TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 526

SPINNING CHARACTERISTICS OF WINGS

II - RECTANGULAR CLARK Y BIPLANE CELLULE: 25 PERCENT STAGGER; 0° DECALAGE; GAP/CHORD 1.0

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SUMMARY

This report is the second of a series in a wind-tunnel investigation planned to determine the aerodynamic characteristics of airplane wings in spinning attitudes. The first report covers the aerodynamic characteristics of a rectangular Clark Y monoplane wing; this report gives the aerodynamic characteristics of a rectangular Clark Y biplane cellule with equal upper and lower wings, gap equal to the chord, no decalage, and 25 percent stagger. The tests were made with the spinning balance in the N.A.C.A. 5-foot vertical tunnel.

The results are given in coefficient form with respect to the body axes. An analysis of the data was made and a discussion of the results based on the analysis is given to aid in predicting the spinning characteristics of airplanes having this wing arrangement.

The analysis indicates that a conventional airplane using this wing combination will, in general, spin with inward sideslip; it will attain equilibrium in a steady spin from 30° to 70° angle of attack if the yawing-moment coefficient produced by interference and parts of the airplane other than the wings is small, about 0.01 opposing the spin; it will not spin if the yawing-moment coefficient is greater than 0.025 opposing the spin; and it is less likely to spin if it is statically unstable in yaw (body axis) in spinning attitudes.

INTRODUCTION

General methods of theoretical analysis of airplane spinning characteristics have been available for some time. Some of these methods of analysis might be used by designers to predict the spinning characteristics of proposed airplane designs if the necessary aerodynamic data were known.

To provide these data, the N.A.C.A. is conducting investigations, using the spinning balance, to determine the aerodynamic forces and moments on airplane models, and on the various parts of airplane models, in spinning attitudes. The present investigation, to determine the spinning characteristics of wings, is planned to include variations in airfoil sections, plan forms, and tip shapes of monoplane wings and variations in stagger, gap, and decalage for biplane cellules. The first series of tests, made on a rectangular Clark Y monoplane wing, are reported in reference 1. That report also gives an analysis of the data for predicting the probable effects of various important parameters on the spin for normal airplanes using such a wing.

The present report is the second of the series. It gives the aerodynamic characteristics of a rectangular Clark Y biplane cellule in spinning attitudes and includes a discussion of the data, using the method of analysis given in reference 1.

APPARATUS AND MODELS

The tests were made on the spinning balance in the N.A.C.A. 5-foot vertical wind tunnel. The tunnel is described in reference 2 and the balance, which measured all six components of the force and moment, is described in reference 3.

The biplane cellule had similar upper and lower Clark Y wings with 25-percent stagger, 0° decalage, and a gap/chord ratio of 1.0. These wings were of laminated mahogany and were rectangular in plan form with 5-inch chords and 30-inch spans. They were rigidly fastened together with struts and braces of 3/32-inch steel rod.

Figure 1 is a sketch of the model showing the locations of the airfoils, the bracing, and the ball-clamp attachment for the spinning balance.

TESTS

In order to cover the probable spinning range, tests were made at approximately 30°, 40°, 50°, 60°, and 70° angles of attack. At each angle of attack tests were made with sideslips of approximately 10°, 5°, 0°, -5°, and -10°. At each angle of sideslip and at each angle of attack tests were made with values of $\Omega b/2V$ of 0.25, 0.50, 0.75, and 1.00. The angles of attack and sideslip were measured in the plane of symmetry at the quarter-chord point of the upper wing. The quarter-chord point of the upper wing was also the center of rotation for all tests. The stops used in setting the model gave angles of attack and sideslip slightly different from those desired. The exact angles tested were measured and the data converted to the even angles. Because of the variations in the balance readings each test condition was repeated five times to insure consistent results.

The tunnel air speed was 75 feet per second for tests with $\frac{\Omega b}{2V}$ = 0.25 and 0.50, and it was 65 and 48.8 for $\frac{\Omega b}{2V}$ = 0.75 and 1.00, respectively. The Reynolds Numbers of the tests were about 196,000 for the highest air speed and 138,000 for the lowest air speed. Previous tests (reference 3) showed no appreciable change in scale effect for this range.

RESULTS AND DISCUSSION

The data were converted to coefficient form by the following relations:

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

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

The forces and moments used to obtain the coefficients were averages of those from the five tests. All coefficients are standard N.A.C.A. coefficients excepting C_m, which is based on the span of the wing instead of the chord, and which may be converted to the standard coefficient by multiplying it by 6. All coefficients are given with the conventional sign for right spins.

The data and attitudes are given for the quarter-chord point of the upper wing at zero radius. The coefficients in body axes may be converted to any other point of rotation in the plane of symmetry by the following relations. The converted coefficients are marked with a subscript.

$$C_{X_1} = C_X\left(\frac{V}{V_1}\right)^2 \qquad C_{Y_1} = C_Y\left(\frac{V}{V_1}\right)^2 \qquad C_{Z_1} = C_Z\left(\frac{V}{V_1}\right)^2$$

$$C_{l_1} = [C_l + \frac{z}{b} C_Y]\left(\frac{V}{V_1}\right)^2$$

$$C_{m_1} = [C_m + \frac{z}{b} C_X - \frac{x}{b} C_Z]\left(\frac{V}{V_1}\right)^2$$

and $$C_{n_1} = [C_n - \frac{x}{b} C_Y]\left(\frac{V}{V_1}\right)^2$$

where x is the distance forward (positive) of the new center of rotation from the quarter-chord of the upper wing.

z, the distance of the new center of rotation below (positive) the quarter-chord of the upper wing.

b, the span of the wing.

