REPORT No. 105

ANGLES OF ATTACK AND AIR SPEEDS DURING MANEUVERS

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By Edward P. Warner and F. H. Norton, Langley Memorial Aeronautical Laboratory.

INTRODUCTION.

The following report was prepared at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics, as it seemed desirable that there should be some study of the attitude assumed by an airplane, and more particularly of its motion with respect to surrounding air when maneuvering, either in ordinary turns, spirals, climbs, and dives, or in those more spectacular feats commonly known as stunts. It is important to secure this information, among other reasons, in order to have definite knowledge as to the distribution of load on the wings, and so to furnish the basis for improved accuracy in stress analysis. An accelerometer can be counted on to give the total load on the wings with great accuracy, but it tells nothing about the distribution of that load along the chord or between the upper and lower wings or about its partition between the front and rear trusses. Knowledge as to these factors can only be gained from measurements of the angle of attack.

The second reason for wishing data on behavior in maneuvers is aerodynamic. If airplanes are to be designed intelligently it is essential that the designer know what they will have to do. If a machine is required to loop easily and rapidly, or to resist falling into spins, or to show any other particular maneuverability characteristic, a necessary preliminary is the securing of information as to the reactions of the air on the machine and the manner in which they should be modified to gain the desired end.

Experiment in this direction has been exceedingly sparse compared with that in other lines. Some work has been done at the Royal Aircraft Establishment with a recording air-speed meter,[1] as well as by observing with a camera obscura and by taking moving pictures from another airplane, the second method being used particularly for spins and spirals, the third for rolls. All of these experiments, with the exception of those on air speeds which were performed in conjunction with some accelerometer tests, were directed primarily toward the determination of attitudes and motions in space rather than with relation to the surrounding air, and this, while interesting, is of little immediate application if taken alone. To make a complete dynamic analysis it is of course necessary that both the angles of attack and the angles of inclination be known; but the angles of attack and accelerations are more important to the designer than are the positions in space. The angles of attack and side slip could obviously be computed if the attitude and component velocities were completely known and if the air were still, but the measurements would have to be made with greater refinement, to give a satisfactory degree of relative accuracy in the determinations of the angles to the relative wind, than is readily attainable by the methods hitherto used.

Some experiments on the direct measurement of angles of attack during maneuvers have accordingly been carried out at Langley Field.

METHODS OF TESTING.

The angle of attack was measured with a simple vane, counterweighted by a rod projecting forward from the pivot. The vane was exceedingly steady, and the angle could easily be read to within a degree under any normal conditions when the vanes were well away from the center

[1] Applied Aerodynamics, by Leonard Bairstow, New York, 1920. Ch. V.

of the machine. An attempt to measure the direction of flow in the slip stream, however, was less successful, the vane fluttering badly because of the more turbulent nature of the relative flow.

The direct measurement of angle of attack during maneuvers is subject to two errors, and the means which reduce one error unfortunately aggravate the other. The most obvious of these two sources of difficulty is the interference of the wings and the disturbance of the air to considerable distances in front of the machine. If there were no complicating factors this interference could be reduced to a point where it would become negligible by carrying the vane on a long pole projecting one and a half or two chord lengths forward of the leading edge, as is the practice when the angle of attack is to be measured during steady straight flight. This is impracticable when the flight path is curvilinear, because the rotation causes different parts of the airplane to move in different directions at the same instant, and a vane carried well forward of the wings would not travel through the air in the same direction as do the wings themselves. In a tight loop the rotation is rapid enough so that moving the vane forward 3 feet would cause an error of approximately 1.5° in the vane reading, entirely aside from any interference effects. Because of these inevitable errors, the measurements can not be relied on for great accuracy; but the two sources of trouble fortunately tend to cancel each other in most instances, the interference making the reading too high, while the rotation in the sense usual in maneuvers (stalling) makes it too low, and the total resultant error probably does not exceed 2° in any instance except at very large angles of attack.

The air speed was measured with a meter of the pressure-plate type in order to bring the dial close to the vane and to facilitate the photographic recording of angle of attack and air speed on a single film. The vane and air-speed meter are shown together in figure 1. The whole instrument is pivoted and has a counterweighted vane behind the pivot to keep the meter always in the same position with respect to the relative wind. The meter is pivoted in the vertical plane only, no attempt having been made to allow swiveling about a vertical axis when side slipping. The member on which the air pressure acts is an aluminum disk 2 inches in diameter (seen edge-on in the lower right-hand corner of the cut). This disk is rigidly attached to one member of a jointed parallelogram linkage. The side opposite to that which bears the disk is pivotally fixed to the airplane, and an extension of one of the other sides carries a pointer moving over a scale. The rearward motion of the disk is opposed by the pull of a rubber band which connects extensions of two adjacent sides of the parallelogram. The air-speed meters were calibrated in flight by flying the airplane steadily at various speeds and observing the position of the pointer. At speeds below the minimum for steady flight the meters were calibrated in a wind tunnel.

