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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 456

THE AERODYNAMIC FORCES AND MOMENTS EXERTED ON A SPINNING MODEL OF THE "NY-1" AIRPLANE AS MEASURED BY THE SPINNING BALANCE

By M. J. BAMBER and C. H. ZIMMERMAN

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/s		horsepower	hp.
Speed		km/h	k. p. h.	mi./hr.	m. p. h.
		m/s	m. p. s.	ft./sec.	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s$^2=32.1740$ ft./sec.^{2}

m, Mass $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C. and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}.

mk^2, Moment of inertia (indicate axis of the radius of gyration k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord.

$\frac{b^2}{S}$, Aspect ratio.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$.

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{D_o}=\frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i}=\frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p}=\frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force.

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting (relative to thrust line).

Q, Resultant moment.

Ω, Resultant angular velocity.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, at 15° C., the corresponding number is 234,000;

or for a model of 10 cm chord 40 m/s, the corresponding number is 274,000.

C_p, Center of pressure coefficient (ratio of distance of $c.\ p.$ from leading edge to chord length).

α, Angle of attack.

ϵ, Angle of downwash.

α_o, Angle of attack, infinite aspect ratio.

α_i, Angle of attack, induced.

α_a, Angle of attack, absolute. (Measured from zero lift position.)

γ Flight path angle.

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By M. J. Bamber and C. H. Zimmerman

SUMMARY

A preliminary investigation of the effects of changes in the elevator and rudder settings and of small changes in attitude upon the aerodynamic forces and moments exerted upon a spinning airplane was undertaken with the spinning balance in the 5-foot vertical tunnel of the National Advisory Committee for Aeronautics. The tests were made on a 1/12-scale model of the "NY-1" airplane.

Data by which to fix the attitude, the radius of spin, and the rotational and air velocities were taken from recorded spins of the full-scale airplane. Two spinning conditions were investigated. All six components of the aerodynamic reaction were measured and are presented in coefficient form referred to airplane axes.

The results show that, except for pitching and yawing moments, the changes in forces and moments introduced by elevator and rudder movements were small and of the same order of magnitude as those introduced by small changes in attitude. The pitching moment was approximately doubled by movement of the elevator from 33° up to 27° down but was little affected by rudder movement regardless of the elevator position. A large yawing moment opposing the spin was introduced when the rudder was moved from full with the spin to full against the spin with the elevator up. When the elevator was down the yawing moment given by full rudder movement was reduced to approximately one fourth its former value.

The results indicate that the change in yawing moment produced by the rudder with the elevator up was the only component of force or moment produced by the elevator and rudder that could not have been balanced in an actual spin by small changes in attitude and angular velocity.

INTRODUCTION

Spinning of airplanes has been the subject of a great amount of research in recent years but the problem is far from a solution at the present time. When considering possible solutions airplanes may be classified under two headings; namely, those which should never be spun and those which should be controllable in the spin.

For the first class, which includes most commercial airplanes as well as bombers and transports for military and naval use, the problem is open to three lines of attack: (1) To make the airplane incapable of attaining a stalled attitude; (2) to so proportion and limit the movement of the stabilizing and control surfaces for a given wing combination that there will always be an aerodynamic diving moment when the airplane is stalled and it will not be possible for any rotation to persist that will give an inertia stalling moment great enough to overcome the aerodynamic diving moment even with all controls set for a spin; or (3) to use a wing and stabilizing surface combination which will be stable in rectilinear flight when the airplane is stalled. Prevention of the stall is undoubtedly a complete solution, but unfortunately it is probable that adverse weather conditions, coupled with improper use of the controls, will cause any airplane to stall if it has good performance and maneuverability characteristics.

The solution of the problem by making the airplane incapable either of maintaining a stall or of maintaining rotation when stalled is closely related to the solution of the problem of making airplanes of the second class, such as pursuit, fighter, or commercial stunting airplanes, readily controllable in the spin. The difference is one of magnitudes of pitching, autorotation, and damping moments. The whole spinning problem therefore reduces to a study of the balance of moments and forces when the airplane is rotating and stalled, and of the nature and magnitude of the changes of those moments and forces with changes in the motion.

The conditions for equilibrium are that for any axis the sum of the moments due to aerodynamic reactions upon the lifting and the control surfaces must equal and oppose the inertia moments, and that the aerodynamic forces must equal and oppose the components of gravity and of centrifugal force. It is possible to calculate the inertia forces and moments for all spinning conditions, but present knowledge of the directions and magnitudes of the forces and moments exerted by the air upon the parts of a rotating airplane is so limited that the engineer has no certain way of knowing whether or not the airplane he is designing will balance in a spin. Consequently, a great amount of time and money which could be saved if sufficient data were available is spent trying to correct the spinning characteristics of airplanes after they are built.