$$\frac{V_1}{V} = \sqrt{\frac{u_1^2}{V^2} + \frac{v_1^2}{V^2} + \frac{w_1^2}{V^2}}$$

$$\frac{u_1}{V} = \cos\alpha\cos\beta + \frac{2zq}{b\Omega}\left(\frac{\Omega b}{2V}\right)$$

$$\frac{v_1}{V} = \sin\beta + \frac{2xr}{b\Omega}\left(\frac{\Omega b}{2V}\right) - \frac{2zp}{b\Omega}\left(\frac{\Omega b}{2V}\right)$$

$$\frac{w_1}{V} = \sin\alpha\cos\beta - \frac{2xq}{b\Omega}\left(\frac{\Omega b}{2V}\right)$$

$$\frac{p}{\Omega} = \cos\alpha\cos\beta$$

$$\frac{q}{\Omega} = \sin\beta$$

$$\frac{r}{\Omega} = \cos\beta\sin\alpha$$

thus
$$\alpha_1 = \tan^{-1}\frac{w_1}{u_1}$$

$$\beta_1 = \sin^{-1}\frac{v_1}{V_1}$$

The data in coefficient form are plotted against angle of attack in the ground system of axes for the longitudinal force $C_X{}''$ in figure 2 and all coefficients are given in the body system of axes in figures 3 to 8. Sample curves of the moment coefficients plotted against angle of side-slip and $\frac{\Omega b}{2V}$ in body axes are given in figures 9 to 11.

The spread of the test data indicated that the results are correct to within the following limits:

C_X,	± 0.01	C_l,	± 0.002
C_Y,	± 0.01	C_m,	± 0.005
C_Z,	± 0.04	C_n,	± 0.002

No corrections have been made for the effects of the tunnel, scale, interference of the balance, or of the struts and bracing system.

The data for $C_X{}''$ are given for the ground system of axes (fig. 2) because these values have been used in the analysis. In order to avoid confusion, the following discussion will be confined to the data in the body system of axes.

The values of C_X, longitudinal-force coefficient (fig. 3), are small and usually negative.

The values of C_Y, lateral-force coefficient (fig. 4), are small and generally positive with negative (outward) sideslip and negative with positive sideslip. The values of C_Y increase with $\Omega b/2V$ and with angle of attack.

The values of C_Z, normal-force coefficient (fig. 5), are large and negative and they increase in the negative sense with $\Omega b/2V$ and with angle of attack up to about 50°. The angle of attack of maximum negative values of C_Z decreases with increasing values of $\Omega b/2V$. The changes in C_Z with sideslip are somewhat irregular and depend upon the value of $\Omega b/2V$.

The rolling-moment coefficient C_l (fig. 6) increases with angle of attack from a negative value at small angles of attack to a positive value at large angles except for small values of $\Omega b/2V$, where the rate of change is small. At low values of $\Omega b/2V$, C_l has a larger positive value with negative (outward) sideslip than it does with positive sideslip; whereas, at the larger values of $\Omega b/2V$, the change in C_l with sideslip becomes smaller and irregular.

The pitching-moment coefficient C_m (fig. 7) generally increases in the negative sense with angle of attack and with $\Omega b/2V$. The changes in C_m with sideslip are irregular.

The yawing-moment coefficient C_n (fig. 8) is small and, in general, decreases with the angle of attack. The changes with $\Omega b/2V$ and sideslip are small and irregular.

ANALYSIS

An analysis of the data was made to show the effects of certain parameters on the steady spinning characteristics of an airplane using this type of biplane cellule. The method of analysis with the assumptions and errors involved is given in reference 1.

Parameters.- Because the wing loading, aspect ratio, radii of gyration, pitching moments, and lift coefficients are mostly dependent upon the characteristics of the particular airplane, values of these variables covering the range for normal airplanes have been used in the analysis. A mean of these values was chosen which gave the following parameters.

Relative density of airplane to air, $\mu = 5$

Pitching-moment inertia parameter, $\dfrac{b^2}{k_Z^2 - k_X^2} = 80$

Rolling-moment and yawing-moment inertia parameter,

$$\frac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2} = 1.0$$

Slope of pitching-moment curve, $C_m = -0.0020\ (\alpha-20^\circ)$

Lift coefficient, $C_L = C_{X''}$ ($C_{X''}$ from test data)

Each of the parameters was varied, one at a time, from the mean value while keeping all of the others at the mean value. The values of the parameters used are:

$\mu = 2.5,\ 5.0,\ 7.5,$ and 10.0

$\dfrac{b^2}{k_Z^2 - k_X^2} = 60,\ 80,\ 100,$ and 120

$\dfrac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2} = 0.5,\ 1.0,\ 1.5,$ and 2.0

$C_m = -0.0010\ (\alpha - 20^\circ),\ -0.0015\ (\alpha - 20^\circ),\ -0.0020\ (\alpha - 20^\circ),\ -0.0025\ (\alpha - 20^\circ),$ and $-0.0030\ (\alpha - 20^\circ)$

$C_L = 0.8\ C_{X''},\ C_{X''},$ and $1.2\ C_{X''}$

The variations in μ include the range of wing loadings of conventional airplanes. The value of $\mu = 2.5$ corresponds to an airplane having a wing loading of 6 pounds per square foot and a span of 31.2 feet, and $\mu = 10$

corresponds to a wing loading of 20 with a span of 26.1 feet; both values are for standard atmospheric conditions at sea level.

The variations in $\frac{b^2}{k_Z^2 - k_X^2}$ and $\frac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2}$ cover the range given in reference 4 for 11 airplanes. These parameters may be written as $\frac{Wb^2}{g\ (C - A)}$ and $\frac{C - B}{C - A}$, respectively, where

$A = mk_X^2$, the moment of inertia about the X axis.

$B = mk_Y^2$, the moment of inertia about the Y axis.

$C = mk_Z^2$, the moment of inertia about the Z axis.

Discussion of results of analysis.- Figures 12 and 13 are sample plots used for obtaining the balance of aerodynamic and gyroscopic rolling moments for various angles of sideslip and yawing moment with angle of attack.

Because of the large values of outward sideslip required for balance at 60° and 70° angles of attack, extrapolation of data beyond the range of $\beta = 10°$ was necessary for most cases. These extrapolated values for a balance of rolling moments, except for a few cases, probably give a reasonable indication of the sideslip necessary to justify their use. Much extrapolation for the values of C_n does not appear to be reasonable so the values are not given for some conditions.

The angles of sideslip required for a balance of pitching moments and rolling moments are plotted against the variations in the parameters in figures 14 to 18. The yawing moments required by the parts of the airplane other than the wings and inertia are plotted against variations in the parameters in figures 19 to 23.