Maneuvers may be divided into four classes—steady symmetrical, steady asymmetrical, unsteady symmetrical, and unsteady asymmetrical. The first class includes only rectilinear flight, both horizontal and inclined. The second group includes turns on the levels, spirals, and some spins. The extent to which spinning is a steady motion is a matter still open for argument, but it is certain that there are some airplanes in which it is a periodic motion of substantially unvarying amplitude. The class of symmetrical unsteady motions is a very large one, taking in loops, zooms, ordinary longitudinal oscillations, and pulling out of dives. Finally, the fourth classification includes rolls and reverse, or Immelman, turns.

These four classes are arranged approximately in order of the difficulty which they present to the experimenter. The steady motions are easy to study, because no recording instruments are necessary, the readings being taken and recorded by the observer. This method was used in the first work done on free-flight testing by the National Advisory Committee for Aeronautics at Langley Field.[2] The symmetrical motions are easier than the unsymmetrical to deal with, because in a symmetrical motion all points along a line perpendicular to the plane of symmetry have the same speed and direction of motion, and it is therefore only necessary, in general, to take readings at one point, whereas in unsymmetrical maneuvers at least two points and sometimes more must be used.

[2] Preliminary Report on Free-Flight Testing, by Edward P. Warner and F. H. Norton; N. A. C. A. Report No. 70, Washington, 1920.

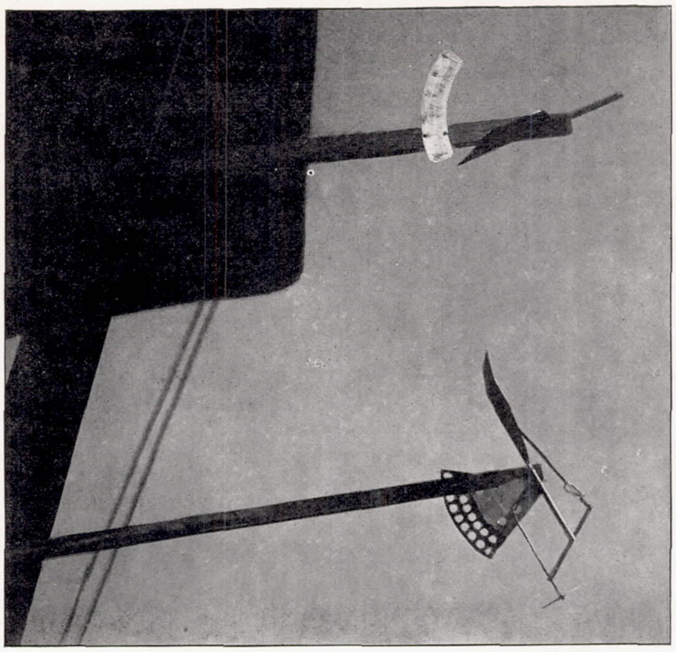

Fig. 1.—The Vane and Air Speed Meter

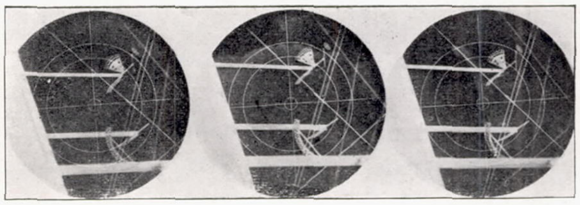

Fig. 2.—Photographs of Vane and Air Speed Meter taken with Gem Camera

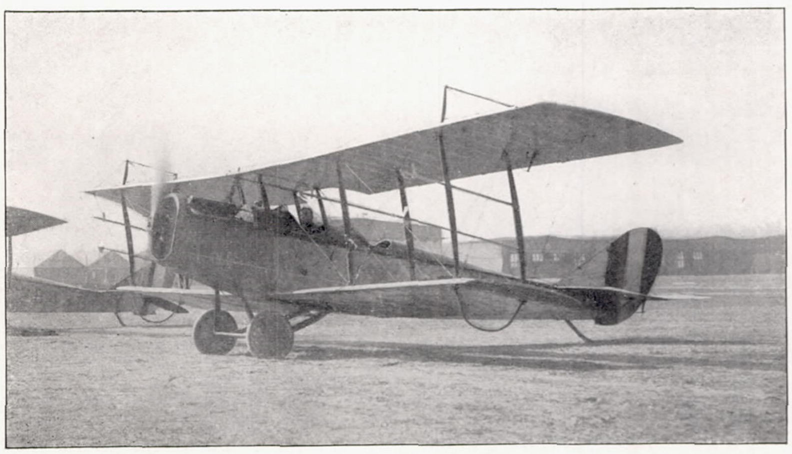

Fig. 3.—The JN 4H Test Airplane

The method used in the present series of tests was to take moving pictures of the vane and air-speed meter, which were fastened about 18 inches apart, with a gun camera. A few exposures from one of the records are shown in figure 2. Only one wing tip at a time could be worked on in this way, and unsymmetrical maneuvers had to be repeated in order to secure complete records. The gun camera is very unsatisfactory for this work, as it does not run as long on a single winding as would be desirable, and as its speed is not sufficiently constant to furnish a good time scale. The governor is of rather crude construction, although amply good enough for gunnery practice, and the rate of taking pictures is considerably affected by accelerations of the air plane. Furthermore, many records were spoiled by jamming of the mechanism.

