

## REPORT No. 559

### THE FORCES AND MOMENTS ACTING ON PARTS OF THE XN2Y-1 AIRPLANE DURING SPINS

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#### SUMMARY

*The magnitudes of the yawing moments produced by various parts of an airplane during spins have previously been found to be of major importance in determining the nature of the spin. Discrepancies in resultant yawing moments determined from model and full-scale tests, however, have indicated the probable importance of scale effect on the model. In order to obtain data for a more detailed comparison between full-scale and model results than has hitherto been possible, flight tests were made to determine the yawing moments contributed by various parts of an airplane in spins. The inertia moment was determined by the usual measurement of the spinning motion, and the aerodynamic yawing moments on the fuselage, fin, and rudder were determined by pressure-distribution measurements over these parts of the airplane. The wing yawing moment was determined by taking the difference between the gyroscopic moment and the fuselage, fin, and rudder moments.*

*The numerical values of the wing yawing moments were found to be of the same order of magnitude as those measured in wind tunnels. A direct comparison between wind-tunnel and flight results will be possible as soon as the tests of a model of this airplane have been completed on the N. A. C. A. spinning balance. The pressure-distribution tests incidentally demonstrated the favorable interference produced by the horizontal tail surfaces on the part of the vertical surfaces below them and the unfavorable interference produced on the part above them.*

#### INTRODUCTION

Several earlier studies of spinning have shown that the nature of the spin may be controlled by relatively small changes in yawing moment. Knowledge of the resultant yawing moment and particularly of the components of this moment contributed by various parts of the airplane is therefore necessary for further progress toward a final solution of the problem of spinning. Although this subject has previously been studied by means of wind-tunnel tests, it has long been recognized that values obtained from tests of small-scale models are subject to scale-effect errors and that correction factors are necessary. Comparisons of the resultant

aerodynamic yawing moments have been made between the results of model tests in wind tunnels and flight tests of the corresponding airplanes at various laboratories, but these comparisons do not give information regarding correction factors that can be applied generally because the resultant moment is composed of several components, some of which, according to present knowledge, are affected by scale considerably more than others. At present it is to be expected from the nature of the flow over the wing that the wing yawing moment is the most sensitive to scale of all the components of yawing moment and, since the wing moment is the largest component assisting the spin, true information regarding the scale correction for wing yawing moments is particularly desirable.

In order to obtain full-scale data for comparison with results of measurements on models, an investigation of the yawing moments produced by various parts of an airplane in spins was made. The values of the separate components, including that produced by the wing, were obtained by simultaneously measuring the motion of the spin and the distribution of pressure over the vertical surfaces of the fuselage, fin, and rudder. The wing yawing moment was taken as the difference between the resultant determined from the spinning motion and that contributed by the fuselage and vertical tail surfaces. In the only previous case where similar pressure measurements were obtained (reference 1) the motion in the spin was not recorded so that the results, although of interest, cannot be properly analyzed for the present purpose.

#### APPARATUS AND METHOD

The airplane used for these tests was the XN2Y-1 training biplane. Since the completion of previous spin tests with this airplane (reference 2), the leading edges of the wings have been covered with sheet metal in order to obtain a smooth leading edge, free of fabric sag, that could be more easily reproduced in a model. The metal fairing extended back to the front spar on both upper and lower surfaces of each wing. The general dimensions and control ranges of the airplane are given in figure 1. The weight was 1,762

pounds at take-off for all tests except one, in which 36 pounds of lead was bolted to the tips of the front lower spars, making the total weight 1,798 pounds. The true moments of inertia were:

- A = 802 slug-ft.<sup>2</sup>
- B = 1,080 slug-ft.<sup>2</sup> without wing-tip ballast and
- C = 1,526 slug-ft.<sup>2</sup>
- A = 1,006 slug-ft.<sup>2</sup>
- B = 1,080 slug-ft.<sup>2</sup> with ballast at tips.
- C = 1,730 slug-ft.<sup>2</sup>

The center of gravity was at 35.4 percent of the mean chord for all tests. The propeller was stopped for all

The quantities measured to determine the spin motion were the same as for previous spin tests (reference 2). A pinhole camera instead of three angular-velocity recorders was used to determine angular velocities. This instrument was a simple pinhole camera with a solenoid shutter and an adjustable base permitting tilting to any angle necessary to orient its normal axis to an approximately vertical direction during the spin. The record trace was made on a photographic plate. The other instruments used were: an air-damped 3-component accelerometer, an electric timer, a control-position recorder, a statoscope,

