more and more as an elevator. The rudder is normally held 3½° right in order to balance the slip stream and propeller torque.

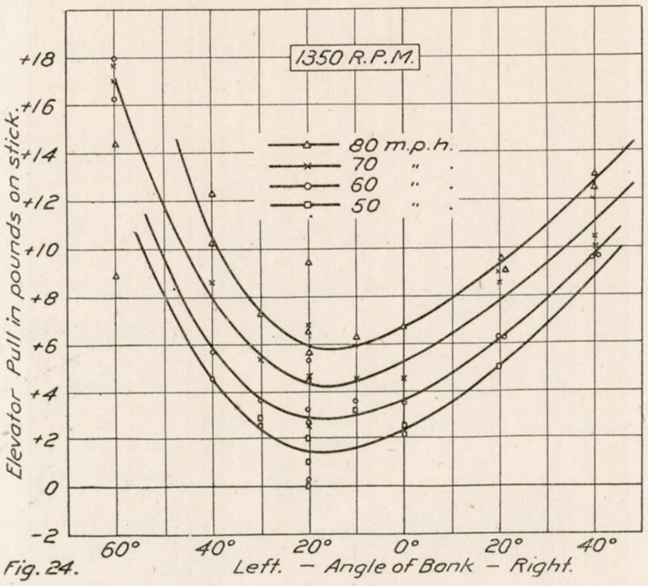

Fig. 24.

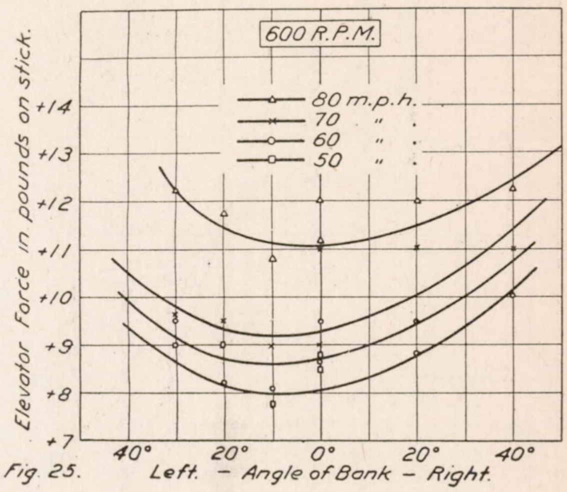

Fig. 25.

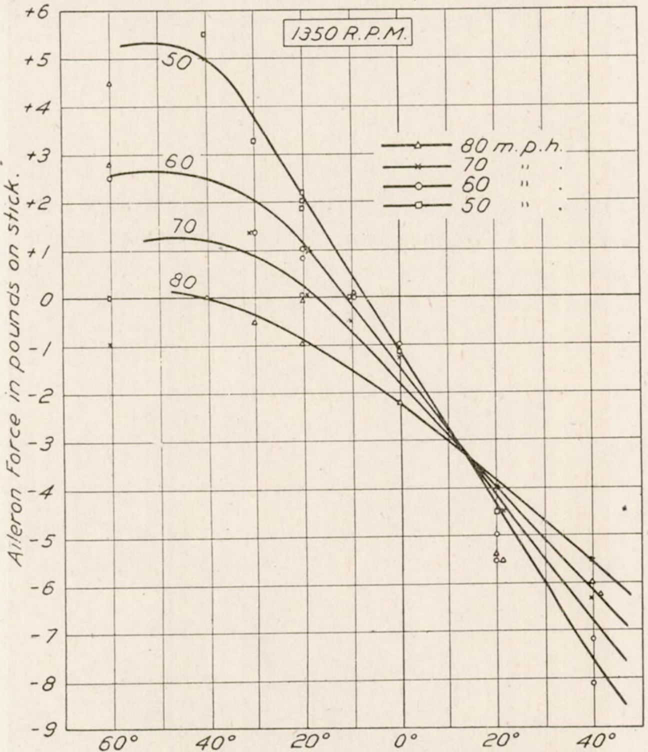

Fig 26

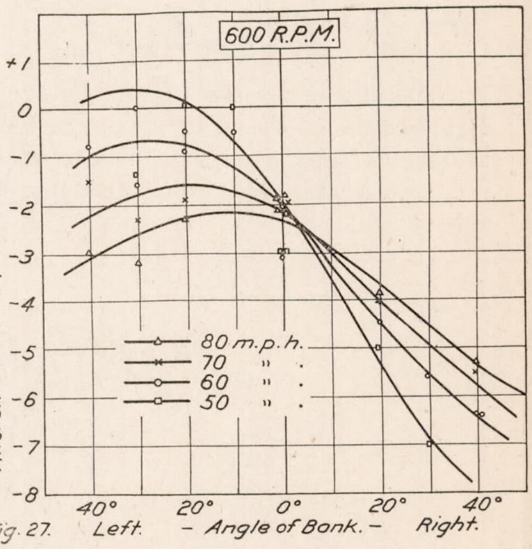

Fig. 27.

CONTROL FORCES IN TRUE BANKS.

The elevator force curves are nearly symmetrical and show increasing values with the angle of bank, as would be expected in view of the higher acceleration acting on the elevator (figs. 24 and 25). In the same way as with fixed controls the stability characteristics seem to be unaltered with free controls in any bank.