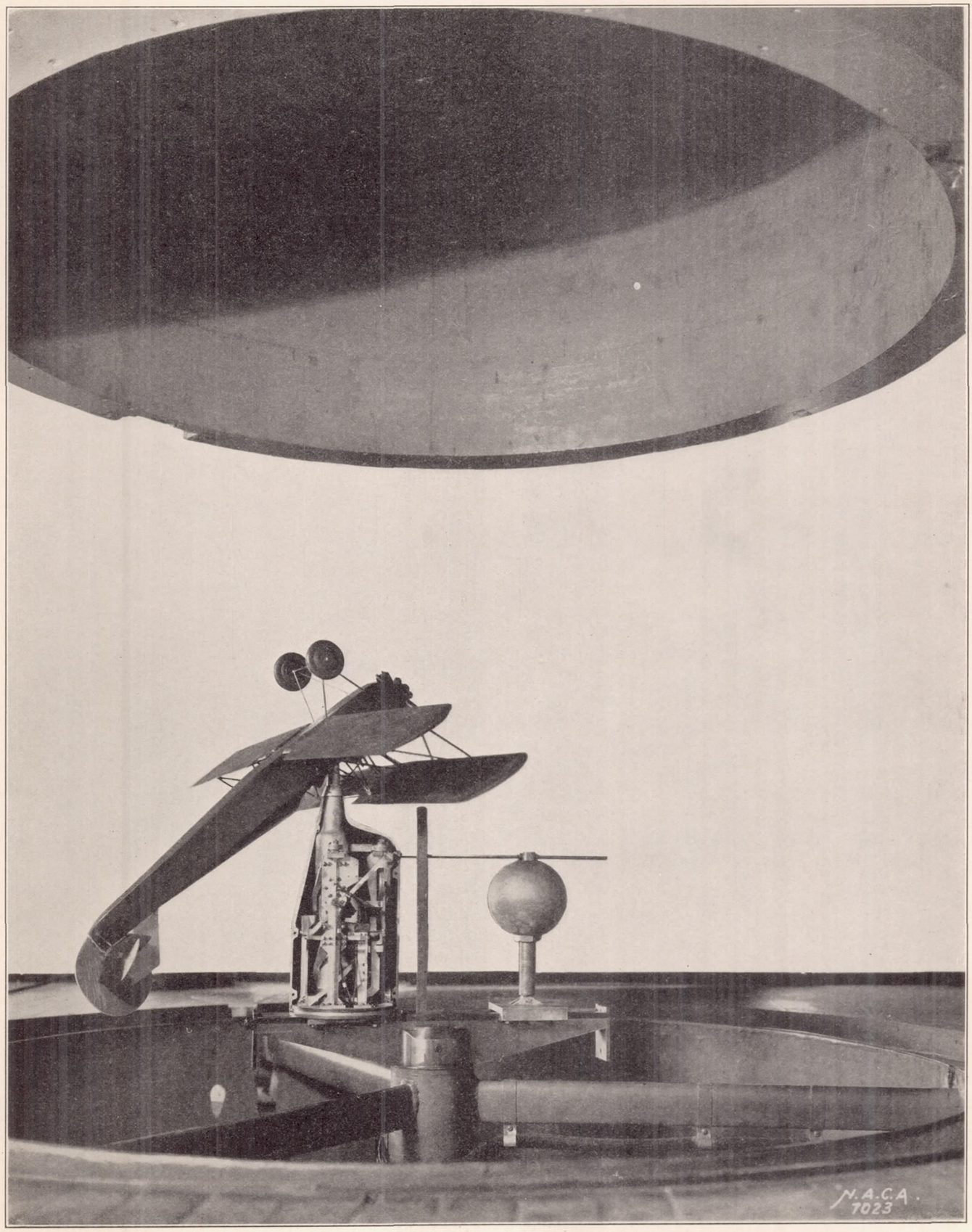

FIGURE 1.—The *NY-1* airplane model mounted in a spinning attitude in the downward flowing air stream. The 6-component balance (shown with cover removed to display mechanism) revolves with the model.

Data upon the aerodynamic characteristics of a spinning airplane may be obtained in several ways; namely, flight tests with full-scale airplanes, flight tests with balanced models, strip-method analysis of wind-tunnel force and moment tests, and wind-tunnel tests of rotating models. A brief discussion of these methods will be given here.

Spinning tests of full-scale airplanes have been made from time to time over a period of years. (See references 1, 2, 3, 4, and 5.) Such tests have revealed the range of attitudes and conditions in which airplanes will spin, they have contributed much to the knowledge of the aerodynamics of the spin, and they undoubtedly must be continued to verify the results obtained by more convenient methods. Because of the expense of making full-scale tests, the danger to equipment and personnel, the difficulty of studying the forces and moments upon the component parts of the airplane, and the fact that the spinning range that can be investigated with a particular airplane is limited, it is desirable that other methods be used for a general investigation of the problem.

Flight tests with balanced models have also been a valuable source of information concerning the spin, and the most notable effort along this line is the series of tests being conducted in England in a vertical tunnel built especially for such purposes. (See references 6 and 7.) Model tests are much less expensive and are not subject to the dangers of full-scale tests. Balanced models, however, are relatively expensive and troublesome to build and use as compared with ordinary models, the tests must be made at very low Reynolds Number, the determination of the aerodynamic forces and moments is difficult and tedious, it is nearly impossible to secure complete data of the effects of small changes in attitude, and it is not possible to determine the aerodynamic reactions upon the component parts.

Strip-method analysis is useful chiefly as a means of studying the effects of certain changes in the aerodynamic characteristics of wings upon the balance in the spin, it being postulated that the results of tests of wings which have all sections at the same angle of attack can be used to predict the characteristics of the same wings when the angle of attack varies along the span. Such analyses are very laborious and of doubtful value in determining the spinning characteristics of a particular airplane.

Several forms of rolling balances have been used for testing the autorotation characteristics of airfoil and airplane models. (See references 8, 9, and 10.) Data from rolling-balance tests are subject to errors because of tunnel-wall, blocking, and scale effects. Much greater velocities may be used in wind-tunnel tests where the model is restrained than in dropping tests, and it is possible to vary the air speed to study the effect of scale. Rolling balances make it possible to measure the forces and moments supplied by the component parts of the airplane. In the past, attempts have been made to use tail moments of a yawed model obtained in straight force tests, but it has been found that such data are likely to lead to erroneous conclusions when applied to the spinning condition. (See reference 11.) Rolling-balance data have been of limited value because it has not been possible to measure all six force and moment components or to reproduce a true spinning condition. The spinning balance used in this investigation is a 6-component rotating balance from which it is possible to obtain wind-tunnel data for any of a wide range of possible spinning conditions.

The present series of tests was undertaken as a preliminary investigation of the effects of changes in Reynolds Number (within the range obtainable), of attitude, and of elevator and rudder settings upon the aerodynamic forces and moments upon a model when spinning. A model of the *NY-1* airplane was used in order that a comparison of the data might be made with those obtained from full-scale spins of the airplane. (See reference 5.)

APPARATUS AND MODEL

Apparatus.—The tests were made on the spinning balance that has been developed for use in the 5-foot vertical wind tunnel of the National Advisory Committee for Aeronautics. The wind tunnel, which is of the open-jet type, is described in reference 12. The spinning balance (fig. 1) consists of a balance head that supports the model and contains the force-measuring units, a horizontal turntable supported by streamline struts in the center of the jet and, outside the tunnel, a direct-current driving motor, a liquid tachometer, an air compressor, a mercury manometer, a pair of indicating lamps, and the necessary controls. The balance head is mounted on the turntable and it may be set to give any radius of spin between 0 and 8 inches.

The balance head contains a vertical spindle to the upper end of which the model is rigidly attached. The spindle has six degrees of freedom, except as restrained by a linkage system which connects it to six measuring units. A line diagram of the force system is shown in figure 2. The lower two thirds of the spindle, the linkage system, the measuring units, and the supporting framework are enclosed by a duralumin case one half of which is shown removed in figure 1.

A diagrammatic sketch of one of the force-measuring units is shown in figure 3. A force of tension or compression in the connecting link is transmitted through the self-alining ball bearings and becomes a moment in the beam about the Emery knife-edge. This moment and a constant moment produced by the spring attached to the beam are balanced by the

pressure of air behind the rubber diaphragm. Air pressure is admitted to the rotating parts of the balance through an oil-sealed slip joint at the bottom of the turntable shaft. The air pressure is regulated