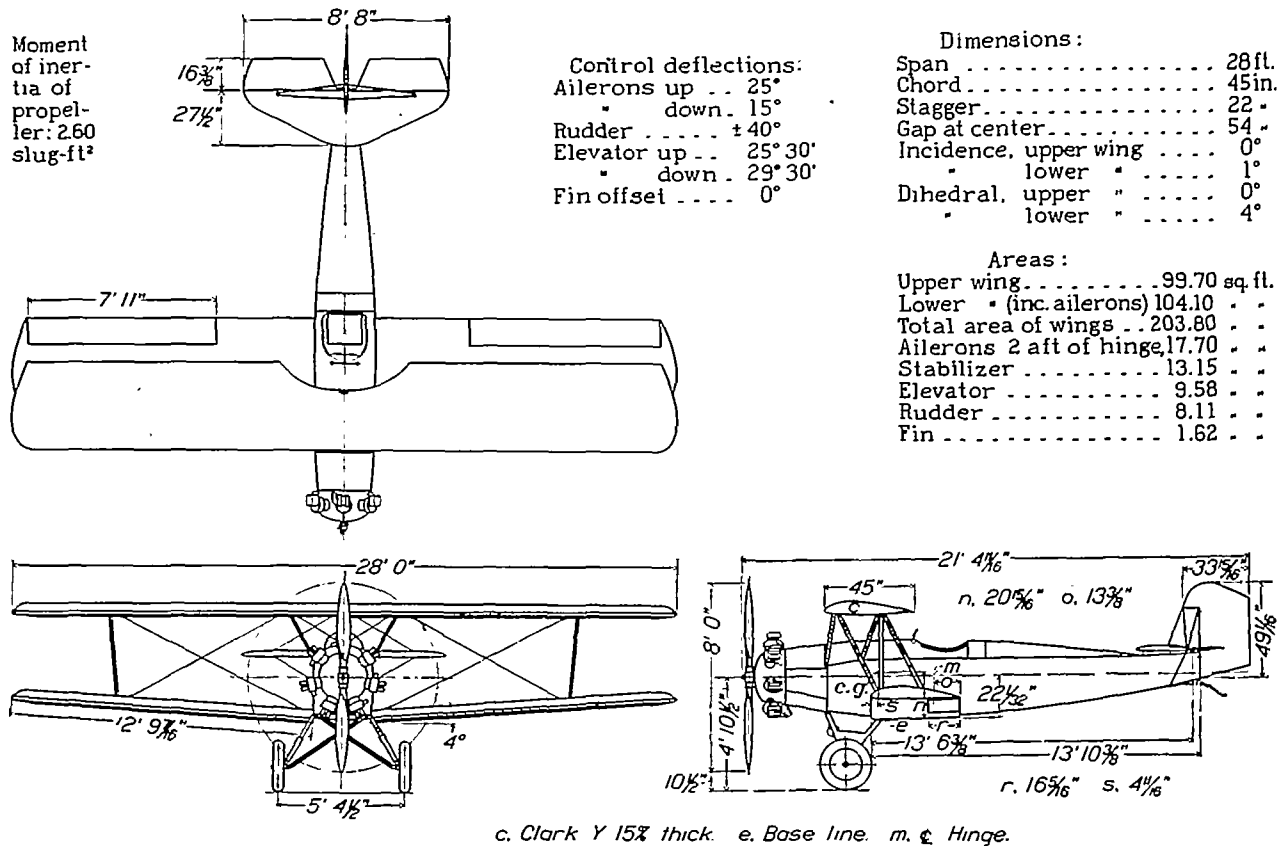


FIGURE 1.—Line drawing and general dimensions of the XN2Y-1 airplane.

tests, but no provision was made for stopping it in one fixed position.

Equipment for the measurement of pressures consisted of a 60-cell recording manometer connected to orifices located on the side of the fuselage and the vertical tail surfaces, as shown in figure 2. Each pressure cell was connected to an opposing pair of orifices to record resultant pressure on the fuselage and tail. The combined internal volumes of the tubing and pressure cells were adjusted for each pair of tubes so that no error would be introduced by the flow of air in the tubing and cells induced by the change of altitude during the spin. Since pressures were measured at 64 points, a switching valve was used to close off one set of tubes and open another.

a sensitive indicating altimeter, and a strut thermometer having a 9-second lag (reference 3).

For the determination of vertical velocity the altitude interval  $\Delta Z$  was found from the relation (reference 4)

$$\Delta Z = RT_m \log_e \frac{p + \Delta p}{p}$$

where  $R$  is the gas constant for dry air.