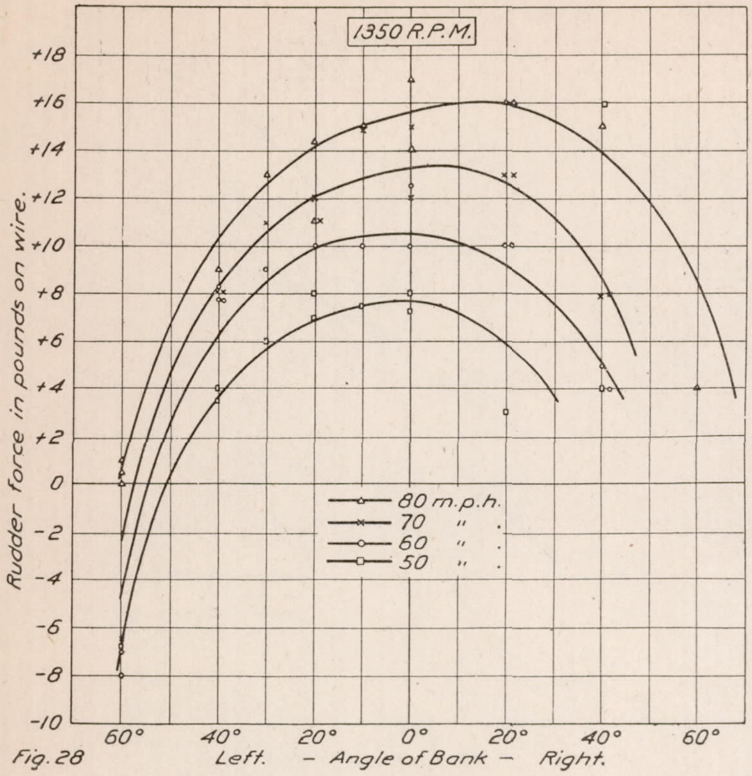

Fig. 28

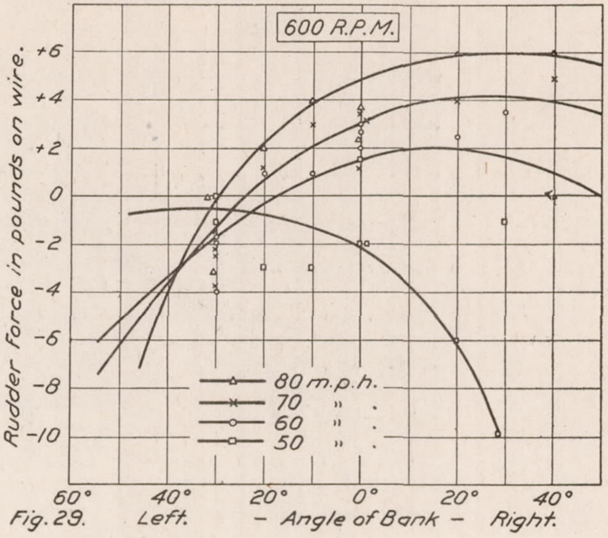

Fig. 29.

The aileron force curves (figs. 26 and 27) are similar to the corresponding position curves and indicate instability, but the slope of the curves increase as the air speed decreases.

The rudder force is normally of considerable magnitude in level flight at 1,350 r. p. m. (fig. 28) and increases with the air speed, but rather strangely falls off as the bank is increased either way. The force curves for 600 r. p. m. (fig. 29) are similar in shape, but cross at 30 left bank, and all the forces are of considerably less magnitude than with the motor on.

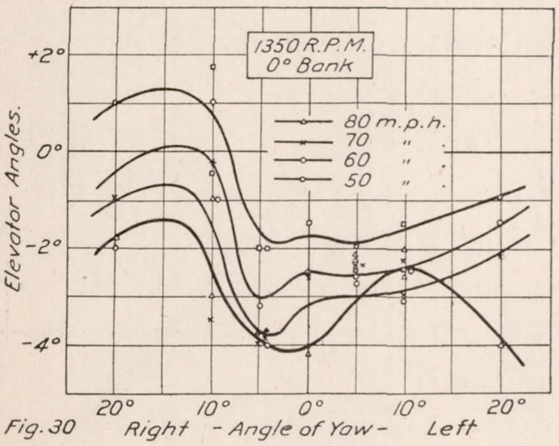

Fig. 30

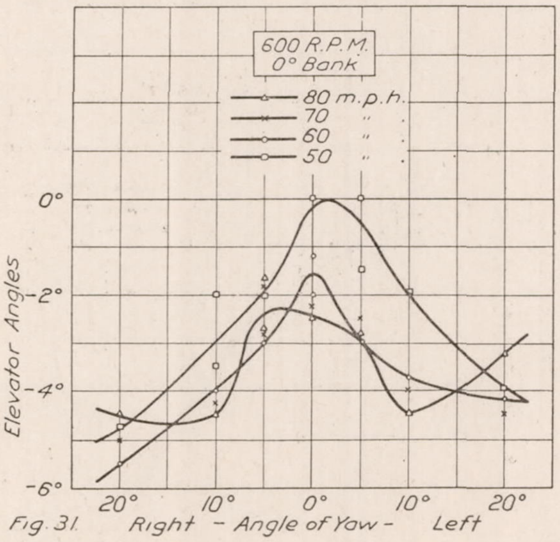

Fig. 31

CONTROL POSITIONS IN YAW.

In figure 30 are plotted the elevator angles for various degrees of yaw at 1,350 r. p. m. The curves are nearly parallel, showing that the longitudinal stability with fixed controls is not affected by the angle of yaw. For angles of yaw up to 5° the stick is pushed forward slightly

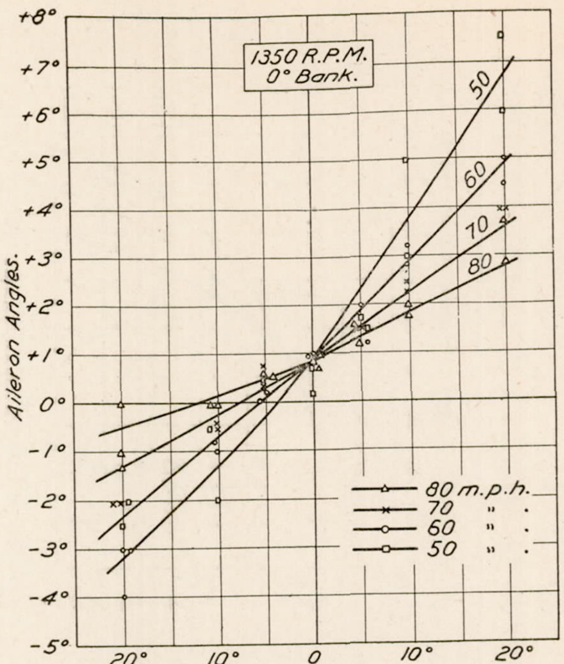

Fig. 32.