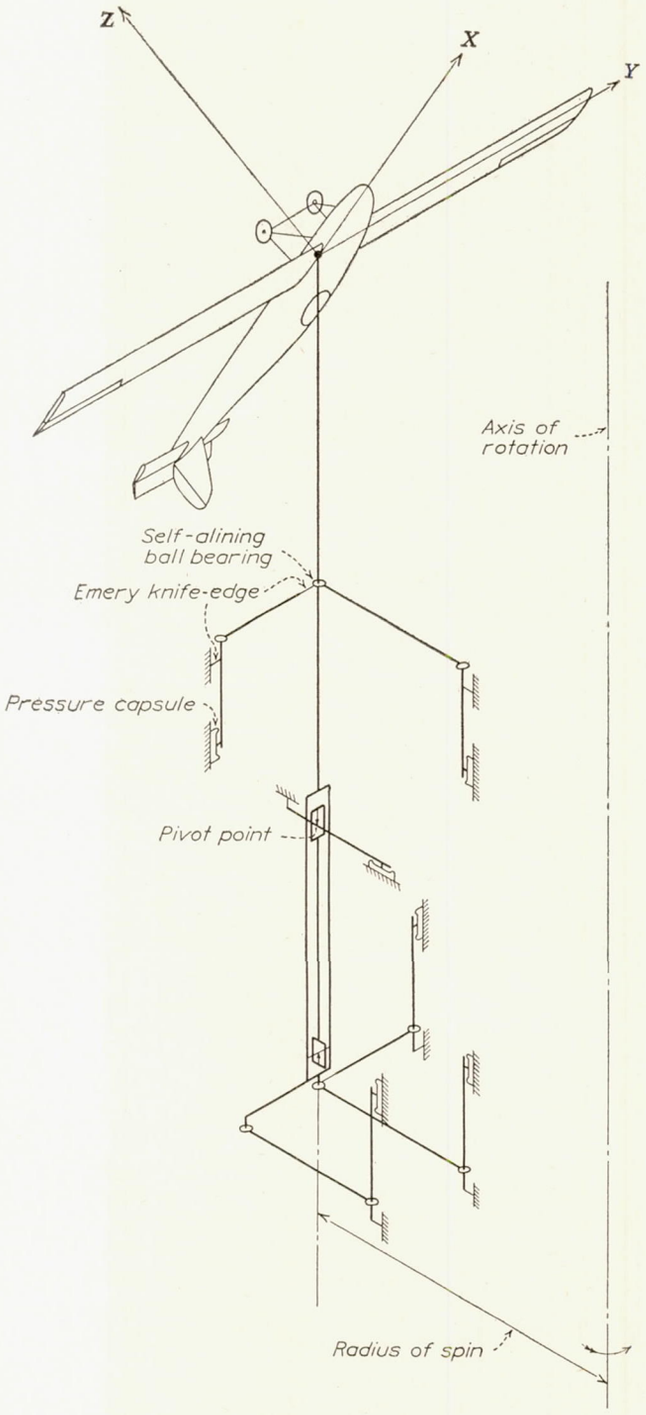

FIGURE 2.—Line diagram of spinning-balance force system.

by valves and indicated by a mercury manometer. Balance is indicated by neon lamps connected through slip rings to the contact points. Since there is but one air-pressure tube leading to the balance, only one reading can be made at a time. Each of the measuring units is fitted with a small glycerin-filled dashpot which serves to damp the oscillations of the beam.

In order that the balance reading might be easily corrected for forces introduced by the weights and the moments of inertia of the model and balance parts, tare readings were made for each spinning condition with the balance head and the model completely enclosed by a shield which was attached to the turntable and rotated with the balance.

Model.—The model, which had been built by the Navy Department for wind-tunnel tests, was a $\frac{1}{12}$-scale mahogany reproduction of the *NY-1* airplane (fig. 1). Originally it differed from the full-scale airplane in the following particulars: There were no landing or flying wires; the landing gear and wing struts were $\frac{3}{32}$-inch rods of circular cross section; a pair of N struts a short distance out from the fuselage were used

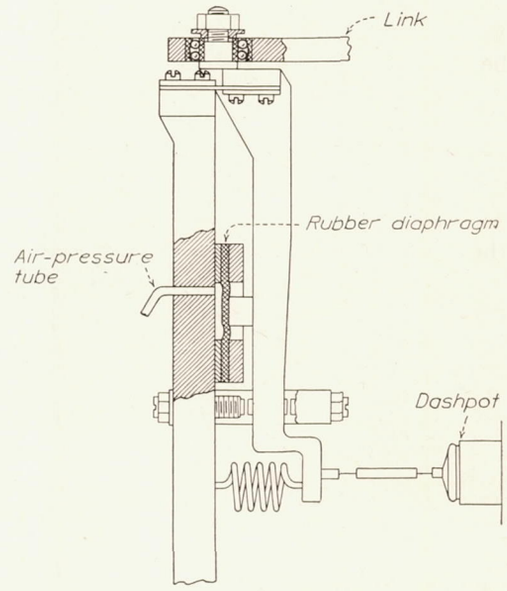

FIGURE 3.—Diagram of a measuring unit of spinning balance.

in place of the cabane struts. The model was equipped with movable elevator and rudder but it had no ailerons. It was rigged with no washin or washout ($\pm 0.1°$) and the fin was set parallel to the plane of symmetry.

For this investigation the original wooden fin and rudder, which were of a thin symmetrical section, were replaced with a $\frac{1}{16}$-inch duralumin flat plate fin and rudder of the same plan form. Additional bracing struts were added between the fuselage and the upper wing. The fuselage was cut out for installation of a ball clamp for attachment to the balance.

TESTS

The direction and velocity of the flow about the balance head were determined in the positions to be occupied by the wings and tail surfaces of the model. These surveys were made with the balance rotating at a speed corresponding to a normal spin and at a radius of 5 inches. The air stream was found to have a

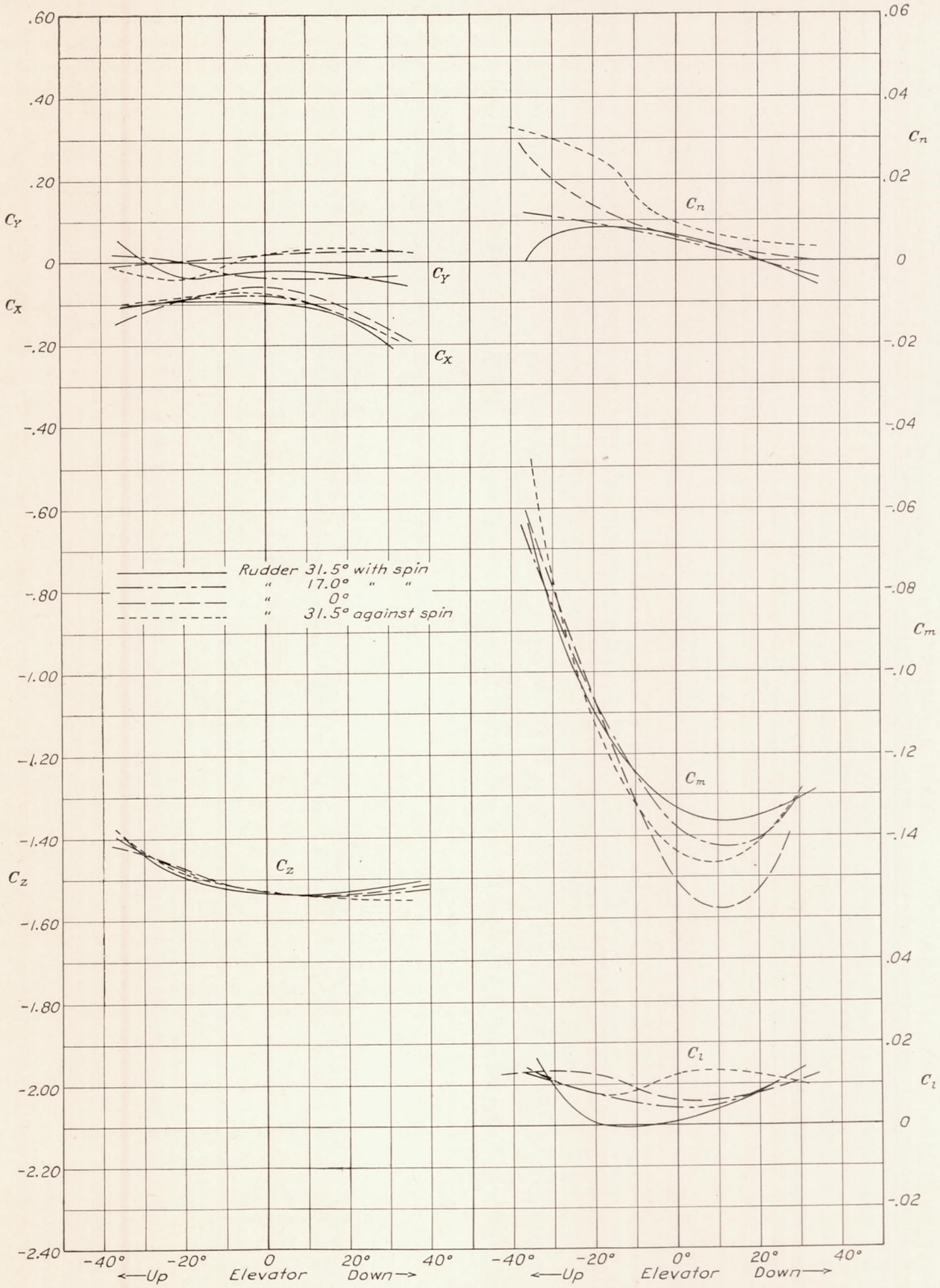

FIGURE 4.—Effect of elevator setting upon aerodynamic characteristics of *NY-1* airplane model in spin of 3.4-inch radius.