$T_m$ , the harmonic mean absolute temperature.

$p$ , the pressure.

Temperatures corresponding to different pressure altitudes were observed at 500-foot intervals during the climb preceding the spin. The pressure  $p$  at the start of the spin was determined from the altimeter reading,

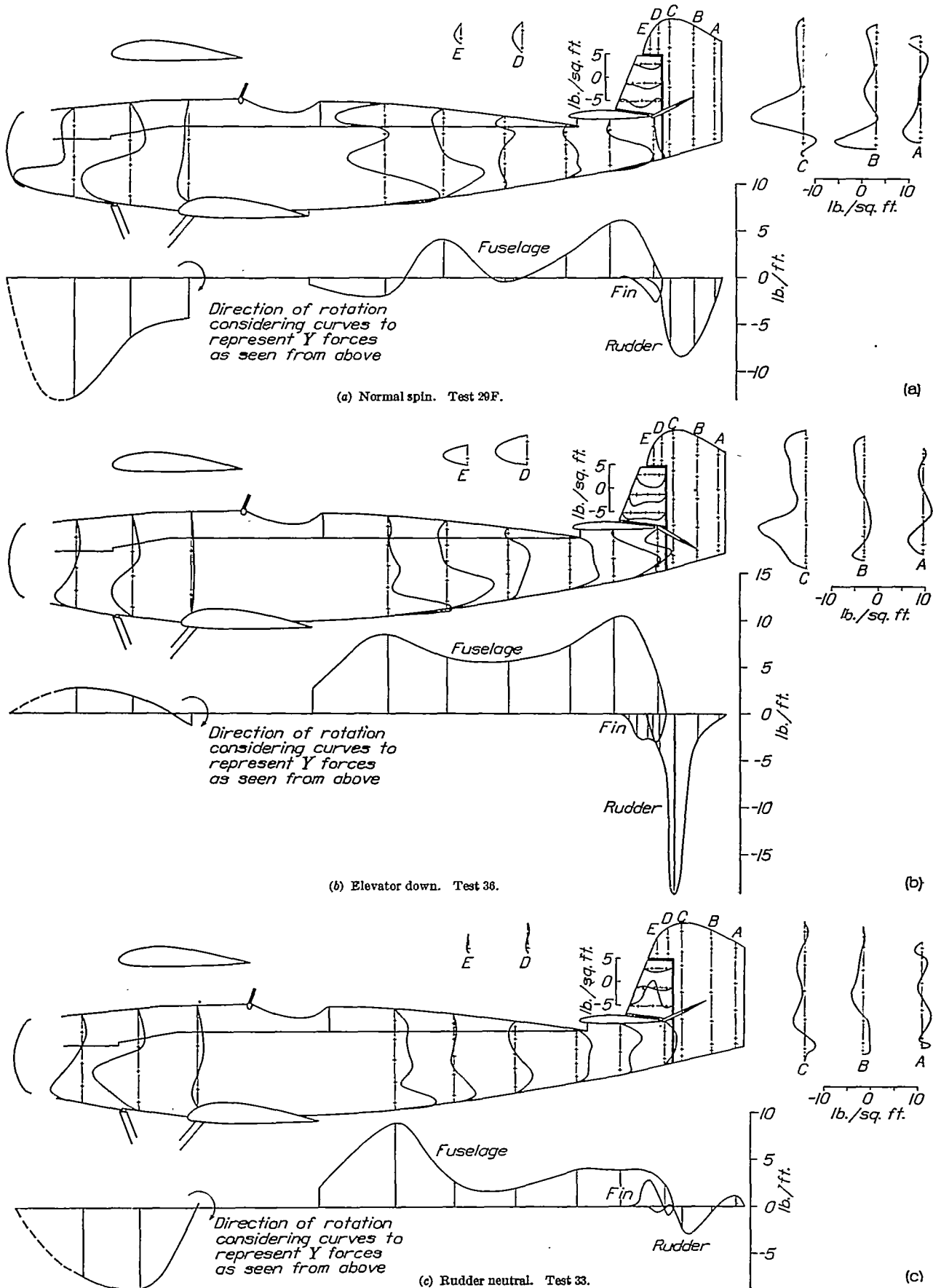


FIGURE 2.—Orifice positions and pressure and force curves for right-hand spins. (Forces plotted to right or up are into the page on the side elevation of the airplane.)

and the change in pressure  $\Delta p$  from the reference was recorded on the time scale by means of a recording statoscope. The mean temperature was taken simply as the arithmetic mean of temperature for the altitude interval, as it differed only slightly from the harmonic mean temperature.