The sideslip required for balance in a steady spin is always positive (inward) and in only two cases is it less than 5°. The changes in sideslip with angle of attack are large. Usually these changes are comparatively small below 50° angle of attack but above this point the sideslip increases rapidly, reaching a maximum above 60° angle of attack and usually below 70°.

The required amount of sideslip generally decreases with increasing slope of the pitching-moment curve (fig. 14). The variation of sideslip with changes in the density of the airplane (fig. 15) are large for most angles of attack and the variations with angle of attack are large for lightly loaded airplanes. The changes in sideslip produced by variations in the lift coefficient are small for a given angle of attack (fig. 16). In general, the sideslip increases with the inertia pitching-moment parameter $\dfrac{b^2}{k_Z^2 - k_X^2}$ (fig. 17) but the rate of change is small and irregular. The sideslip decreases with an increase in the rolling-moment and yawing-moment inertia parameter $\dfrac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2}$ (fig. 18) and the changes are large for the higher angles of attack.

An analysis was made with the data converted to the quarter-chord point midway between the wings of the biplane. The analysis showed that the sideslip required was generally about 2° less than it was for the original data. In other details the variations were quite similar. The results are not given because of the extrapolation required to obtain the data.

The yawing-moment coefficient C_n required by the parts of the airplane other than the wings is negative and, for a steady spin, requires a yawing moment opposing the spin except for a single case where it is positive, but small. The changes in C_n required with the various parameters are too small to be of much importance except for the inertia parameter $\dfrac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2}$ and the density parameter μ.

The yawing-moment coefficient required is about -0.005 for the lowest relative density used (fig. 20) and it increases somewhat for the higher densities. The value of C_n decreases from about zero for the lowest value of $\dfrac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2}$ to about -0.02 for the highest value (fig. 23).

The analysis with the data converted to the quarter-chord point midway between the wings of the biplane showed the same general characteristics and usually slightly larger values of $-C_n$ than were obtained for the original data.

The prediction of the possibility of an airplane's spinning or the probability of its attaining a dangerous spin is dependent, using the foregoing analysis, upon the aerodynamic yawing-moment characteristics of the parts of the airplane other than the wings and of the interference effects.

The aerodynamic yawing moments produced by the fuselage and landing gear depend upon their shape and distribution of area. Some results obtained by the British for fuselages are reported in references 5 and 6. The N.A.C.A. is conducting an investigation with pressure distribution on the fuselage and tail surface of an XN2Y-1 airplane in flight and the results are to be published later. The yawing moments produced by the empennage depend upon its distance from the center of gravity; upon the areas, the shape, and the location of the vertical and the horizontal surfaces with respect to each other as well as to the fuselage; and upon the limits of the control movements and their attitude with respect to the relative wind. The effects of some of these variables have been investigated and are reported in references 5 to 10.

The geometry of the spin indicates that the greater the sideslip in the outward sense and/or the higher the rate of rotation, the more effective the vertical tail surfaces will be for producing yawing moments opposing the spin. Another factor that must be considered is the static stability of the airplane in yaw (body axes) in the particular attitude in question. If the airplane is statically stable, outward sideslip will give an increment of yawing moment opposing the spin and if it is statically unstable, inward sideslip will give an increment of yawing moment opposing the spin. In other words, an airplane that has fin area ahead of the center of gravity is less likely to attain a dangerous spin if the sideslip is inward than if the sideslip is outward.

Since the analysis shows that an airplane with this wing arrangement will probably always spin with inward sideslip, the vertical tail surfaces will be at a disadvantage for producing yawing moments opposing the spin especially at the higher angles of attack, where β is large and the airplane is likely to spin flat. In order to increase the yawing moments opposing the spin from the fin and rudder as well as from stability, if the airplane is statically stable in yaw, any change in the parameters that will reduce β will be beneficial. The analysis shows that β will be reduced especially at the higher angles of attack by increasing $-C_m$, μ, and $\frac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2}$, and by reducing $\frac{b^2}{k_Z^2 - k_X^2}$. The yawing-moment coefficients produced by the wings, however, show increasing values aiding the spin, with increasing values of $-C_m$ (fig. 19), and $\frac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2}$ (fig. 23). The resulting effects, on the spin, of changing either or both of these two parameters will depend upon their relative importance for the particular airplane.

It is apparent that to predict the spinning characteristics of a particular airplane, the aerodynamic characteristics must be better known than they are at present. These results, however, indicate some interesting facts about the spinning characteristics of normal airplanes using this wing arrangement. These facts may be stated as follows: (1) The airplane will normally spin with inward sideslip. (2) Yawing-moment coefficients, about -0.02 or less, opposing the spin will be required to make the airplane balance in a steady spin from 30° to 70° angle of attack. (3) Yawing-moment coefficients opposing the spin slightly greater than the maximum required for a balance, in any particular case, will prevent the steady spin. A maximum value of -0.025 should be sufficient to prevent the steady spin for all normal conditions. (4) Some parameters give opposing results and the prediction will depend upon the relative importance of the variables.

CONCLUSIONS

Provided that the added arbitrary constants to the rolling-moment and yawing-moment coefficients are of the right order of magnitude, the following conclusions are indicated by the analysis presented for a conventional biplane with rectangular Clark Y wings having 25 percent stagger, gap equal to the chord, and zero decalage.

1. The value of the yawing-moment coefficient required from the fuselage, tail, and interference effects for steady spinning equilibrium is small and nearly always negative (opposing the spin) throughout the angle-of-attack range investigated. It appears that the spinning attitude of the airplane will depend mostly upon details of arrangement of the fuselage and tail.

2. The maximum yawing-moment coefficient that must be supplied by all parts of the airplane other than the wings to insure recovery from steady spinning equilibrium is $C_n = -0.025$.

3. Decreasing the static stability in yaw when feasible (making more positive the slope of curve of yawing moment against sideslip, e.g., adding fin area ahead of the c.g.) about body axes at spinning angles of attack decreases the possibility of attaining equilibrium of yawing moments and hence tends to prevent the spin.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 16, 1935.