twist of 0.4°, which was corrected for by increasing the rotational speed of the balance. In the region to be occupied by the tail there was an outflow of about 1° and an increase in velocity of about 2.5 percent caused by the blocking effect of the balance head and turntable. Since these parts were partly shielded by the model when force tests were being made it is unlikely that they then affected the air flow to the extent the survey indicated.

For the force and moment tests two left spinning conditions were chosen from uncorrected data obtained in a series of full-scale spins of the *NY-1* airplane. (The corrected data appear in reference 5 as test nos. 30L and 19L. It may be noted that the actual differences are small.) The principal characteristics of the spins, the difference being due to changes in moments of inertia, are given in the following table:

Radius, feet	α	β	σ (90°−T)	Ω rad./sec.	V ft./sec.	δ_E	δ_R	δ_A	φ_1	θ_1	ψ_1
3.4	50°	−30′	5°54′	2.76	91.4	33°	34°	0°	−7°17′	−38°17′	18°58′
6.2	46°20′	1°42′	8°30′	2.20	92.4	33°	34°	0°	−6°44′	−42°17′	13°53′

where $+\beta$ is sideslip outward and φ_1, θ_1, and ψ_1 are angles defining the attitude. As here used, φ_1 is the vertical angle between the Y (span) axis and the horizontal, positive when the right wing tip is the lower; θ_1 is the vertical angle between the X (fuselage) axis and the horizontal, negative when the tail is above the horizontal; and ψ_1 is the angle between the spin radius and the projection of the X axis upon the horizontal, positive when the airplane has been rotated in a clockwise direction (viewed from above) about a vertical axis, from a position in which the X axis intersects the spin axis. For the attitudes defined, small changes of θ_1 give negligible changes of β and nearly equal changes of α (α approximately $=90°+\theta_1$), small changes of φ_1 give negligible changes of α and nearly equal changes of β (β approximately $=\sigma+\varphi_1$), and small changes of ψ_1 give negligible changes of both α and β.

A preliminary series of tests was made in each of the spinning conditions with tunnel air speeds of 45, 50, 60, 65, 70, 75, and 80 feet per second to determine the scale effect. The scale effect over this range was found to be negligible and all further tests were made at 65 feet per second (Reynolds Number approximately 153,000) at which speed the operation of the balance was most satisfactory. The control settings and attitudes for the remainder of the tests are given in the following tables:

Radius=3.4 inches. Ω=23.7 radians per second. V=65 feet per second (tunnel velocity)

δ_E	δ_R	φ_1	θ_1	Ψ_1
33°, 18°, 3°, −27°	31°30′	−7°17′	−38°17′	18°58′
33°, 18°, 3°, −27°	17°	−7°17′	−38°17′	18°58′
33°, 18°, 3°, −27°	0°	−7°17′	−38°17′	18°58′
33°, 18°, 3°, −27°	−31°30′	−7°17′	−38°17′	18°58′
33°	31°30′	−3°, −5°, −9°	−38°17′	18°58′
33°	31°30′	−7°17′	−36°, −40°, −42°	18°58′
33°	31°30′	−7°17′	−38°17′	15°, 17°, 21°

Radius=6.2 inches. Ω=18.77 radians per second. V=65 feet per second (tunnel velocity)

δ_E	δ_R	φ_1	θ_1	Ψ_1
33°, 18°, 3°, −27°	31°30′	−6°44′	−42°17′	13°53′
33°, 18°, 3°, −27°	17°	−6°44′	−42°17′	13°53′
33°, 18°, 3°, −27°	0°	−6°44′	−42°17′	13°53′
33°, 18°, 3°, −27°	−31°30′	−6°30′	−42°17′	13°53′
33°	31°30′	−5°, −9°, −11°	−42°17′	13°53′
33°	31°30′	−6°44′	−38°, −40°, −44°	13°53′
33°	31°30′	−6°44′	−42°17′	12°, 16°, 18°

RESULTS

The forces measured by the balance units for the various test conditions were plotted and data for the calculations of the forces and moments about the body axes were taken from the charts, it being assumed that these values should follow smooth curves. The forces and moments so obtained were reduced to coefficient form by the relations:

$$C_X=\frac{X}{qS} \qquad C_Y=\frac{Y}{qS} \qquad C_Z=\frac{Z}{qS}$$

$$C_l=\frac{L}{qbS} \qquad C_m=\frac{M}{qbS} \qquad C_n=\frac{N}{qbS}$$

where the symbols X, Y, Z, L, M, N, q, b, and S have their usual significance. The lower wing was considered as extending through the fuselage in computing wing area. It should be noted that the span was taken as the fundamental length in all the moment equations to facilitate the transfer from one set of axes to another and to make the moments appear in their proper magnitude with respect to each other (b/c = 7.66). The results, in absolute coefficient form, are presented as curves in figures 4 to 10, inclusive.

At least one repeat test was made for each test condition and differences in balance readings were found, in general, to be within 5 percent. A comparison of the force and moment values computed from the flight tests and those obtained from the spinning-balance measurements is given in the discussion.

No corrections were made for tunnel-wall or blocking effects.

DISCUSSION

Changes in control settings.—The effects of changes in elevator and rudder settings are shown in figures 4 to 7, inclusive. The changes in C_X, C_Y, C_Z, and C_l are small and will be discussed in connection with attitude changes.

The pitching-moment coefficient, C_m, was approximately doubled as the elevator was moved from full with the spin to neutral. Further movement against the spin had a comparatively small effect. The curves are similar to those for an airfoil when passing through