RESULTS OF TESTS.

The first experiments were made in steady straight flight and with direct reading in order to see how serious was the error due to interference between the wings and the vane. A JN4H airplane was used in these and in all subsequent tests, and is shown, as fitted up for the tests, in figure 3. The vane readings were compared with the values of the angle of attack determined for the same airplane in Report No. 70 by the use of a liquid inclinometer when flying level, and it was found that interference increased the vane reading by from 1° to 1½° at all air speeds from 70 miles per hour to 90 miles per hour. At speeds lower than these the interference is more marked, increasing to 4° at 50 miles per hour. It is not probable that the error due to interference goes on increasing rapidly as the angle of attack increases beyond the burble point, since the degree of upward diversion of the air forward of the wings is dependent on the lift coefficient.

The next type of evolution tested was an ordinary spiral. During a tight spiral at 80 miles per hour the angle of attack rose to 7°, although the angle for equilibrium in straight flight at this speed is only 0.8°. Allowing for an interference error of 1.5° in the angle when spiraling, and taking lift coefficients determined in free-flight tests of the JN4H, it appears that the lift coefficient at 5.5° is 1.84 times as large as that at 0.8°. Neglecting the effect of descent in spiraling, the theoretical angle of bank corresponding to this load factor would be 57°. No apparatus for making accurate measurements of banking angle was available, but it was evident from direct inspection that the angle of bank was approximately 60° (within 10° plus or minus). The experimental determination of the angle of attack, therefore, checks well with the computed value in this simple case.

The first real stunt to be considered was the spin. It can easily be shown that the angles of attack at the wing tips during any unsymmetrical maneuver are:

$$\tan \alpha_R = \frac{-w + \frac{s}{2} \cdot p}{-u - \frac{s}{2} \cdot r}$$

for the right wing, and

$$\tan \alpha_L = \frac{-w - \frac{s}{2} \cdot p}{-u + \frac{s}{2} \cdot r}$$

for the left, where u and w are the components of velocity parallel to the X and Z axes, respectively, and p and r are the angular velocities about those axes, as is customary in stability work, and $\frac{s}{2}$ is the distance from the plane of symmetry, the X axis being taken parallel to the wing chord. Similarly, the components of velocity parallel to the plane of symmetry are:

$$V_R = \sqrt{(u+\frac{s}{2}\cdot r)^2 + (w-\frac{s}{2}\cdot p)^2}$$

and

$$V_L = \sqrt{(u-\frac{s}{2}\cdot r)^2 + (w+\frac{s}{2}\cdot p)^2}$$

if v, the velocity of side slip, be neglected.

The determination of α_R, α_L, V_R, and V_L, therefore, makes possible the calculation of μ, w, p, and r. The solutions for these four velocities are:

$$u = -\left(\frac{V_R \cos \alpha_R + V_L \cos \alpha_L}{2}\right)$$

$$w = -\left(\frac{V_R \sin \alpha_R + V_L \sin \alpha_L}{2}\right)$$

$$p = \frac{V_R \sin \alpha_R - V_L \sin \alpha_L}{s}$$

$$r = \frac{V_L \cos \alpha_L - V_R \cos \alpha_R}{s}$$

Direct observation of the angle of attack after the attainment of steady conditions showed a great difference among spins. The angle of attack at the inner wing varied from 35° in the slowest true spins to 75° in the most rapid maneuvers. The angle on the outer wing varies much less, ranging only from 7° to 10° in the tests made.