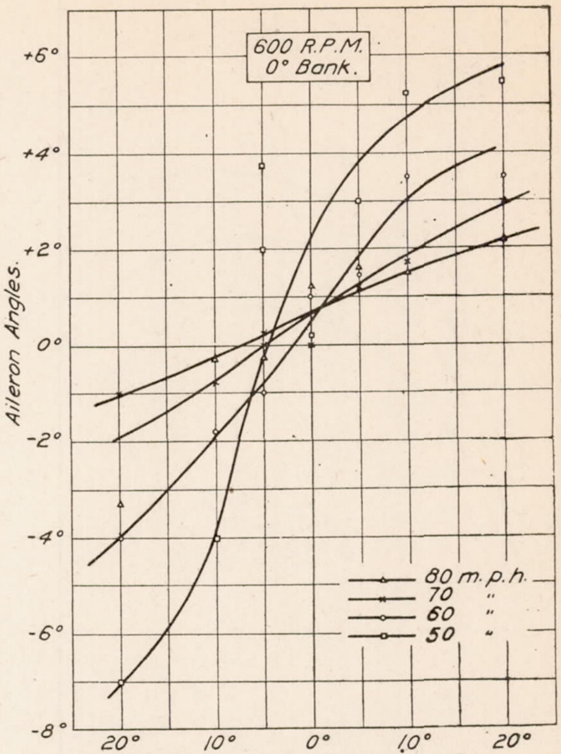

Fig. 33

to balance the machine, but at larger angles it is pulled back because the slipstream is deflected away from the tail. At 600 r. p. m., however (fig. 31), as there is no slipstream, the stick is pushed forward about proportionally to the angle of yaw, but at 80 m. h. p. the curves falls off at 20° yaw.

The curves of aileron angles against yaw are plotted in figures 32 and 33, and in general the aileron angle is proportional to the angle of yaw and inversely proportional to the air speed. At 600 r. p. m. there is a reversal of slope for the slow speeds at small angles of yaw.