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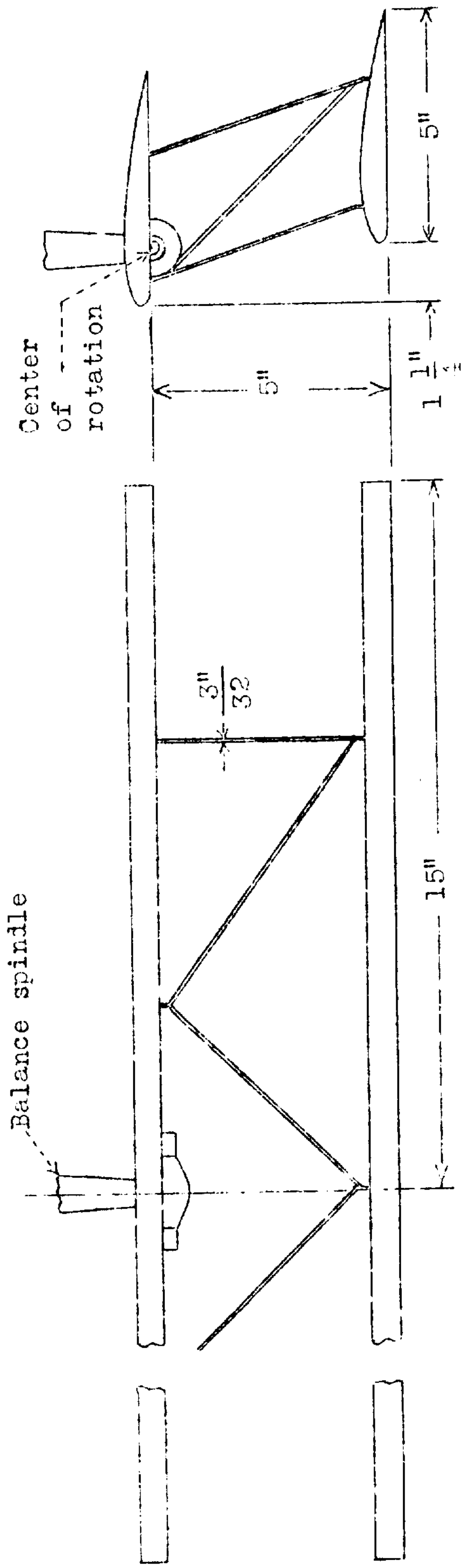


Figure 1.-Clark Y biplane cellule.

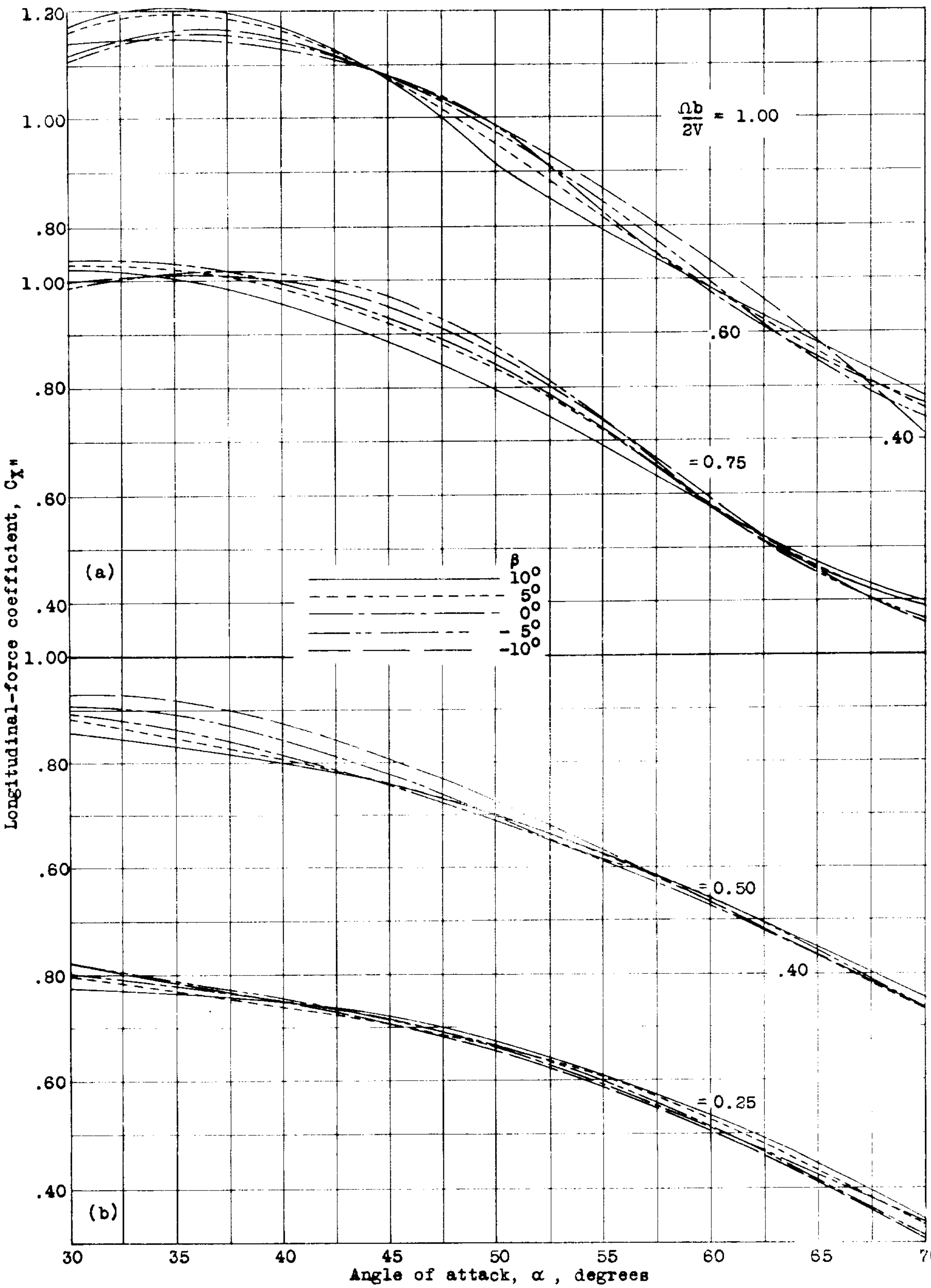


Figure 2.- Variation of longitudinal-force coefficient $C_{X''}$ (ground axes) with angle of attack.