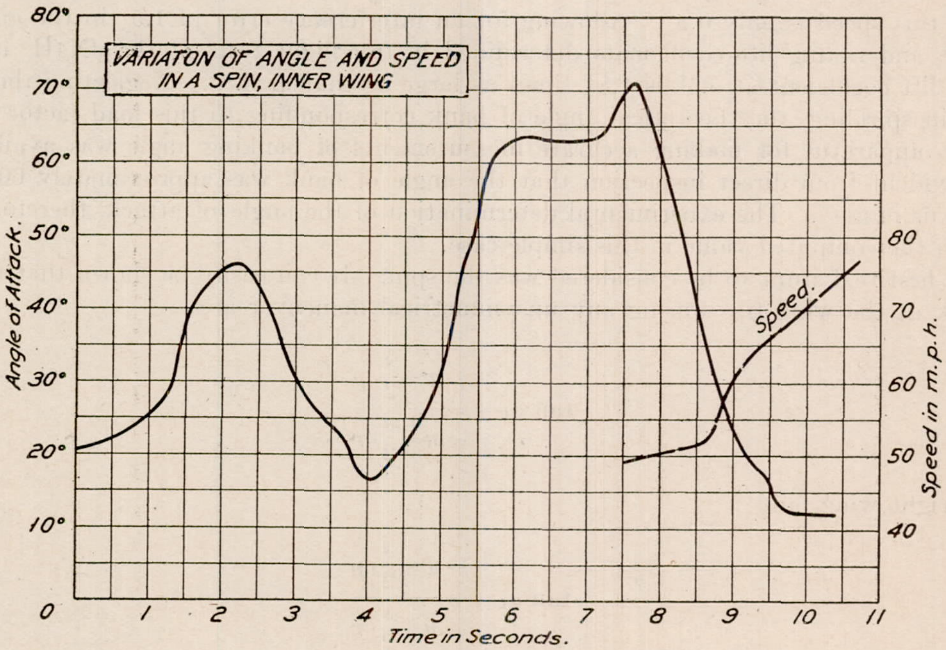

FIG. 4.

In using the gun camera the records were started early enough to catch the beginning of the maneuver from the instant when the pilot pulled his stick back to stall the machine. The variation of angle of attack on the inner wing tip during a spin and of speed during the recoveries are plotted in figure 4. Complete speed records could not be plotted because the speed during the spin was below the lower end of the scale (48 miles per hour). Both of these spins were executed with the stick clear back and with the controls crossed (left rudder, right aileron). It will be noted that the spin starts with a large oscillation as the rudder is put over, and that this oscillation is very quickly damped out, disappearing after a single swing. As the controls are centralized the angle increases for an instant and then falls off rapidly. Accelerometer records on this same airplane show a continuous oscillation of small amplitude throughout the duration of the spin, but this oscillation could not be observed on the vanes. In spins of long duration (too long to be followed throughout with the gun camera) the vanes reached a perfectly steady reading, varying less than one degree therefrom.

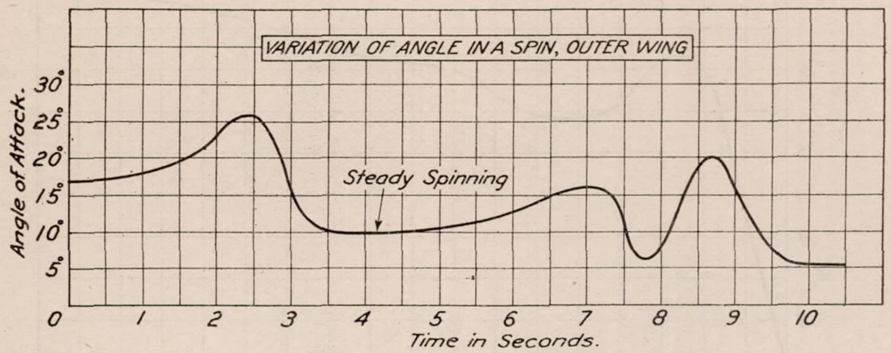

FIG. 5.

The variation of angle on the outside wing is plotted in figure 5. Here, too, there is an oscillation, the angle of attack increasing as the machine starts to fall into the spin and then falling off as the rate of rotation approaches its steady value. The speed during steady spinning was about 60 miles per hour, the descent during these spins being very slow while the rotation was rapid.

A very approximate solution for the velocities, taking V_R as 88 feet per second, V_L as 66, α_R as 8°, and α_L as 61°, due allowance having been made for interference, gives:

$$u = -59.6 \text{ feet per second.}$$
$$w = -35.0 \text{ feet per second.}$$
$$p = -1.56 \text{ radians per second.}$$
$$r = -1.90 \text{ radians per second.}$$

The angle of attack at the plane of symmetry is 30.4°, which is of the same order of magnitude as the angles of attack found during spins by British experimenters [3] using an entirely different method.

It is evident that, if spinning is a steady motion, there must be no unbalanced forces or moments, the air reactions on the airplane being completely expressed by a single vector passing through the center of gravity. The resultant of all the components of force parallel to any given line must then pass through the C. G. The particular line which is of most interest in this connection is the Z axis of the airplane, which has been taken as perpendicular to the plane of the wings. The coefficient of force normal to the chord of an aerofoil reaches a maximum at the burble point, drops off slightly thereafter to a minimum at about 25°, and then increases again until an angle of attack of 90° is reached. The curve in figure 6 represents the variation of normal force with angle of attack for the wing used on the JN4H, although a part of the curve was lifted from a wind tunnel test of a slightly different aerofoil, the tests of the JN wing itself having extended only to 20°. It is probable, however, that all thin aerofoil sections of the same general form have closely similar characteristics at angles beyond that of maximum lift.