The spins were started at 6,000 feet altitude with motor stopped and allowed to continue for 1,000 to 1,500 feet descent to establish steady conditions. The instruments were then started at an altitude noted on the altimeter. The pinhole-camera shutter was opened for about  $1\frac{1}{4}$  turns; the exact time was indicated by marks made photographically on the accelerometer film record. When about half of the 1,000 feet altitude loss to be recorded had passed, the manometer switching lever was operated. Four of the less important pressure points were connected to the manometer at this time in place of four other points at which pressures were recorded in the first part of the test

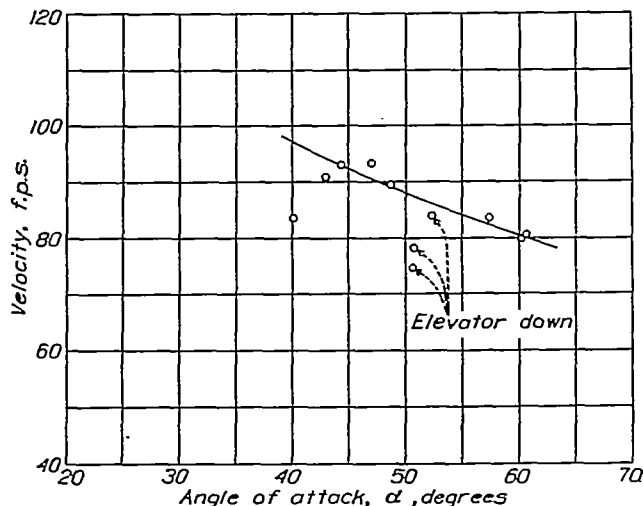


FIGURE 3.—Velocity against angle of attack for spins of the XN2Y-1 airplane.

record. The records were stopped at the end of exactly 1,000 feet of altitude loss, indicated by the altimeter.

The lateral forces and yawing moments arising from the air forces on the sides of the fuselage, fin, and rudder were obtained by plotting the pressure measurements to scale and integrating mechanically in the order made evident by the pressure and force curves shown in figure 2. Corrections were made to the plotted values for changes in rudder angle from the standard setting.

#### PRECISION

An exact statement regarding the precision of the determination of air forces and moment by the pressure-distribution method is difficult to make. An analysis of the errors and an estimate of the probable magnitude of such errors are given in reference 5. Because the pressures measured were small, the greatest care was taken concerning the physical factors affecting the

accuracy of these tests. Repeated calibrations at regular intervals during the course of the tests showed negligible changes in the slopes of the manometer-calibration curves; the installation was well made with regard to smoothness of the orifices; the pressure tubes were accurately balanced for capacity effect; the manometer was so oriented as to minimize acceleration effects; and the personal errors were kept at a minimum. The precision suffered to some extent because it was not possible to use a sufficient number of orifices; in fact, it was impracticable to include some parts of the airplane, such as the struts, landing gear, wheels, and engine in the measurements. Some difficulty was experienced because of large fluctuations of pressure caused by turbulent flow at many of the pressure points. These sources of error, however, were not serious because the yawing moments contributed by the parts not measured could not have been great and the orifices were distributed so that the large spacings were on areas near the yawing-moment axis. Likewise, the errors due to the fluctuating pressures could be kept small by carefully reading mean values on the pressure records. It is therefore considered safe to estimate that the errors in the air moment measurements are within limits of  $\pm 8$  percent. These limits are twice as broad as those estimated for the work reported in reference 5.

The measurement of spin motion was made particularly difficult by oscillations in the spin, which were much more troublesome in these tests than in previous tests with the same airplane. In fact, the records included in the present report represent only 15 percent of the records made; many had to be discarded because of oscillations and the remainder because of other faults made evident by the appearance of the records. All of the records except one taken when the wing tips were ballasted were discarded and it is possible that the one retained was incorrect because of oscillations in the spin. The usual method of detecting the oscillations was to note whether or not the pinhole-camera record was a regular figure; if, however, the period of an oscillation was the same as the period of rotation, this record might appear to be regular. If such an error did occur in these tests, it would affect the values of angular velocity in pitch, sideslip, and inertia yawing moment in the first order, and all the other variables of the spin motion in the second order. These particular effects would be expected because the oscillations of this airplane during the spin were mainly about the longitudinal axis.

The method employed for measuring the vertical velocity should have a good degree of precision for the determination of vertical interval, since the pressures could be determined to closer than 0.1 percent and the temperature to within a fraction of a degree. The lag of the thermometer was of the order of  $0.2^\circ$  F. It was

not practicable to determine the humidity; in the warmest weather or for two or three of the records reported herein, there may have been an error of 0.8 percent involved in assuming the air to be dry. It is

For this reason the values that fell some distance below the curve were arbitrarily moved up to it as a correction for vertical air currents.