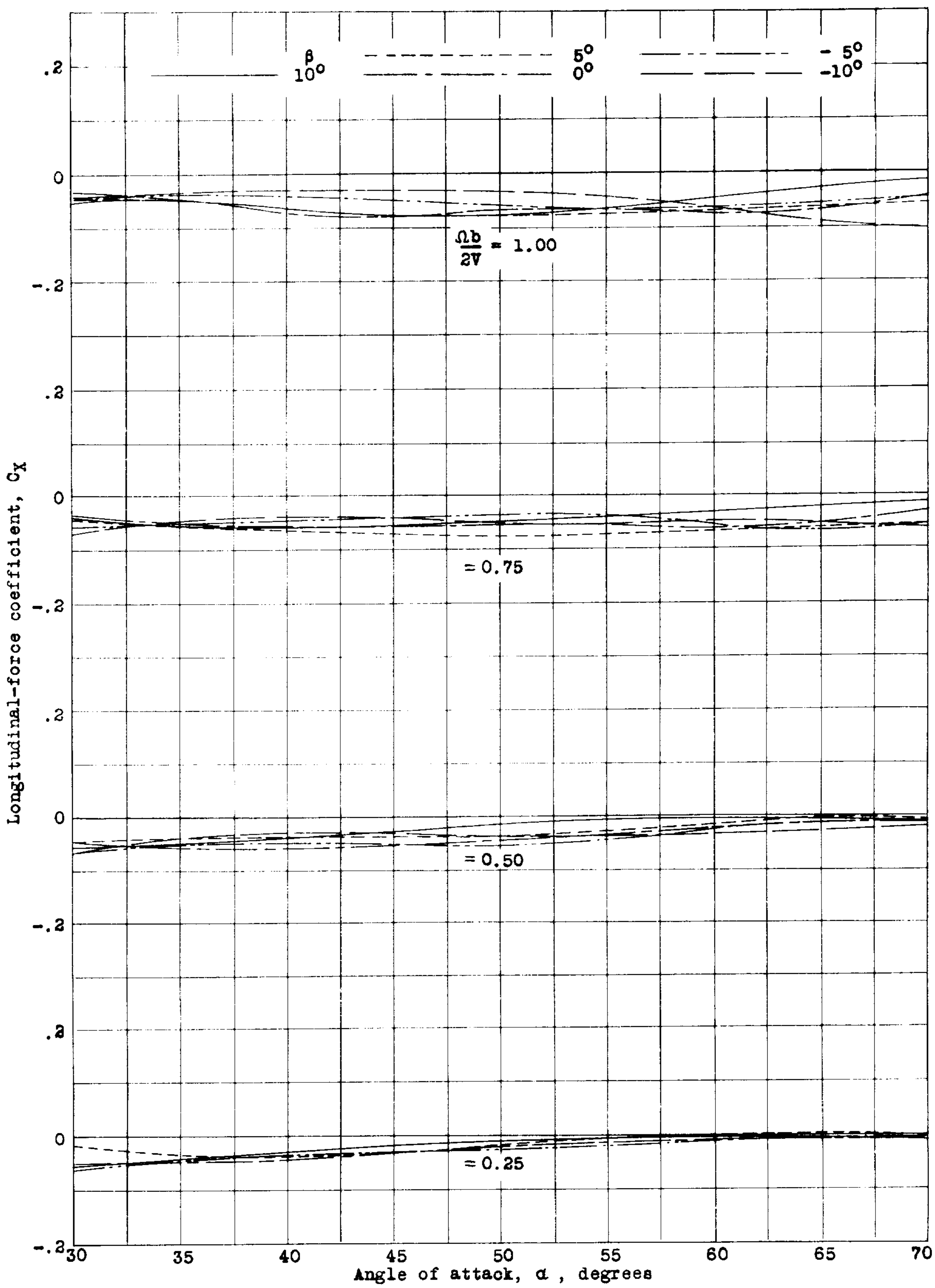


Figure 3.- Variation of longitudinal-force coefficient C_X (body axes) with angle of attack.