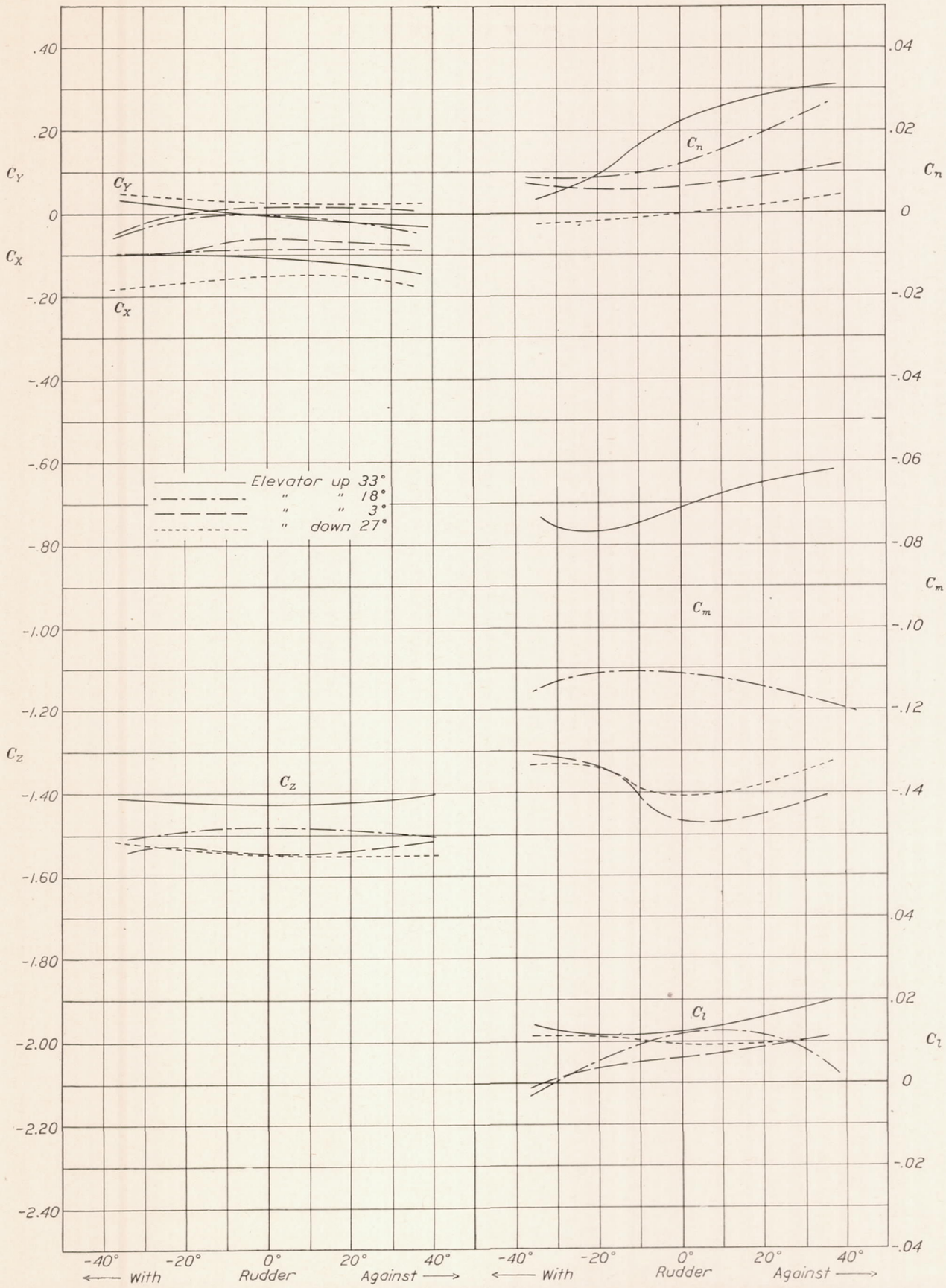

FIGURE 5.—Effect of rudder setting upon aerodynamic characteristics of *NY-1* airplane model in spin of 3.4-inch radius.

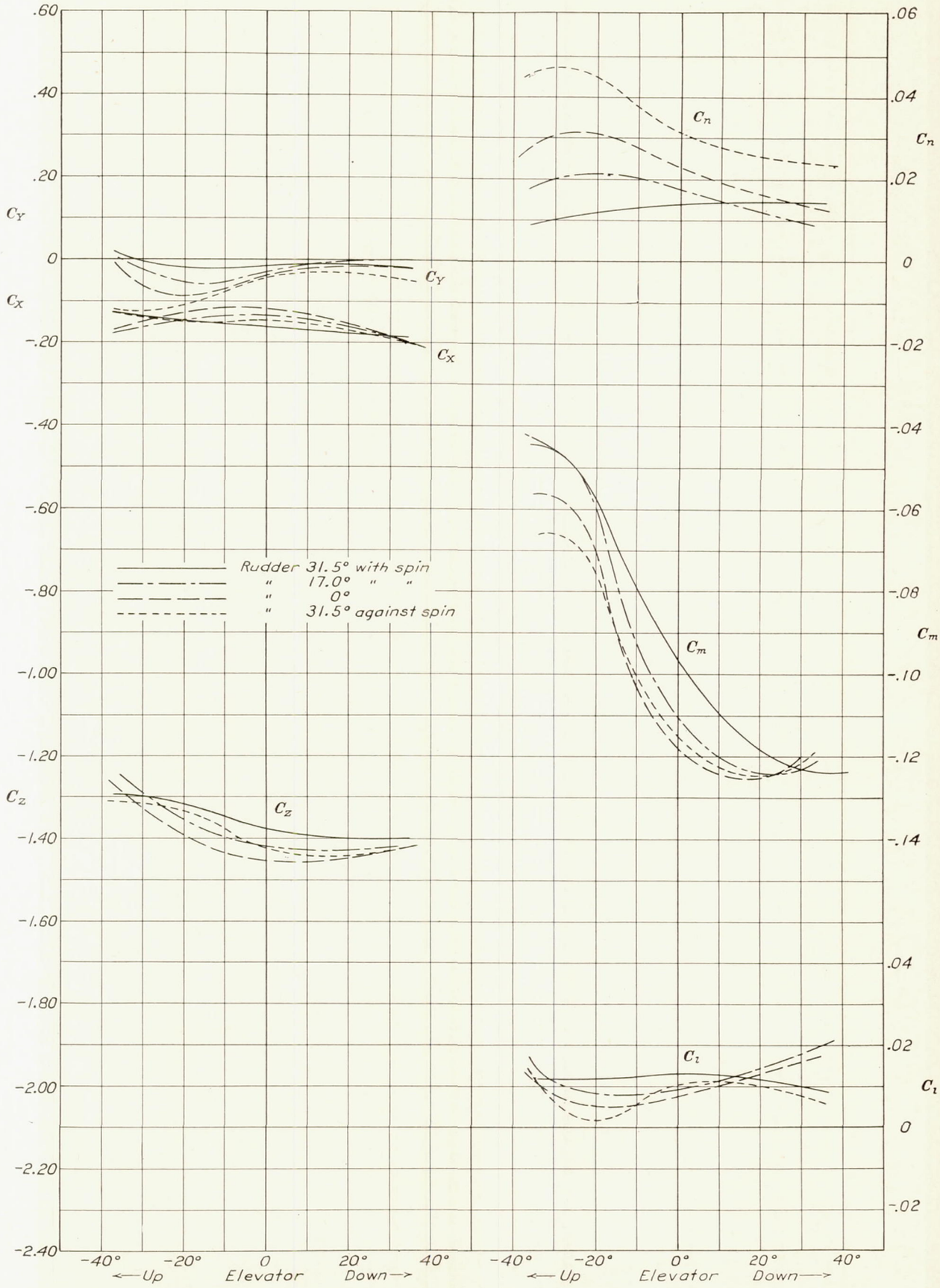

FIGURE 6.—Effect of elevator setting upon aerodynamic characteristics of *NY-1* airplane model in spin of 6.2-inch radius.