The estimated limits of error for the fundamental measurements of motion are summarized as follows:

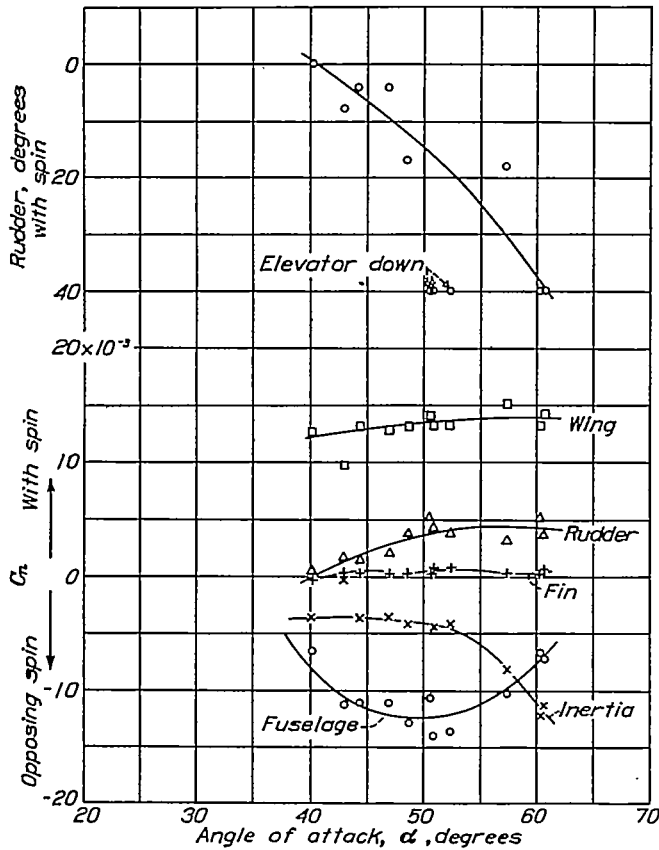


FIGURE 4.—Variation of yawing-moment coefficient and rudder angle with angle of attack for spins of the XN2Y-1 airplane.

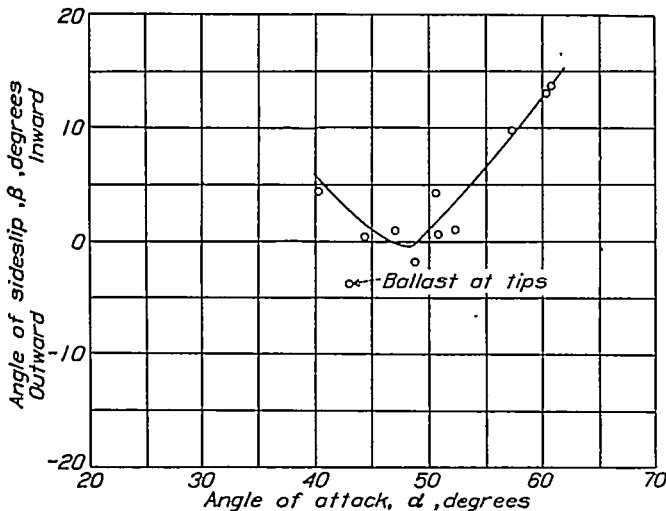


FIGURE 5.—Angle of sideslip against angle of attack for spins of the XN2Y-1 airplane.

to be noted, however, that velocity computed on the basis of change of density height, which refers to distance above the earth, does not take into account the possible existence of vertical currents in the atmosphere. Plotting the values of velocity obtained by this method (fig. 3) shows evidence of such a condition.