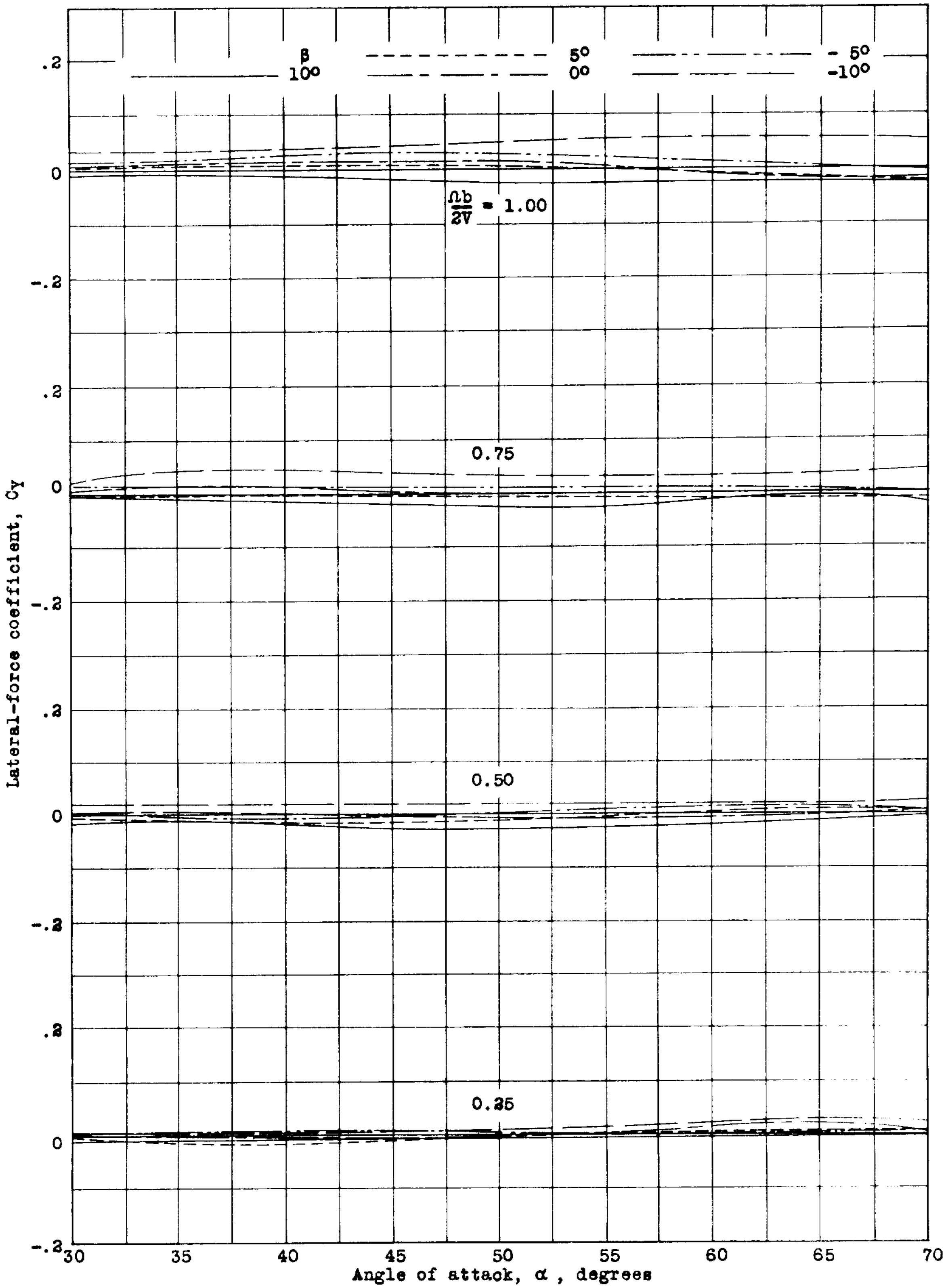


Figure 4.- Variation of lateral-force coefficient C_Y (body axes) with angle of attack. Signs for right spins.

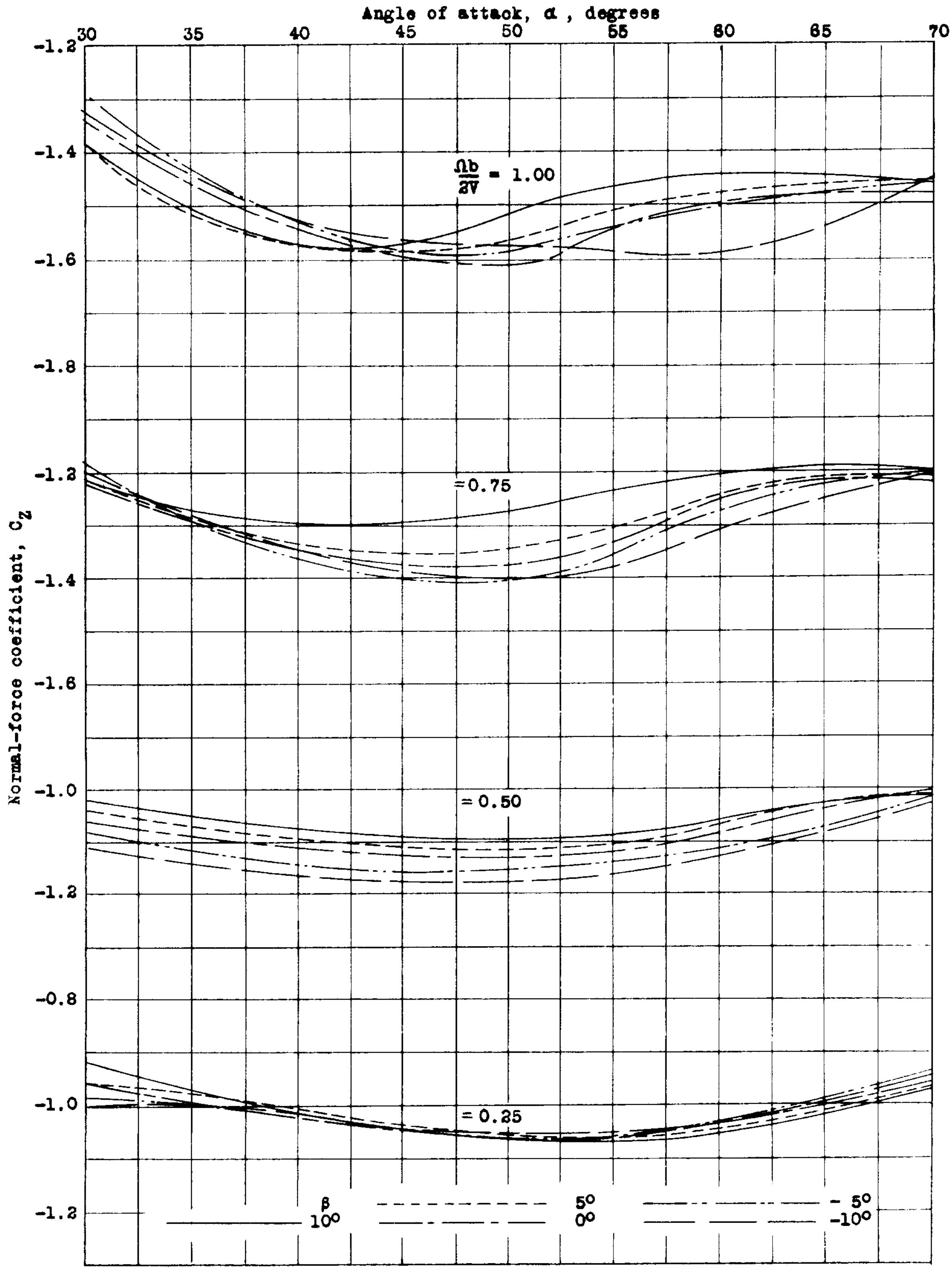


Figure 5.- Variation of normal-force coefficient C_Z (body axes) with angle of attack.