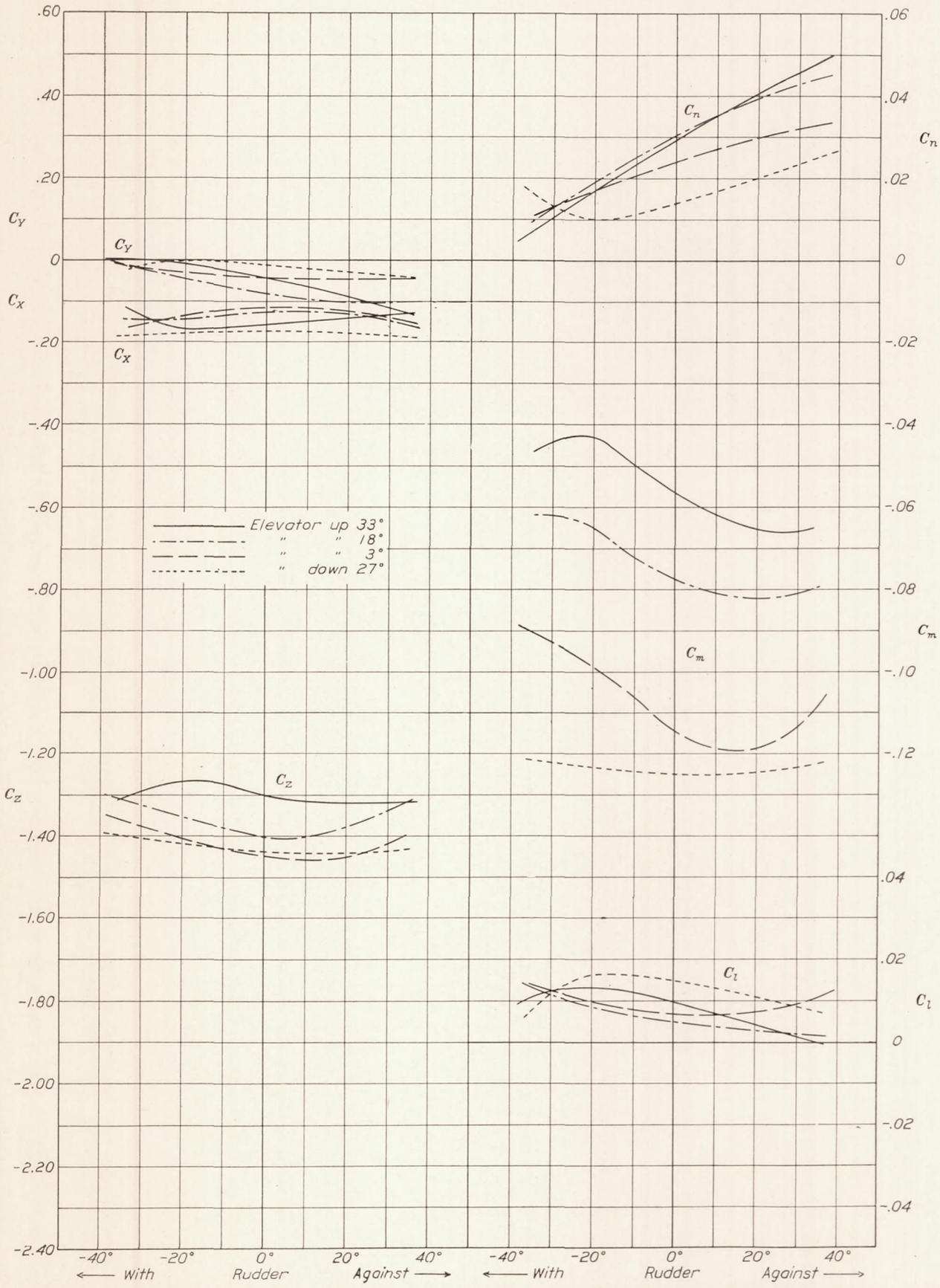

FIGURE 7.—Effect of rudder setting upon aerodynamic characteristics of *NY-1* airplane model in spin of 6.2-inch radius.

the stall. Movement of the rudder gave small changes of C_m but no general tendency was revealed.

When the elevator was up the value of C_n was increased, in the sense to oppose the spin, as the rudder was moved from full with the spin to full against it. The change of moment was approximately proportional to the change of rudder position. When the elevator was down (against the spin) rudder movement had practically no effect in producing a yawing moment opposing the spin, this being especially true in the case of the spin of small radius. These results might have been predicted because a considerable portion of the rudder was exposed to the undisturbed air when the elevator was up but the rudder was almost entirely shielded when the elevator was down. They confirm the deductions from smoke-flow tests (reference 13) and are similar to the results obtained in tests of various stabilizer locations (references 14 and 15).

Changes in attitude.—Small changes in attitude (see figs. 8, 9, and 10) gave changes in C_X, C_Y, C_Z, and C_l of the same order of magnitude as those given by full movement of the elevator and/or rudder. Within the range of attitudes tested, the changes in C_n were not sufficient to balance those obtained with elevator movement. It is apparent that small changes in attitude coupled with a small increase in rotational velocity, and hence inertia stalling moment, might lead to a balance with elevators down. Since changes in