To find the condition necessary in order that the resultant of the normal components may lie in the plane of symmetry it may be assumed that each aerofoil element formed by two planes parallel to the plane of symmetry acts independently of every other such element, and that the forces and moments acting on the wing may be found by summing the elementary forces and moments arising on each element. This method has been found to give good results

[3] A Mathematical Study of Spinning, by Lindemann, Glauert, and Harris: R. and M. No. 411, British Advisory Committee for Aeronautics.

in propeller design, and its application to wings has been justified in numerous experiments on the auto-rotation of aerofoils in the wind tunnel and on warped aerofoils, carried out at the National Physical Laboratory. It furnishes a very powerful means of analyzing the unsymmetrical motions of airplanes.

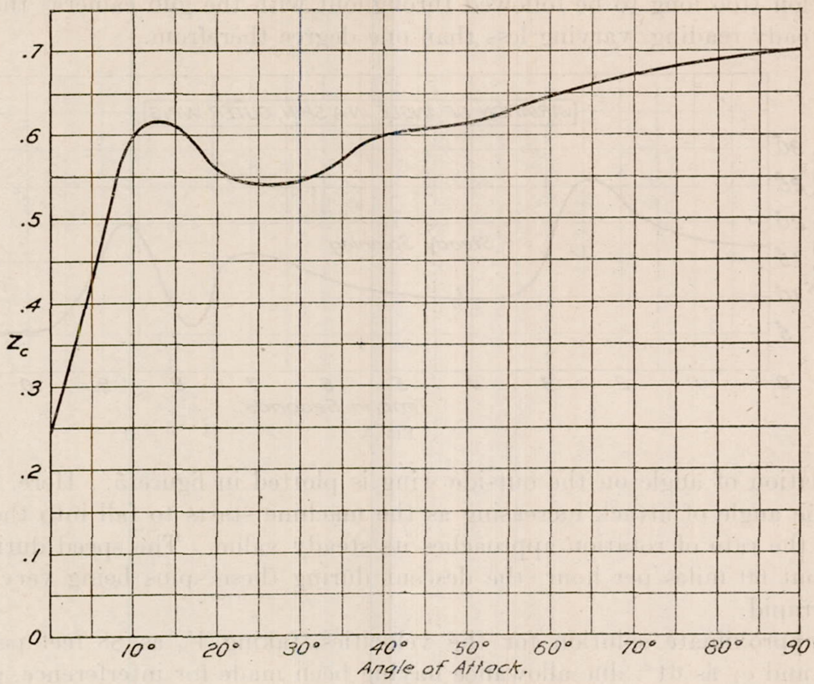

Fig. 6.

The condition of equilibrium, if the aerofoil element theory be used, is that

$$\int_{-\frac{s}{2}}^{+\frac{s}{2}} Z_c \cdot c \cdot [(u+rx)^2 + (w-px)^2] \cdot x \cdot dx$$

must be equal to zero, where s is the total span, c the chord, x the distance of an element from the plane of symmetry, and Z_c the coefficient of normal force at the angle

$$\alpha = \tan^{-1}\frac{-w+px}{-u-rx}$$

Z_c over the inner wing, where the angle of attack varies roughly from 35° to 65°, is nearly constant, while the coefficient on the outer wing increases from the plane of symmetry, reaching a maximum about halfway out, the wing there meeting the air at the angle of maximum lift, and then falls off again as the tip is approached. If the angles of attack at the outer strut on a JN are 8° and 61° the angles of attack at the extreme tips of the upper wings, which overhang the outer strut points by about 7 feet, are 0.7° and 75°. There, therefore, is no change in the direction of the load at the outer tip, as the angle of attack does not pass the angle of zero lift. It is very probable, however, that it would do so in some instances, as the spins from which these data have been taken were not extreme ones. In some spins the vane on the inner wing continuously recorded an angle of from 77° to 79°, corresponding to an angle of approximately 90° at the wing tip.

In figure 7 there are plotted curves of V, α, Z_c, and $Z_c V^2$, or mean loading per square foot, against x, the values taken for u, w, p, and r being those already given as computed from the observations. The total moment about the line corresponding to the plane of symmetry ($x=O$) of the area under the third of these curves should be zero if the experimental results and the assumptions made in the computation were correct. The agreement proves to be rather poor, the center of action of the normal force, as found from the curve of loading in figure 7, lying on the outer wing and 1.25 feet from the plane of symmetry, but it is good enough to make sure that the load curve in figure 7 represents with reasonable accuracy the form of the curve of load distribution along the span during a spin. The maximum loading occurs near the middle of the outer bay, and is 38 per cent larger than the mean loading. The load factor given by the curve is 1.25, which is somewhat smaller than the load factor found with an accelerometer in similar spins. It is probable that the principal cause of the discrepancies lies in the fact that the ailerons are not centered, and that the actual coefficient of normal force on the outer portion of the outer wing is therefore less than it was assumed to be in making the computations.