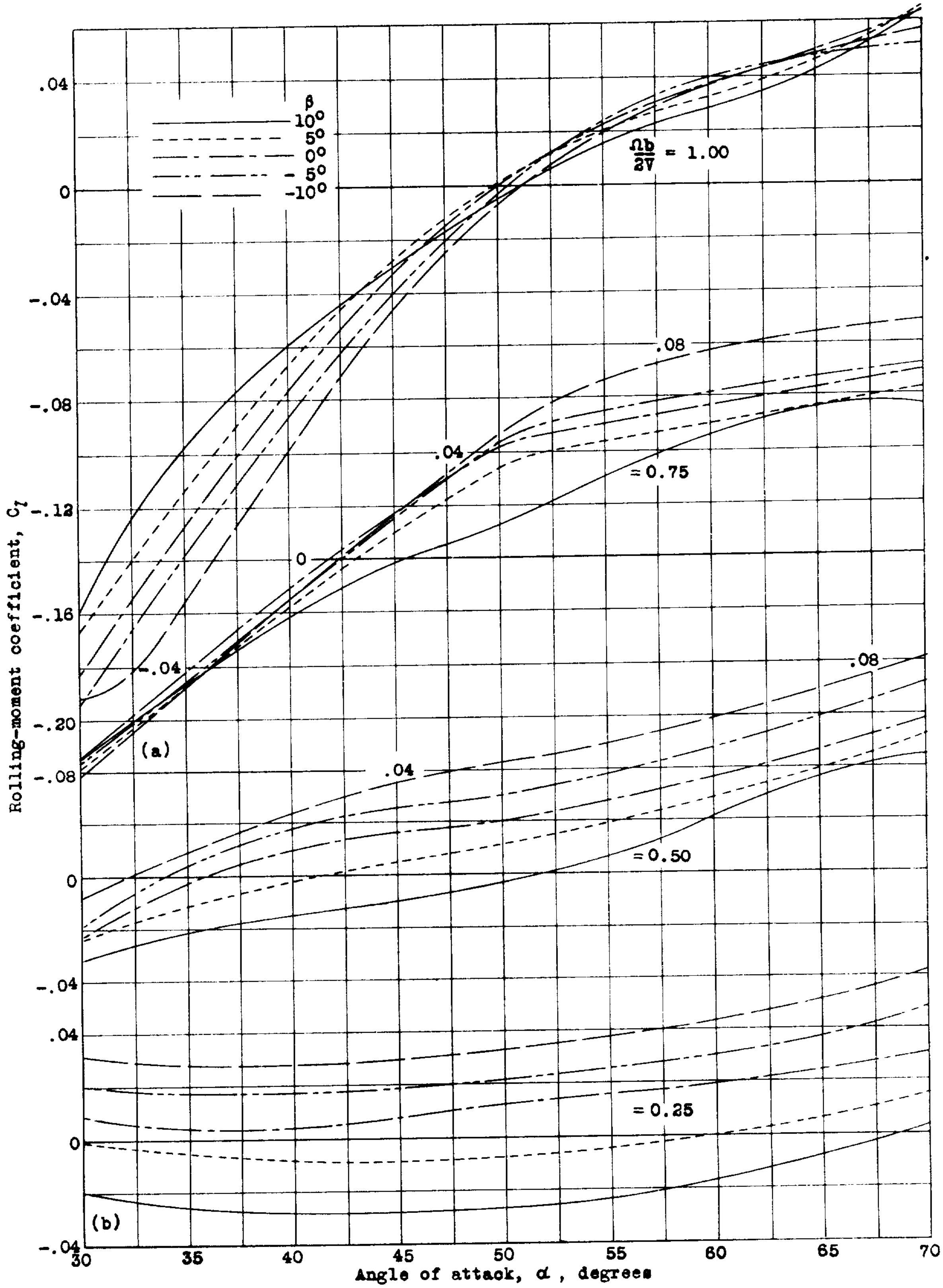


Figure 6.- Variation of rolling-moment coefficient C_l (body axes) with angle of attack Signs for right spins.