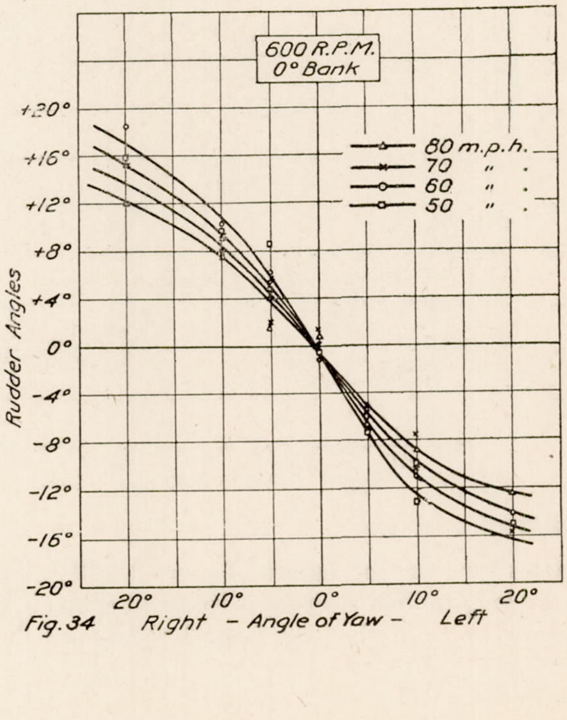

Fig. 34

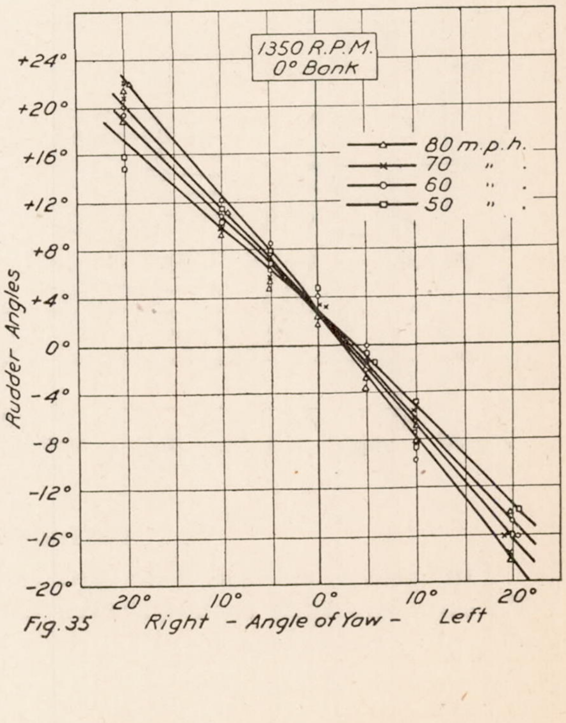

Fig. 35

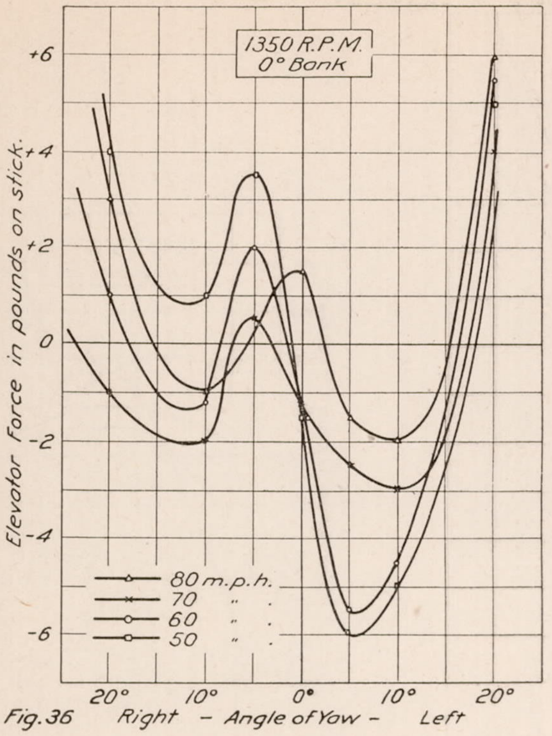

Fig. 36

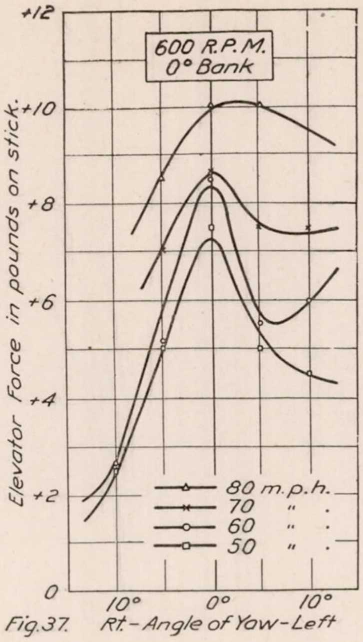

Fig. 37.

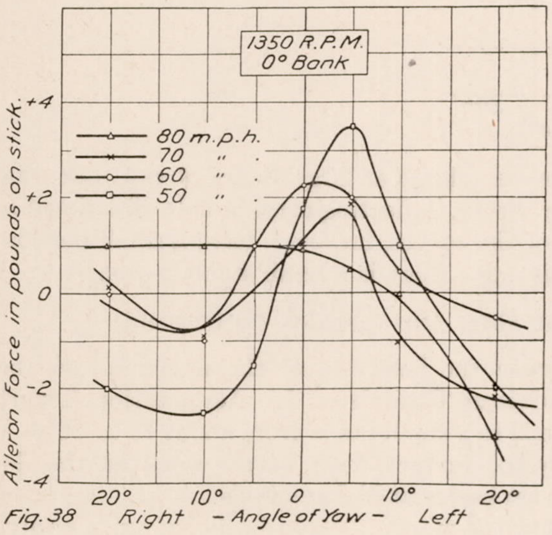

Fig. 38

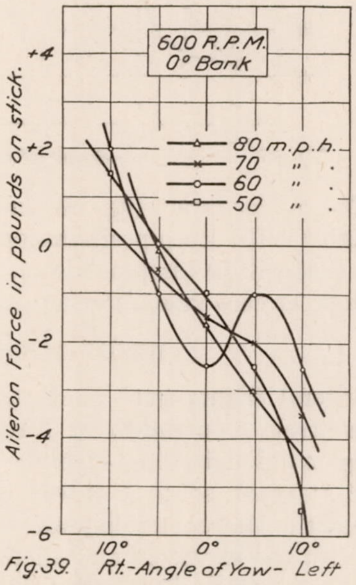

Fig. 39.

The curves of rudder position (figs. 34 and 35) show that the rudder must be kept over to hold the yaw, and the air speed has very little effect on this angle. On comparing the rudder with the ailerons it will be seen that the controls are crossed, as would be expected in a side slip.

CONTROL FORCES IN YAW.

The elevator forces (figs. 36 and 37) decrease with the angle of yaw up to about 10°, at which point they rapidly increase due to the tail coming out of the slipstream. In general the longitudinal stability with free controls is unaffected by yawing.

The aileron force curves are shown in figures 38 and 39 and indicate a positive slope at low speeds and small angles of yaw, especially with open throttle, but at large angles of yaw the slope is always negative, that is, right force is used to hold right yaw.