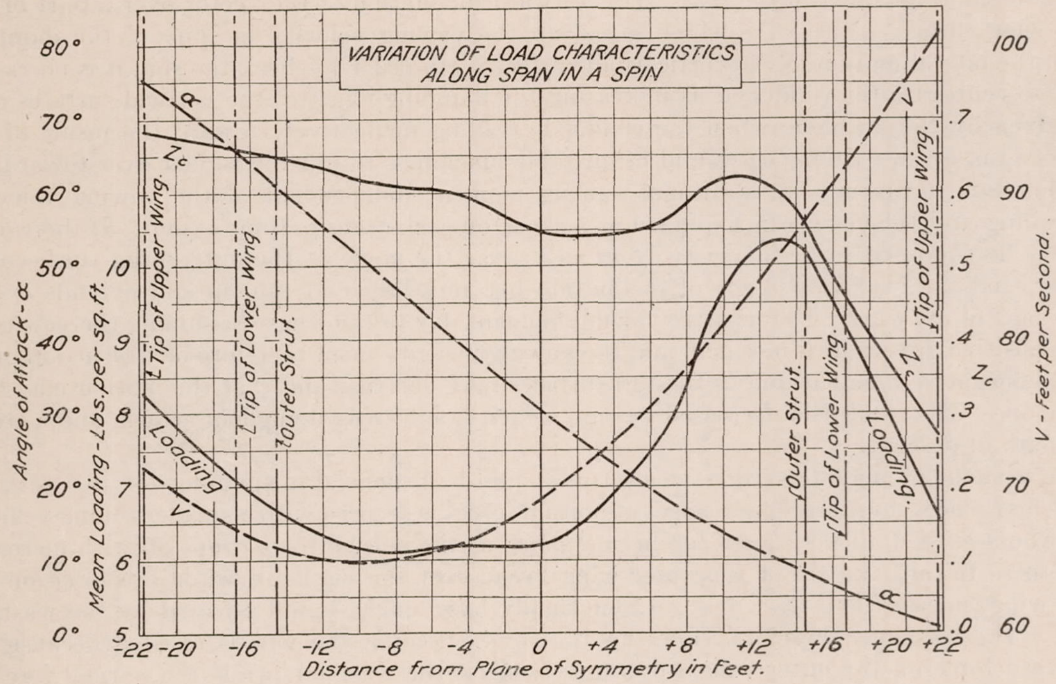

Fig. 7.

It will be noted in figure 7 that the resultant speed does not by any means vary uniformly along the wing, but falls off to a minimum just beyond the inner strut on the inner wing and then increases again toward the tips.

From the structural standpoint the spin presents no very special terrors, and need not be taken into account at all as a controlling factor in an airplane built for general stunting. It is, however, of special interest because it is a maneuver which almost any airplane is liable to have to execute on some occasion. No pilot loops or does vertical banks without intending to, but there is always a possibility of falling into a spin when turning too flatly or attempting to fly at a very large angle of attack, so large that the ailerons become ineffective.

The most striking features of the spin, structurally speaking, are the uneven distribution of load along the span of the outer wing and the distribution between the upper and lower wings of a biplane combination. The first of these features has already been commented on. The second applies particularly to the inner wing. Near the tip of that wing, where the angle of attack is from 60° to 75°, the center of pressure lies about 45 per cent of the way back on the chord, and it is probable, although no direct experiments are available at such angles, that the lower wing carries about 70 per cent of the load. This concentration of load on the lower wing is, of course, most marked when the upper and lower wings are of equal span.

The load on the drag truss when spinning is negligible. The drag is very large, but is carried through the interplane bracing, the resultant reaction on all elements of the wings except those near the outer wing tip being virtually perpendicular to the chord.

Accelerometer tests have shown a load factor which does not exceed 2.2 during the worst spins, and is materially less than that in most instances. Making all due allowance for the unusual distribution of load, it appears certain that an airplane designed to sustain a load factor of 3.5 with the C. P. forward and a factor of 4 in the lower rear spar with the C. P. at 45 per cent of the chord from the leading edge will be strong enough to stand any kind of a spin.

All along the inner wing the resultant force on the wing is virtually perpendicular to the wing chord, and the same condition prevails over a part of the outer wing. As the angle of attack falls below 20°, however, the vector inclines forward of the perpendicular to the chord and remains so inclined until the angle reaches about 4°. At angles smaller than that the perpendicular is inclined to the rear. This forward inclination of the vector over a part of the outer wing furnishes the force which keeps up the yawing velocity in spite of the damping due to the lateral motion of the vertical tail surfaces. In order to check the spin it is necessary either to centralize the rudder, thus increasing the damping effect of the vertical surfaces over that given by the fin alone when the rudder is trailing ineffectively toward the inside of the path of spin, or, in extreme cases and in unstable machines, to put the rudder over toward the outside, thus furnishing an additional yawing moment independent of the yawing velocity. The rolling and the yawing in a spin act as a check on each other to some extent. If the rolling velocity be supposed to be increased from any cause the angle at the outer wing tip becomes smaller, and the backward angle of inclination becomes larger at the tip and extends over a larger part of the wing. The positive yawing moment due to the wings (assuming the yaw to be in the positive direction) is lessened, and the yawing velocity must therefore be lessened in order that the negative moment due to the tail surfaces may decrease and that the motion may be a steady one. The result is a decreased yawing velocity, a decreased angle of attack, and a steepened path of descent.