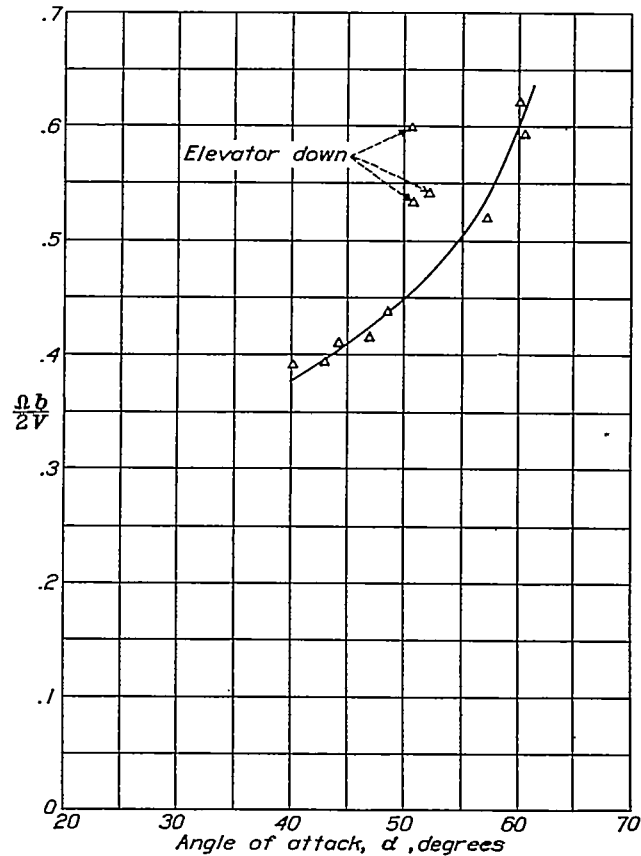


FIGURE 6.—Spin coefficient  $\Omega b/2V$  against angle of attack for spins of the XN2Y-1 airplane.

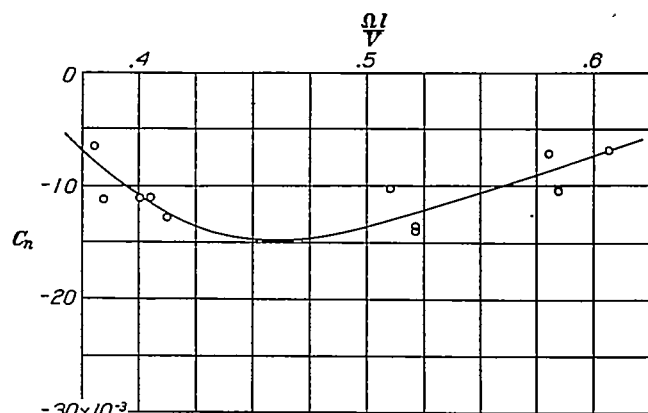


FIGURE 7.—Fuselage yawing-moment coefficient against  $\Omega l/V$  for spins of the XN2Y-1 airplane.

Components of angular velocity,  $\pm 3$  percent; acceleration,  $\pm 0.05 g$ ; interval of altitude,  $\pm 1$  percent; time,  $\pm 2$  percent; weight,  $\pm 1$  percent; and moments of inertia,  $\pm 2.5$  percent,  $\pm 1.3$  percent, and  $\pm 0.8$  percent for A, B, and C, respectively, for airplane-swinging measurements. The increment of moment of inertia added as ballast is probably known very accurately.

A consideration of the probability of occurrence of large accidental errors shows that the possible limits of the errors previously stated would seldom be reached in individual measurements and, when they were, a wide scattering of points would be obtained. Since the scattering of points is not great, it seems apparent that the accidental errors were small, especially as the one divergent point is known to be subject to a highly probable error. In addition to the accidental errors there may be a residual error dependent upon the precision of the moment-of-inertia measurements. The limit of the inertia-yawing-moment error taken from the limits of the moment-of-inertia errors is 12 percent for the tests without ballast and 46 percent for the test with ballast. The 12-percent limit of residual error would introduce error limits of about 10 percent for high angles of attack and of about 2.8 percent at low angles of attack into the wing yawing-moment results. Whatever error in inertia yawing moments exists as a result of errors in moment-of-inertia measurements is of the same absolute value for the test with ballast as for tests without ballast, but the percentage error is 3.7 times as great. In conclusion, it may be stated that the values for wing yawing moments are believed to be well within  $\pm 10$  percent at all but the highest angles of attack tested and that this limit may be reached at the high angles.

#### RESULTS AND DISCUSSION

The important parameters of the spins reported are given in table I.

Coefficients of the components of yawing moment for the fuselage, fin, rudder, and wings are plotted against angle of attack in figure 4. The rudder deflections are plotted for reference on the same angle-of-attack scale.

For purposes of studying the results, curves showing the variation of three other parameters are given; the angle of sideslip  $\beta$  plotted against angle of attack in figure 5, the spin coefficient  $\Omega b/2V$  plotted against angle of attack in figure 6, and the coefficient  $\Omega l/V$  ( $l$  is the length from the center of gravity to the rudder hinge) plotted against fuselage yawing-moment coefficient in figure 7.