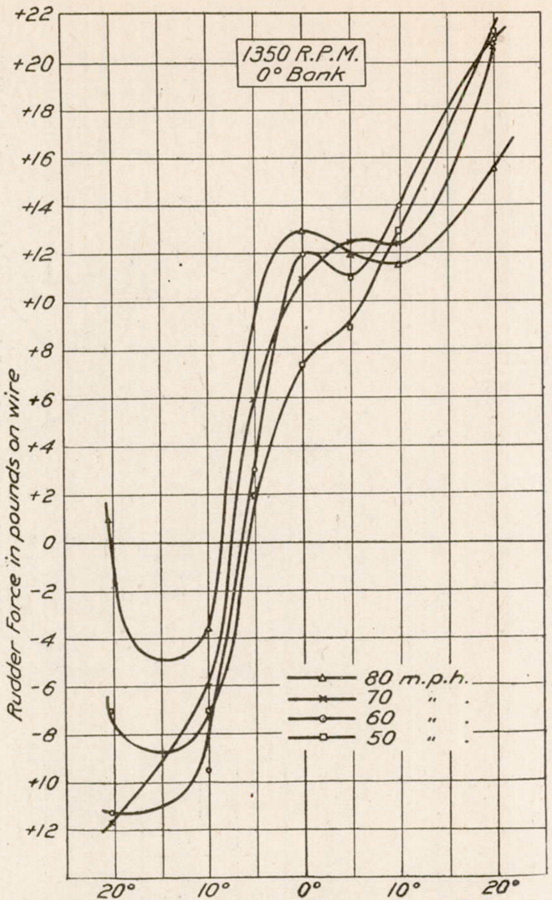

Fig. 40 Right – Angle of Yaw – Left

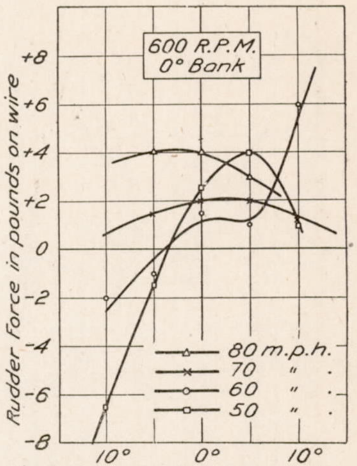

Fig. 41. Rt.-Angle of Yaw-Left

The rudder forces (figs. 40 and 41) are quite large at large angles of yaw, but what is most noticeable is the steep positive slope of the curves, indicating considerable directional instability a fact that will be discussed later. Most of the curves, however, have a small portion of negative slope at zero yaw, showing that at this angle there is a small stable region.

ACTUAL FLIGHT WITH FREE AND LOCKED CONTROLS.

Several flights were made to determine the behavior of the machine with locked and free controls. As shown in National Advisory Committee for Aeronautics Report No. 70, the region of longitudinal stability is confined to a small range from about 45 to 50 m. p. h. with locked elevator, so that it was necessary to conduct most of the work at this low speed, whereas the lateral stability would have been better at higher speeds.

With the elevators and ailerons locked the machine could be flown quite easily with the rudder, and gentle turns were successfully made. It was impossible, however, to fly for more than half a minute with all three controls locked, as a bump would send one wing tip down, a side slip ensuing that would not correct itself. The departure of this machine with locked controls from stability is, however, not very large.

It was found possible to fly not only safely but quite satisfactorily with the rudder locked. Turns could be made up to 80° banks smoothly, and with only a slight amount of side slip in coming out. The control seemed much better with the throttle open than when closed. With the ailerons locked the machine could be controlled and banks successfully made, but in coming out of the bank the side slip was excessive and a good deal of altitude must be lost before an even keel is reached. In this case the control is better with closed throttle.

In any flight condition, except rapid gliding flight, if the rudder was released the machine would begin to yaw and would soon whip into a very rapid spin from which there seems to be no way of extricating it without the use of the rudder, so that any loss of rudder control would be an extremely serious matter. This dangerous feature could easily be remedied by the addition of a slightly larger fin. This emphasizes the fact that wind-tunnel tests for stability with free controls should be made with the movable surfaces removed or freely hinged. It was also noticed that the *C. G.* position had a marked effect on the directional stability with free controls, a small shift forward of its normal position making the machine almost completely directionally stable.

THE FREE FLIGHT DETERMINATION OF LATERAL DERIVATIVES.

For the computation of the stability characteristics of an airplane it is necessary to obtain experimental values of the resistance derivatives, which are 18 in number for a symmetrical airplane. The values of these derivatives are usually determined from the results of wind-tunnel tests. As the wind-tunnel tests do not, however, take into account the effect of the slipstream, and as the scale correction necessary to apply to the model results is unknown, it will be of great value to compute the resistance derivatives from data obtained in free flight. Unfortunately, it is quite difficult to determine all of the derivatives in this manner, and only a few can be obtained directly. It was one of the objects of this investigation to determine the value of Y_v, the lateral force, L_v the rolling moment, and N_v, the yawing moment, due to slide slipping, in free flight.

The method employed to determine Y_v consisted in finding the lateral acceleration experienced in various side slips and at different air speeds, and from this, the curve of lateral force against angle of yaw is plotted, and from the slope of this curve Y_v is computed. The lateral acceleration was determined from the readings of a bubble inclinometer, for in level flight the lateral acceleration is given by:

$$a = g \tan \alpha$$

where g is the acceleration of gravity and α is the angle read on the inclinometer.

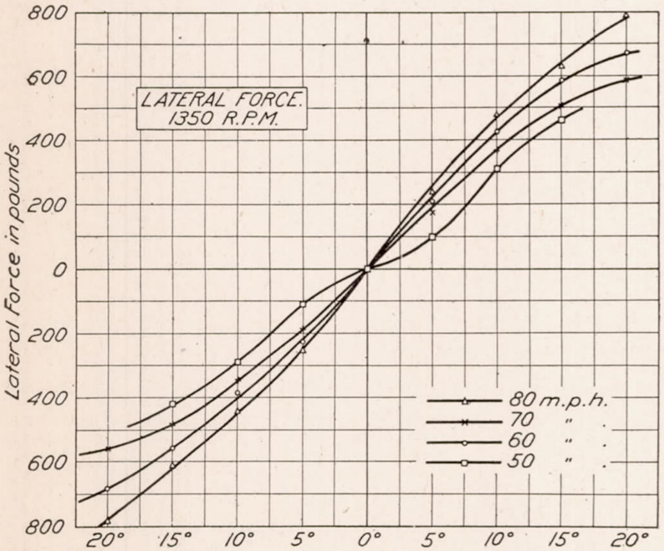

Fig. 42.

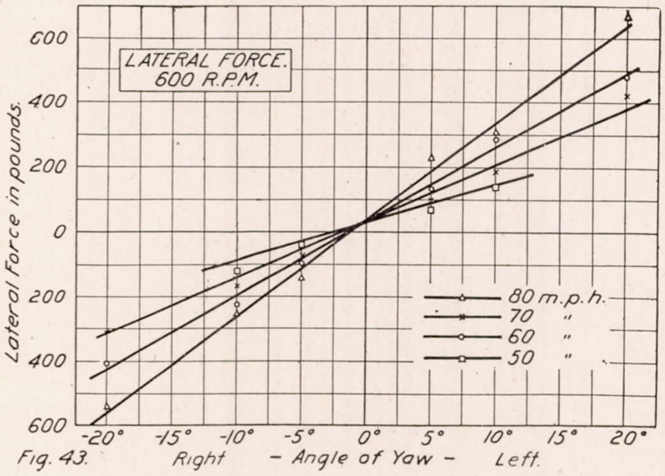

Fig. 43.