A washout of angle toward the wing tips should be beneficial in spinning for two reasons: In the first place, equilibrium in respect of normal forces is secured with a smaller rolling velocity than would exist if all the chords lay in one plane, as the normal force drops off with increased abruptness toward the tip of the outer wing because of the washout, while the force on the other wing, presented to the air at an abnormally large angle, is not affected by the washout at all. The washout, therefore, slows up the spin. Second, the yaw is resisted because the backward force on the outer wing tip is increased by the washout, while the normal force at the inner wing tip, inclined forward of the perpendicular to the plane of the chords near the plane of symmetry, has a forward component. Both of these changes in the forces act together to give a negative yawing moment and to resist the spin.

The yaw in a spin is primarily dynamic, not static, and it is damping of yawing velocity, not "directional stability" in the common sense, that is of concern. To speak in more correct terms N_r, not N_v, is the dominant factor, although it is impossible to frame any estimate of the importance of the latter derivative until measurements of side-slipping velocity in spins have been made. Since damping moment varies as the square of the distance from the C. G., while statical moment varies only as the first power, the fin surface should all be as far away from the C. G. as possible. The flat sides of a deep fuselage may be useful in giving "weathercock stability," but they are of little assistance in damping motions; and it is of interest to note in this connection that the old pushers with open tail structures and all the fin surface at a maximum distance from the C. G. were practically immune from spins even when heavily loaded, and that the first true spin of which there is any record was performed by the late Lieut. Parke, R. N. A. S., on the all-inclosed Avro—a machine with an extremely deep flat-sided fuselage.

What is really wanted to make airplanes which will not spin, as has been pointed out by Dr. Leonard Bairstow and others as a result of experiments on the auto-rotation of stalled aerofoils, is a wing cell for which the normal force has no maximum for any angle less than 90°. Failing such a wing, it appears that spinning dangers can be ameliorated by using washout of angle near the tips and by securing the largest possible negative value of N_r.

LOOPS.

The experiments on loops were carried out in the same way as those on spins, except that only one wing needed to be considered, since a properly executed loop is a symmetrical maneuver. The best record obtained is plotted in figure 8, and is typical of the form of all the others.

The most interesting feature of these curves of speed and angle is the light which they shed on the question of "hang loops," and on the reasons for the great difficulty experienced by some pilots in getting around a loop without hesitating on top, in the upside-down position. It will be observed that, as the stick was pulled back, the angle of attack increased rapidly. At the end of two seconds the angle of maximum lift was reached, but the angle continued to increase until, after another one and a half seconds, it attained a value of 24°, at which point the lift is only 80 per cent of that at 12°, and is equal to that at 6°. The effectiveness of the wing in the necessary centripetal force to carry the airplane around the loop was then no greater, at that instant, than it would be if the angle of attack had been reduced by 6°, but the drag, acting to decrease the speed and so to decrease the lift, is 780 per cent greater at 24° than at 6°.

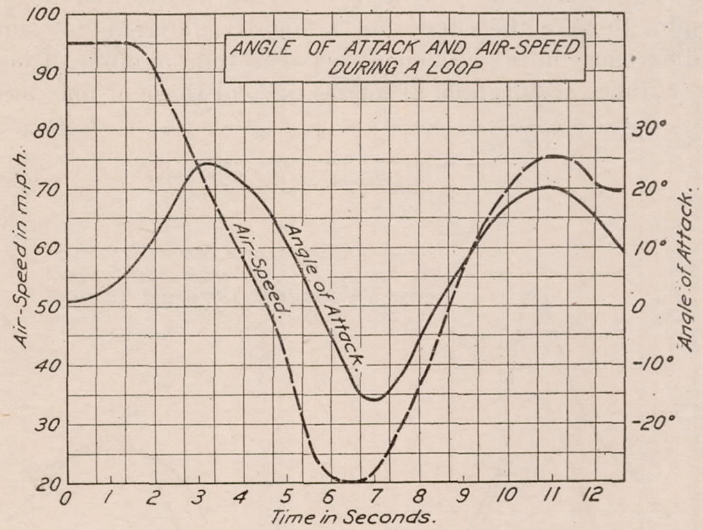

FIG. 8.