The absolute values of the wing yawing-moment coefficient, insofar as they are used consistently with the precision of these tests, are probably the most important results of the investigation. They provide a means of checking the results of wind-tunnel tests for this very important factor in spinning equilibrium. Full-scale measurements are very desirable since the yawing moment depends on the separation of flow over the wings and is therefore likely to be affected by scale and turbulence. The values obtained in these tests are within the range and toward the upper limit of values obtained in earlier wind-

tunnel tests. A comparison of these flight results with the most nearly applicable wind-tunnel tests made up to the present time with the N. A. C. A. six-component spinning balance should not be attempted because there is too much difference in stagger, airfoil section, gap/chord, and dihedral. Tests of a model of the XN2Y-1 airplane are now being undertaken.

Attention is called to the fact that, although the wing yawing-moment coefficients are plotted against angle of attack, changes in other variables may have had some effect on the values measured. The angle of sideslip and the spin coefficient both varied considerably, as shown by figures 5 and 6.

The wing yawing-moment curve (fig. 4) was not drawn through the point at  $\alpha=43.0^\circ$  because judgment would indicate that a sharp depression should not exist in the curve in this range. Since the algebraic sum of the ordinates of the five yawing-moment curves is zero, an error occurring in the measurement of one of the four independently measured quantities produces an error of equal magnitude in the wing yawing moment. An inspection of the curves indicates that the measured value of inertia yawing moment might be in error the amount necessary to move the point most of the way up to the curve. The possibility of this particular error is discussed in the section on Precision.

The yawing moment produced by the fin is, as expected from its size and position, very small.

The yawing moment produced by the fuselage reaches a maximum at  $50^\circ$  angle of attack and decreases rapidly as the angle of attack increases to  $60^\circ$ . In the absence of changes of other parameters, it would be expected that an increase in either angle of attack or  $\Omega l/V$  would cause an increase in fuselage yawing-moment coefficient. It is to be noted, however, that the angle of sideslip becomes large inward in this angle-of-attack range. A rough estimate of the increment of lateral velocity at the tail, due to increases in angle of attack and in the parameter  $\Omega l/V$ , shows the effect to be of about equal magnitude and opposite sign to the corresponding increment due to the increased inward sideslip.

The yawing moment produced by the rudder in steady spins varied only slightly throughout the angle-of-attack range of the tests, even though the rudder angle was varied from  $0^\circ$  to  $40^\circ$  with the spin. It is interesting to note that the rudder set full with the spin produced about as much yawing moment with the spin when the elevator was down as it did at a setting of  $15^\circ$  with the spin and the elevators full up.

The distribution of lateral force over vertical areas of the fuselage, fin, and rudder shows points of interest. The curves in figure 2(a) are for test 29F, which was a normal right spin. Figures 2(b) and 2(c) give, respectively, the curves for the right spin with elevator

down (test 36) and for the right spin with rudder neutral (test 33). It will be noted that in test 29F the largest pressures occurred on the nose aft of the engine. This condition occurred frequently, particularly for spins at high angles of attack, which, in these tests, were associated with large inward sideslip. The forces were such as to produce moments resisting the spin but not ones of large magnitude because of the proximity of the area to the center of gravity. In the case of the PW-9 airplane, which spins with large inward sideslip as may be deduced from the pitch angular-velocity records of reference 1, the forces on the nose were large against the spin and, because of the great area, the spin-resisting moments were large enough to be very important. On the tail of the fuselage of the XN2Y-1 large forces were produced under the stabilizer. Very little lateral force was exerted on the section of the fuselage just forward of the stabilizer. This configuration of the force curve, involving a maximum under the stabilizer and a minimum just forward of the stabilizer, was observable in some form on every pressure record taken. Figures 2(b) and 2(c) show how changes in control position and the associated changes in spin conditions affected the pressure distribution.

The low-pressure area ahead of the stabilizer suggests the possibility of improving the fuselage yawing-moment characteristics by extending the stabilizer forward. This change, as a matter of fact, was made several years ago by the manufacturers of the airplane, although for a different purpose. They installed a stabilizer and elevator of aspect ratio 1, the area being the same as that for the standard stabilizer and elevator. The chord was therefore very great, extending forward over most of the region shown in these tests to give low pressures. The effect was a large improvement in an otherwise dangerous spin. In the light of present knowledge on the subject, it is evident that a considerable increase in fuselage yawing moment was obtained. It seems that this low-pressure region may also occur on other airplanes. The British have tested and found beneficial what they call an "antispin fillet" (reference 6). It is a forward extension of the stabilizer having a span of about 4 inches on each side of the fuselage. Such a horizontal surface might possibly induce beneficial interference similar to that induced by the stabilizer.