If the machine has an angle of bank ϕ, g will evidently be replaced by the resultant normal acceleration, R. Also, when the machine has an angle of pitch of θ, the term $\cos \theta$ must be introduced into the equation, so that it will then be:

$$a = g \frac{\cos \theta}{\cos \phi} \tan \alpha$$

As all the tests were made with the angle of bank at zero, and since the longitudinal angle in no case was enough to introduce any appreciable error, the simplified equation may be used.

There is one other correction, the deviation from the true reading when the air speed head is yawed. This correction was determined by a wind tunnel test of the instrument, and was found to be negligibly small.

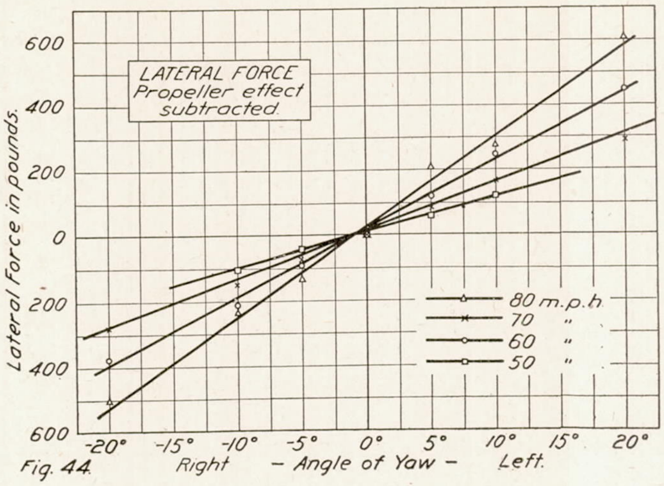

Fig. 44

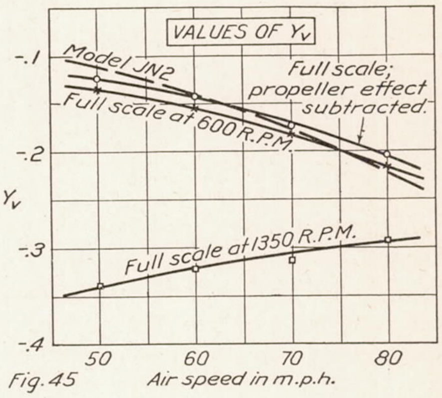

Fig. 45

In figure 42 are shown the curves obtained at 1,350 r. p. m. by plotting the lateral force in pounds, against angle of yaw, for different air speeds. In figure 43 is plotted the same thing at 600 r. p. m. It will be noticed that the lateral force is considerably smaller, being reduced by about 25 per cent. It might be thought that this difference was due to the fin effect of the propeller, but as will be shown later, this is not nearly enough to account for the difference. The discrepancy can only be accounted for, then, by the effect of the slipstream on the body, fin, and rudder.

It is desirable to determine Y_v without the effect of the propeller for comparison with model tests. This might be done by stopping the propeller in the air, but as it could not be stopped in the same position every time, it would lead to considerable errors. As the lateral force on a propeller can be computed very closely from tests run by the N. P. L., it was thought that the best results would be obtained by running the airscrew at approximately the speed of no thrust, and then subtracting its lateral force from the total of the whole machine. These corrected curves are shown in figure 44.

The derivative Y_v is equal to:

$$\frac{57.3}{Um} \cdot S$$

where U is the forward velocity in ft./sec.
m is the mass of the machine in slugs.
S is the slope of the lateral force curve in lbs./degree.

The values of Y_v as determined from the mean slope of the force curves are shown in figure 45, together with the curve obtained for the JN2 model,[2] showing a remarkably close agreement between the model and the full-sized machine with the propeller effect subtracted. The values of Y_v at 1,350 r. p. m. are, however, quite different, being nearly twice as large, and the slope of the curve is in the opposite direction. While these results give one greater confidence in the model tests for strictly comparable conditions, at the same time they emphasize the fact that all models should be tested with a revolving propeller to give actual slipstream effects, as the error introduced into stability calculations by neglecting the slipstream may be very large.

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[2] Dynamical stability—Hunsaker.

The determination of L_v was accomplished by applying to the wing tips weights which were balanced by a certain movement of the ailerons. In this way it was possible to determine what angular setting of the ailerons corresponded to a given rolling moment and from these values the rolling moment produced in various degrees of yaw could be determined from the original curves shown in figures 32 and 33. As it would have been quite impossible to take off or land the machine with the large unbalanced weights on the wing tips it was necessary to apply equal weights on the wings and when in the air to release one of the weights so that the unbalanced force would remain. This was accomplished by placing on each wing tip a box with a hinged bottom containing sand so that the sand could be released from the cockpit, as shown in figure 46. Each one of the boxes was capable of holding 150 pounds and the machine was taken off with both boxes filled with a known weight of sand, and when ready to begin the test one box was emptied. When the test was completed the other box was emptied so that a landing could be made with no load in the boxes. Curves of rolling moment against aileron angle are shown in figure 47, and it will be seen that the lateral control on this machine is very powerful as an unbalanced load of 150 pounds on one wing tip can be easily supported, and this is all the more remarkable as this is a machine with ailerons only in the upper wing. The value of L_v is determined by the following formula:

$$L_v = \frac{57.3}{-Um} S$$

the symbols having the same meaning as before.