After reaching the maximum just mentioned the angle of attack decreased rapidly to a value of −15°, the speed at the same time falling to approximately 20 miles per hour (the air-speed meter was modified to extend its range to lower speeds in these tests, but the readings of minimum speed are not very accurate). In other words, the airplane was stalled on its back and was dropping, gaining speed at the same time. The angle then increased to a second maximum of 20° as the machine began to flatten out. It was very evident to the pilot and observer that there was a negative loading on the wings at the top of the loop, and the machine seemed to hang in the inverted position for a perceptible interval before the nose whipped downward. The natural tendency is for a pilot who finds himself in this position to attribute it to having failed to pull the nose up quickly enough to get around the critical portion of the loop before the momentum is exhausted, and his next attempt he will try to pull the stick back more sharply, resulting in the attainment of a still larger angle of attack and a still quicker loss of speed and more rapid dimunition of angle. It appears that the trouble is due entirely to too abrupt a pull up, and that far better results would have been attained if the stick had been eased forward as soon as the nose of the machine was well started upward. There has been no opportunity up to the present time to repeat these experiments on a loop executed more gently.

A comparison of the results of these tests with a computation from model experiment of the probable path of a similar machine in looping disposes one to pessimism with regard to the possibility of basing an analysis of such maneuvers on tests of models under steady conditions. Although the computation was carried out [4] on the assumption of an instantaneous pulling up

[4] Stresses in Diving and Looping; Bulletin of the Airplane Engineering Department, U. S. A., June, 1918.

of the elevator to the limit of its travel, an abruptness which would never be approached in practice, neither the first maximum value of the angle nor the minimum were as extreme as the angles found on actual test, the first being 17° and the second 6°. The difference between the two results is partly accounted for by the difference in speed at the start of the loop, the computation having been carried through on the assumption that the airplane was diving at 123 m. p. h. when the elevator was pulled up, partly by the fact that the C. G. was farther back in the actual airplane than it was assumed to be in the model, and the machine was therefore somewhat more responsive to longitudinal control, and partly by the effect of the slipstream of the control; but these factors can hardly be allowed for quantitatively, and the extent of the difference between the free-flight test and the computation is rather disappointing.

If the angle of attack and the speed be known it should be possible to compute the normal force acting on the wings, provided that a wind tunnel test on a model of the aerofoil used is available. This has been done for the case illustrated in figure 8, and the computed normal force is plotted against time in figure 9. No test of the actual aerofoil used was available for very large positive or negative angles (beyond +20° and −5°), and it was therefore necessary, as in the computations for spin, to take the curves for a slightly different but similar aerofoil. It is probable that the differences in lift coefficient between thin aerofoils of normal type and with virtually flat lower surfaces are neglible at angles beyond those of maximum lift coefficient.

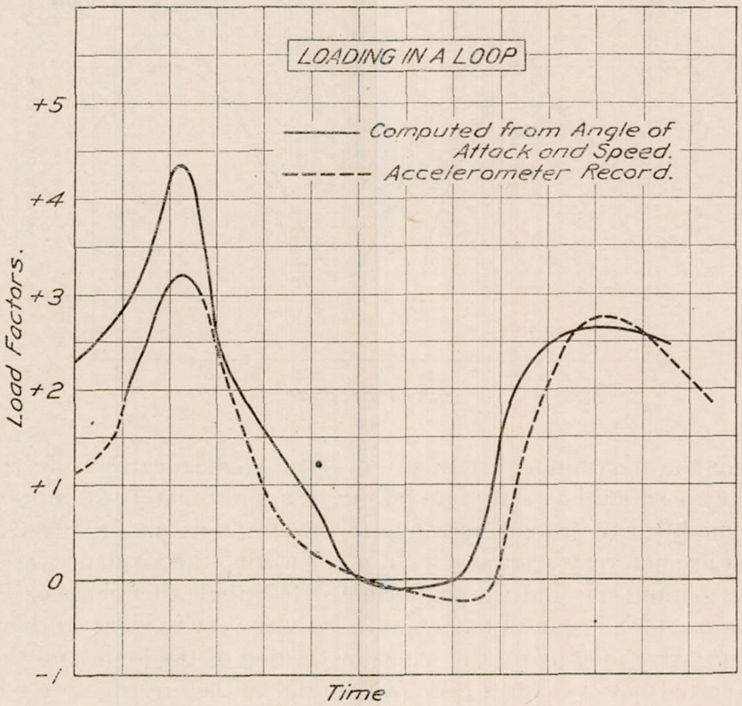

FIG. 9

The computed curve of normal force shows a general correspondence of form with the curves determined directly by the use of the accelerometer for similar loops, but the maximum loading found by computation is far larger than that actually existing, The difference between the two maxima appears too large to be accounted for by errors or lag in the instruments, crude though they are, and the only other explanation that occurs is that the actual coefficient of normal force may be different when the airplane is accelerating and when the angle of attack is changing rapidly from that existing under steady conditions. Further tests on this point both in full flight and on models, are to be undertaken as soon as possible, as the point is one which has an important bearing on the maximum loading attainable and consequently on the necessary load factors to be used in design, as well as on longitudinal controllability.

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