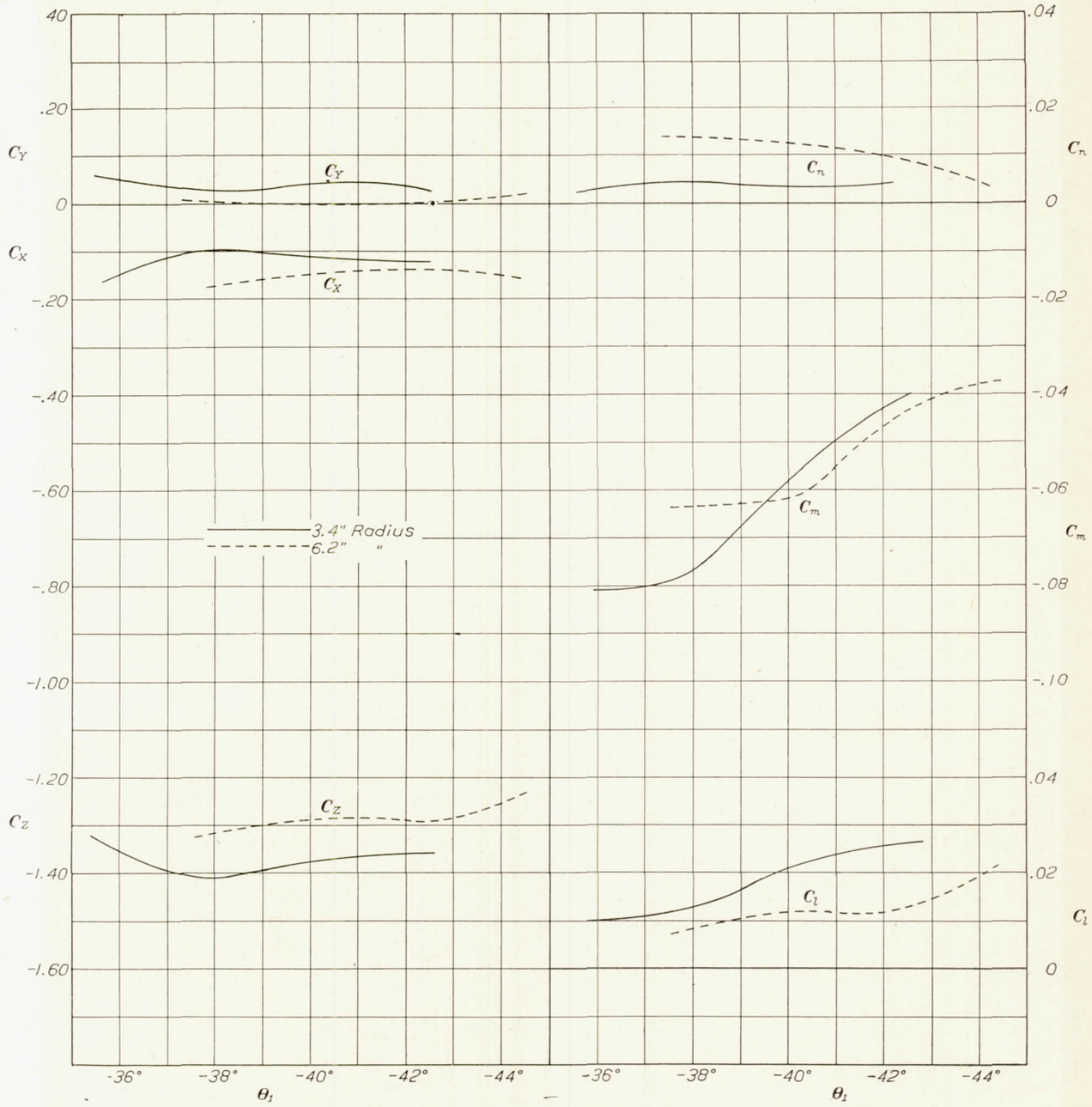

FIGURE 8.—Effect of inclination of thrust axis to horizontal (θ_1) upon aerodynamic characteristics of *NY-1* airplane model when spinning.

C_n produced by small changes in attitude were of the same order of magnitude as those given by elevator movement when the rudder was with the spin, it appears that it would be quite possible for the airplane to continue the spin with very little change in attitude if the elevators were down.

The results indicate that, with the elevators up, relatively large changes of attitude would be necessary to balance the change of C_n due to rudder movement. It is likely that if a large change in attitude would give a balance of C_n, balance of the other forces and moments would be disturbed and the spin would not continue. This conclusion is confirmed by flight results, which showed the impossibility of maintaining balance with the rudder against the spin and with the elevators up.

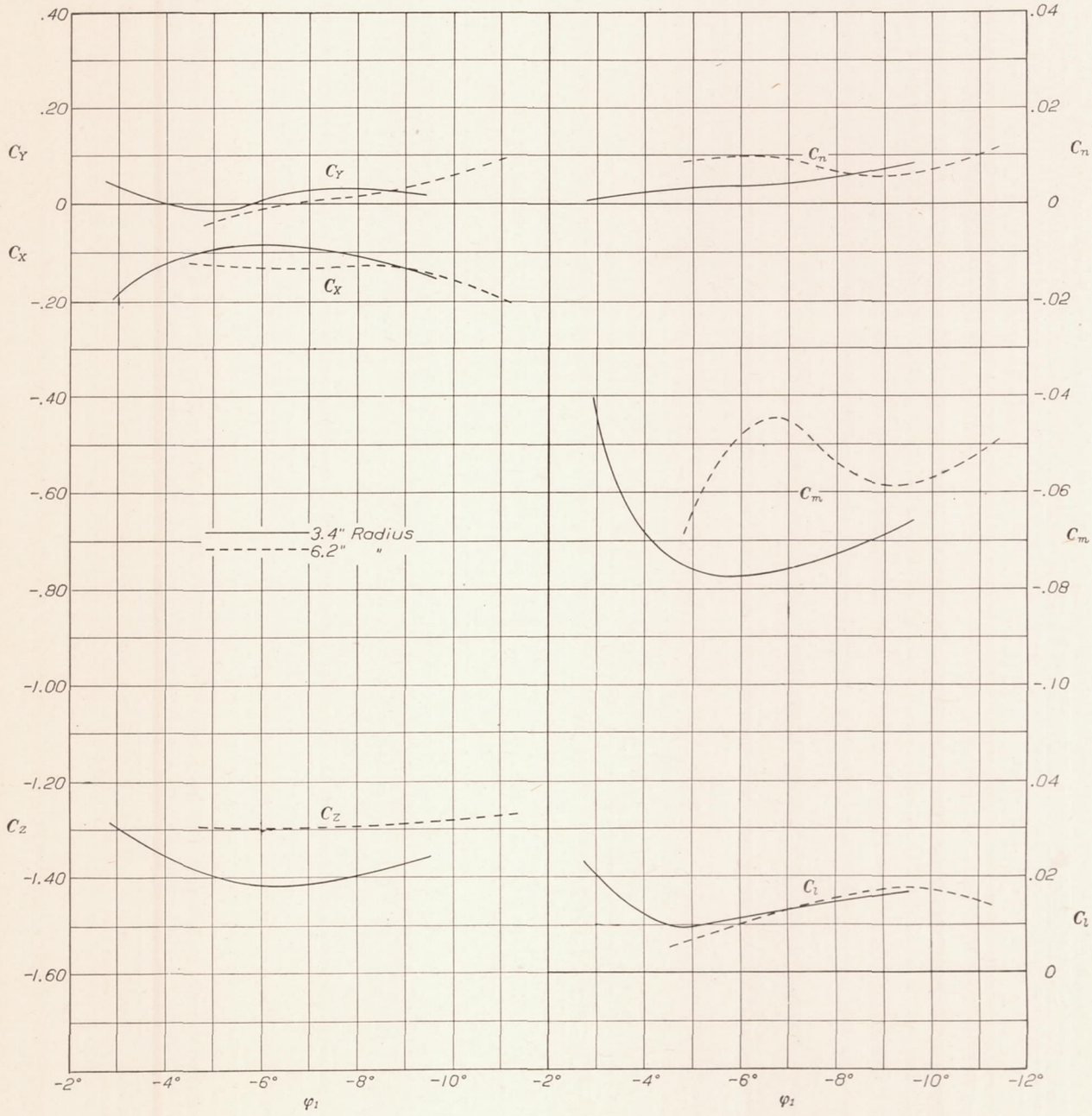

FIGURE 9.—Effect of inclination of span axis to horizontal (φ_1) upon aerodynamic characteristics of *NY-1* airplane model when spinning.

Full-scale tests confirm these deductions. In a spin made with the elevator down (no. 54L, reference 5) the only definite changes revealed were a decrease in radius, a decrease in resultant air velocity, and an increase in rotational speed. The sideslip, the flight path, and the angles of attack at the center section were intermediate between those for the spins described under Tests.

With the elevators down, the changes in C_n due to rudder movement were small and it appears that the airplane might continue to spin in this condition regardless of rudder position. This possibility was not thor-

oughly investigated in flight but in the few cases tried recovery was effected with little increase in the number of turns necessary.

Comparison between full-scale and model data.—A comparison between the full-scale and the model data for the steady spin is given in the following table:

Radius, inches	Test	C_R	C_Q	C_n''
3.4	Full scale	1.414	0.0759	0.0015
	Model	1.415	.0765	.027
6.2	Full scale	1.466	.0674	.0010
	Model	1.301	.0619	.023

The limits of error in the full-scale measurements (reference 5) are given as 7 percent for the vertical velocity and 3 percent for the rotational velocity, and since the squares of both of these quantities enter into the computation of the coefficients it is evident that the tunnel measurements are well within the limits of accuracy of the flight tests.