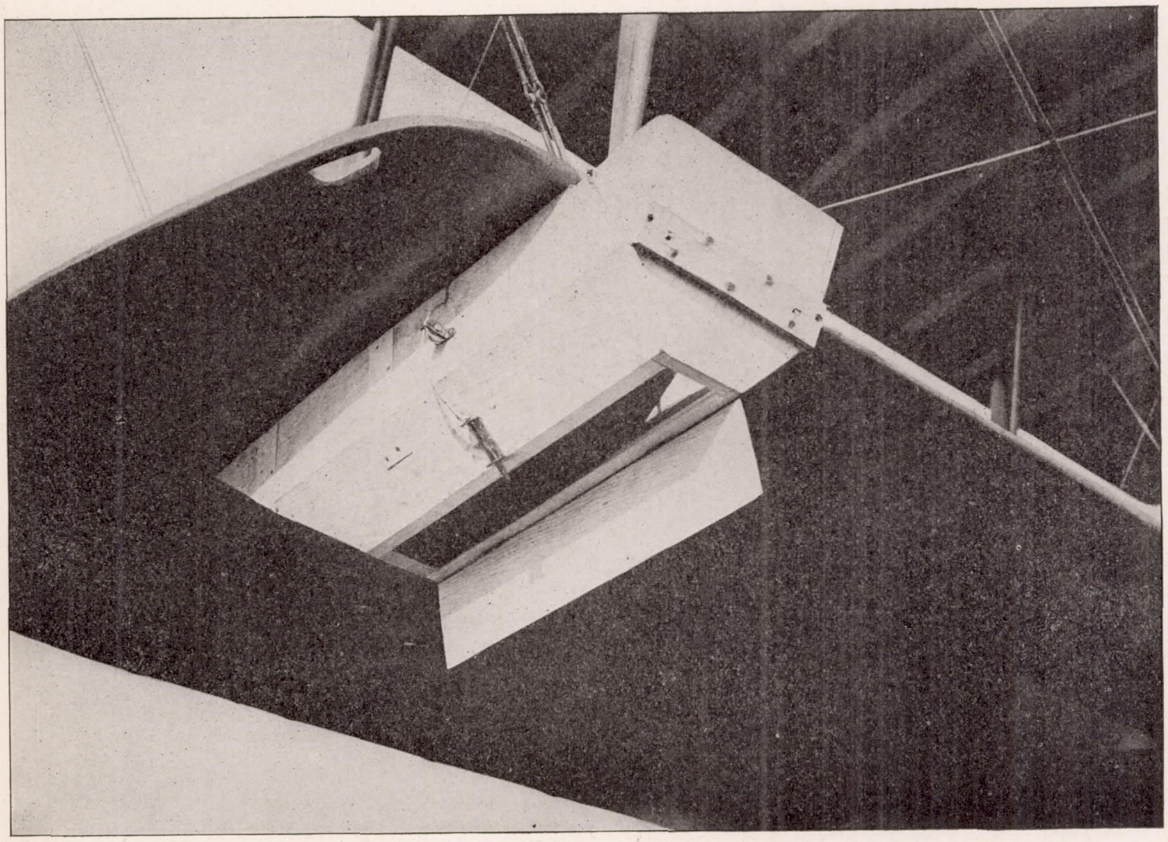

FIG. 46.—Method of applying a known rolling moment to the machine.

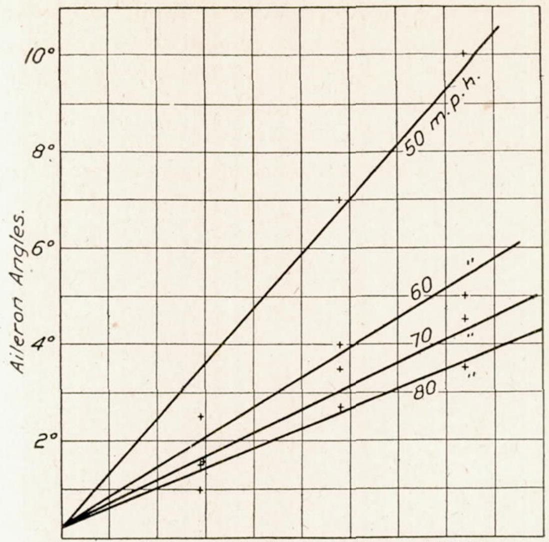

Fig 47

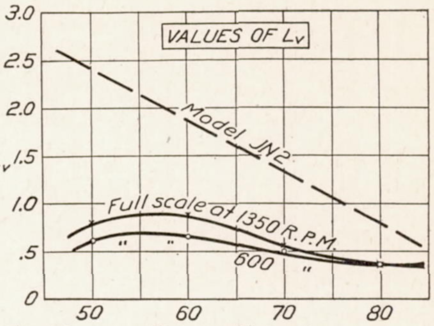

Fig. 48

In figure 48 there are plotted the curves for L_v with the motor on and the motor off and it will be seen that although the curves are quite consistent in shape, there is a slight difference between them, that is, the value with the motor on is slightly larger than the value with the motor off, but when comparing these values with the curve obtained from the model it will be seen that the full flight values are much lower than the latter, especially at the lower speeds. It is an interesting fact, however, that the curves from the full-sized test and from the model test seem to approach each other at the higher speeds and this can be explained by the fact that the ailerons at the high speeds on the full-sized machine are nearly at zero degrees, so that it approaches more and more the condition in which the model was tested, and it is believed that the discrepancy between the two tests is due to the fact that in the model ailerons were always kept at zero degrees, whereas, they should have been rotated to different angles for each angle of incidence of the machine.