Examination of the pressure curves for the rudder shows the effects of the presence of the stabilizer and elevator. Large forces are developed on the lower portion of the rudder; in the wake of the stabilizer and elevator the forces are small.

It is interesting to consider the effect on the spin of adding an increment of pure yawing moment. The

change in rudder yawing moment obtained by changing the rudder setting is such a moment except for the associated changes in interference yawing moment on the fin and fuselage, and possibly a small amount of interference pitching moment. The rudder moment-coefficient curve indicates that a change of  $C_n = -0.003$  was sufficient to change the equilibrium angle of attack from  $60.5^\circ$  to  $40^\circ$ . The interference yawing moment on the fin and fuselage could reasonably be expected to be appreciably less than another increment of  $-0.003$ . These values indicate, then, that a very small increment of yawing-moment coefficient ( $C_n < -0.006$ ) is all that is required to change the equilibrium of a flat spin to that of a definitely steep spin.

#### CONCLUSION

The components of yawing moment produced by various parts of an airplane have been measured in flight. The numerical results for the wing were of the same order of magnitude as similar quantities measured in wind tunnels; a direct comparison between model and flight results will be possible when the tests of a model of this airplane have been completed. An incidental feature of the tests was a clear demonstration of the strong favorable interference effects of the horizontal tail surfaces on the vertical areas under them and the corresponding unfavorable interference on the vertical areas above them.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,  
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,  
LANGLEY FIELD, VA., February 20, 1936.

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TABLE I.—SPIN DATA

Test	$p$	$q$	$r$	$\frac{X'}{mg}$	$\frac{Y'}{mg}$	$\frac{Z'}{mg}$	$\Omega$	$\frac{Z''}{mg}$	$\alpha_s$	$\beta$	$\gamma$	$V$	Radius	$\frac{\Omega b}{2V}$	$C_l$	$C_m$	$C_n$	Control settings
	rad./sec.	rad./sec.	rad./sec.				rad./sec.		°	°	°	ft./sec.	Feet					
29F <sup>1</sup>	1.51	1.01	2.88	-0.018	0.062	1.13	3.40	0.969	60.7	13.7	86.0	80.2	1.6	0.593	0.035	-0.084	0.011	Normal. <sup>4</sup>
29G	1.60	1.02	2.99	-0.052	.059	1.12	3.55	.935	60.4	13.0	88.0	79.9	1.6	.622	.037	-.094	.012	Do.
20	2.22	.61	2.78	-.011	.043	1.25	3.61	.967	60.6	4.3	84.5	84.5	2.0	.598	.018	-.106	.009	Elevator down 26°35'.
30	1.91	.33	2.55	-.008	-.010	1.20	3.20	.955	62.4	1.0	85.0	83.8	2.3	.535	.009	-.088	.004	Do.
36	1.99	.34	2.50	-.035	-.019	1.23	3.21	.977	60.9	.6	84.5	84.2	2.3	.534	.009	-.087	.004	Do.
33	1.95	.65	1.75	-.027	.040	1.56	2.70	.988	40.2	4.4	80.2	97.0	2.7	.390	.009	-.043	.003	Rudder neutral.
31	1.80	.40	2.11	-.009	.023	1.30	2.80	.973	48.6	-1.9	83.7	89.7	3.5	.437	.008	-.059	.004	Rudder 17° with spln.
32C	1.83	.36	2.03	-.000	.005	1.35	2.78	.995	47.0	.9	83.4	93.2	3.9	.414	.007	-.055	.004	Rudder 4° with spln.
34B	1.87	.34	1.97	-.006	.006	1.35	2.73	.966	44.4	.4	83.2	93.0	4.0	.411	.006	-.053	.004	Do.
35	1.56	.76	2.53	-.035	.049	1.60	3.11	.957	57.4	9.7	85.3	83.2	2.2	.523	.022	-.074	.008	Rudder 18° with spln.
27B <sup>1</sup>	1.91	.18	1.83	.014	-.026	1.41	2.64	.980	43.0	-3.9	82.1	94.0	4.7	.393	.004	-.047	.0005	Rudder 8° with spln.

<sup>1</sup> Accelerometer readings corrected to  $c.g.$

<sup>2</sup> Angle of attack for airplane  $X$  axis.

<sup>3</sup> Normal control setting: Ailerons neutral. Elevator up 23°50'. Rudder 40° right. Stabilizer 0°48.6' to  $X$  axis.

<sup>4</sup> All right-hand spins.

<sup>5</sup> 36 pounds of ballast added at wing tips.