There is one important difference which is as yet not explained. The fundamental relations of mechanics show that the aerodynamic moment about the vertical axis through the center of gravity of the airplane (C_n'')

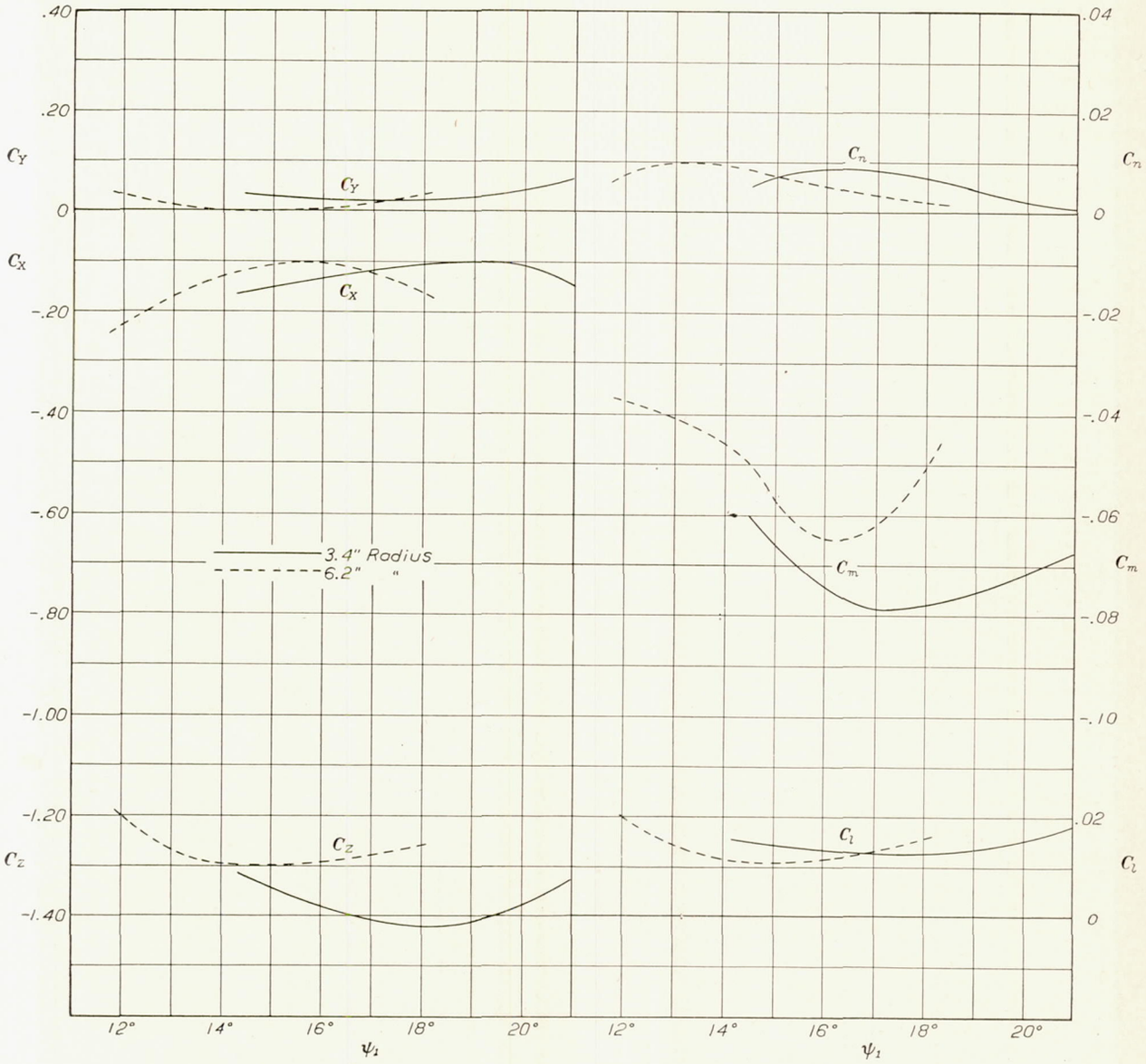

FIGURE 10.—Effect of yaw about vertical axis (ψ_1) upon aerodynamic characteristics of *NY-1* airplane model when spinning.

The resultant force and moment coefficients (C_R and C_Q) are in good agreement for the case of the spin with the smaller radius but the values from model tests are about 10 percent lower than the values computed from the full-scale spin of 6.2-foot radius.

is very small, being equal to the gyroscopic moment of the propeller about that axis. A yawing moment opposing the spin and equal in magnitude to about one third the resultant moment was found in the tunnel measurements.

An attempt was made to explain this discrepancy on the basis that there was washin of the left wing and that the fin was set at an angle to the plane of symmetry on the full-scale airplane while both washin and fin angle were zero for the model. Accordingly, the lower left wing of the model was given 1°15′ washin and an additional test made, but no appreciable change in moment about the vertical axis was obtained. No tests were made with different fin settings but rudder-moment curves indicate that a change in fin setting could have produced only a small change in C_n''. It was found possible to reduce C_n'' to zero by giving the model about 12° of outward sideslip.

It is believed that the differences revealed between the full-scale and the tunnel results are not such as to change the slopes or configurations of the curves of figures 4 to 10, and that they do not affect the analysis given in the preceding discussion or the conclusions to which it points.

CONCLUSIONS

1. A rudder may be rendered ineffective as a source of yawing moments in the spin by the shielding effect of the stabilizer and elevator.

2. Small changes in attitude coupled with changes in rotational velocity may be sufficient to balance force and moment changes given by changes in elevator setting or by changes in rudder setting with the elevators down.

3. Large changes in attitude are necessary to produce moments sufficient to balance the yawing moment about the body axis given by movement of an unshielded rudder.

4. The spinning balance is a practical and economical means of obtaining valuable data upon the aerodynamic forces and moments given by a spinning model and its component parts.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *February 7, 1933.*

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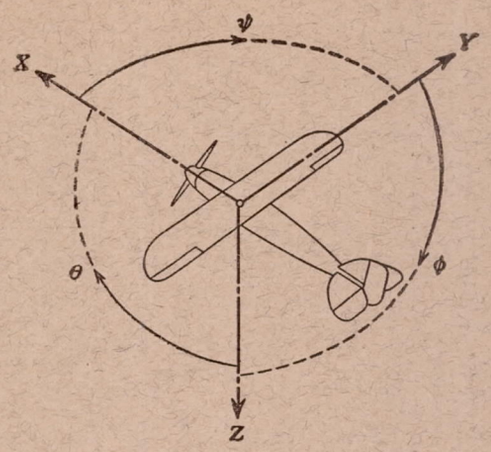

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	ϕ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	ψ	w	r

Absolute coefficients of moment

$$C_l=\frac{L}{qbS} \qquad C_m=\frac{M}{qcS} \qquad C_n=\frac{N}{qbS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p, Geometric pitch.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slipstream velocity.
T, Thrust, absolute coefficient $C_T=\frac{T}{\rho n^2 D^4}$
Q, Torque, absolute coefficient $C_Q=\frac{Q}{\rho n^2 D^5}$
P, Power, absolute coefficient $C_P=\frac{P}{\rho n^3 D^5}$.
C_S, Speed power coefficient $=\sqrt[5]{\frac{\rho V^5}{P n^2}}$.
η, Efficiency.
n, Revolutions per second, r. p. s.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS

1 hp. = 76.04 kg/m/s = 550 lb./ft./sec.
1 kg/m/s = 0.01315 hp.
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.
1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.