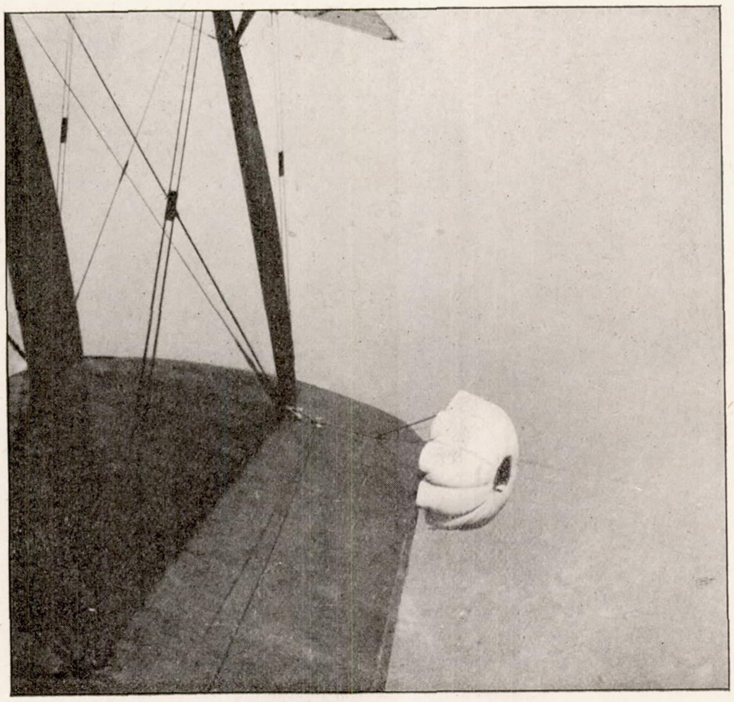

FIG. 49.—Method of applying a known drag to the wing tip by means of a small parachute.

The determination of N_v was accomplished by releasing small parachutes from one wing tip and measuring the pull of the parachute through a string which connected it to a spring scale in the cockpit, as shown in figure 49. In this way the moment for one degree change in rudder angle can be easily found and by using this constant the curve of rudder angle for various angles of yaw can easily be converted into yawing moment. The curves of yawing moment against rudder angle are shown in figures 50 and 51, each point representing the average of a large number of readings. The forces with the small parachute were so small that the accuracy of these readings is not great. N_v is found in the same way as L_v from the slope of the rudder position curves and the values obtained are plotted in figure 52. It is evident that the throttle setting makes very little difference with the value of N_v and that the values do not agree very closely with the model results, as the full scale results have a somewhat lower value than those of the model.

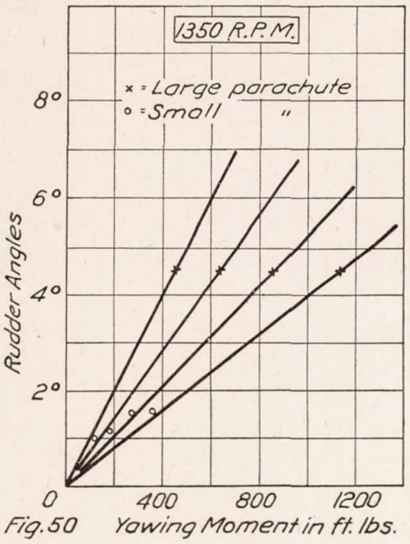

Fig. 50

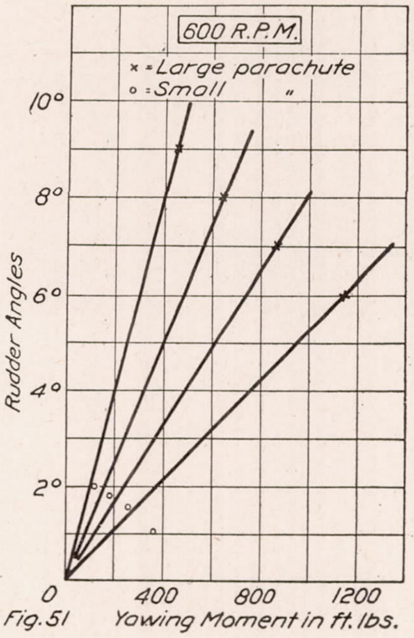

Fig. 51

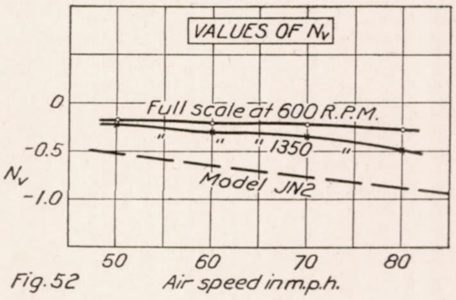

Fig. 52

It should be realized when comparing these full flight stability derivatives with those from the model tests that the values obtained in full flight on account of the inherent errors in such testing can not be depended upon to better than 15 per cent and on the other hand the model test was made on a JN2 model, which is somewhat different from the JN4H, although the values of these stability derivatives should not be appreciably affected by this difference.

CONCLUSIONS.

The longitudinal stability is but little affected by either bank or side slip, although the forces and positions of the elevator may change to a considerable extent. In any bank the machine tends to increase its bank unless restrained both by force and by position of the ailerons. In a side slip the machine will continue to increase the angle of yaw unless restrained by the rudder. It is recommended that the lateral dihedral be increased, and that more fin surface be added, in which case the machine would probably be laterally stable at least through a small range about its symmetrical position. Also the leading edge of the fin should be moved to the left and a balanced portion added to the top of the rudder in order to neutralize the constant force on the rudder bar. The value of Y_v is greatly altered by the slipstream, so that the results from model tests can only be applied to gliding flight. The value of L_v is quite different at low speed from the model value, but agreement is approached at high speed. N_v is only slightly affected by the engine speed, and is not in close agreement with the model.

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