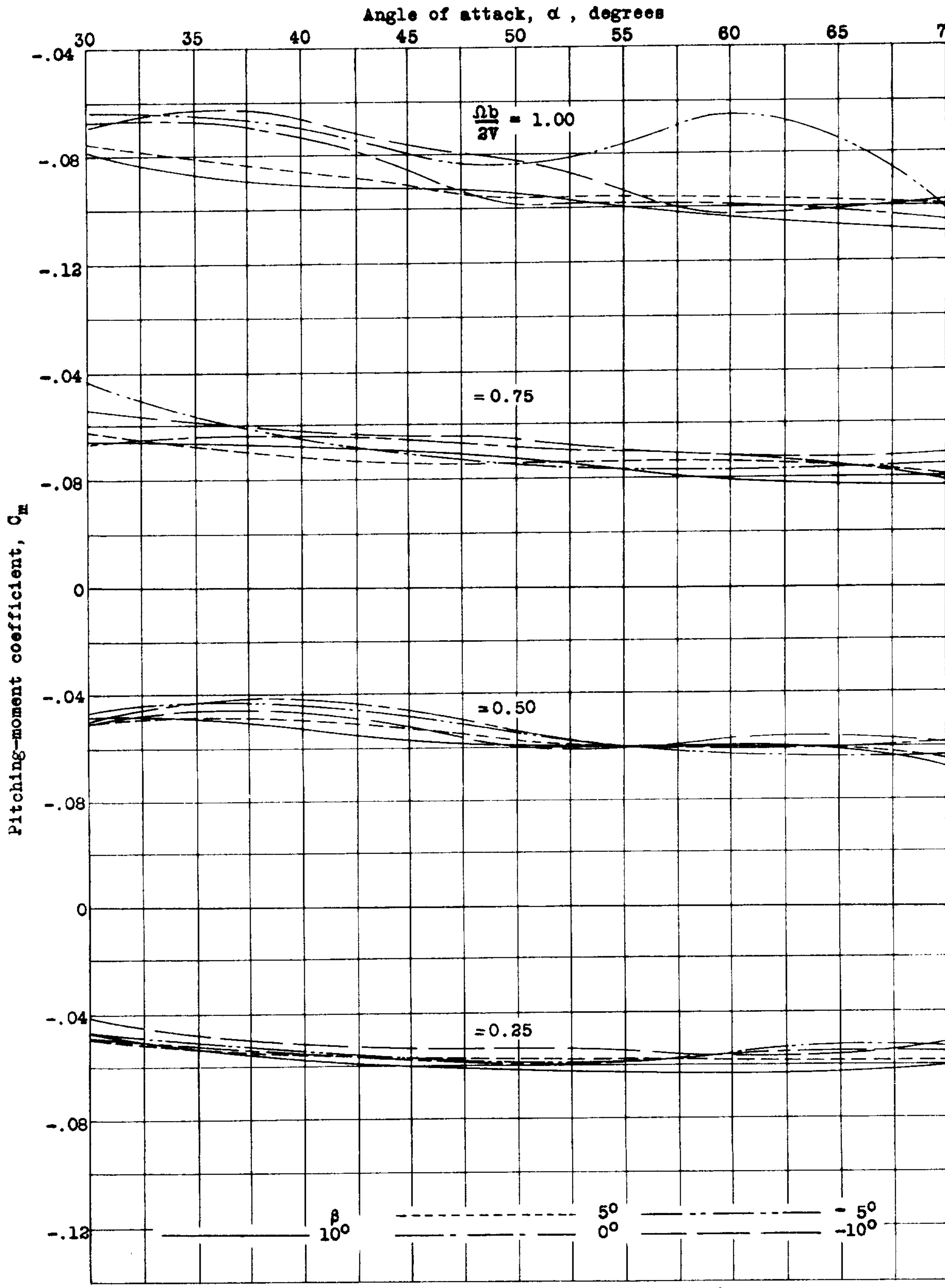


Figure 7.- Variation of pitching-moment coefficient C_m (body axes) with angle of attack.

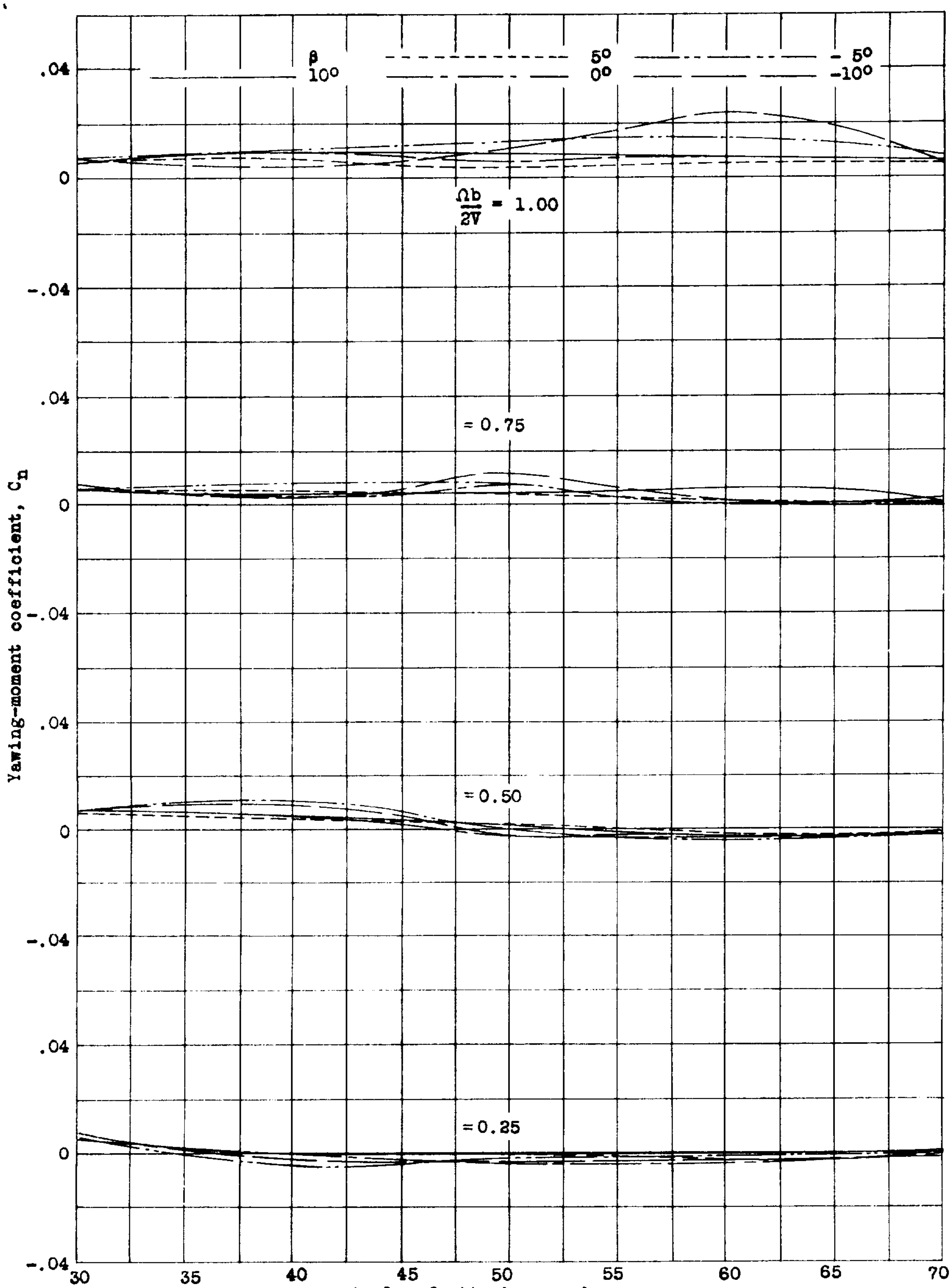


Figure 8.- Variation of yawing-moment coefficient C_n (body axes) with angle of attack. Signs for right spins.

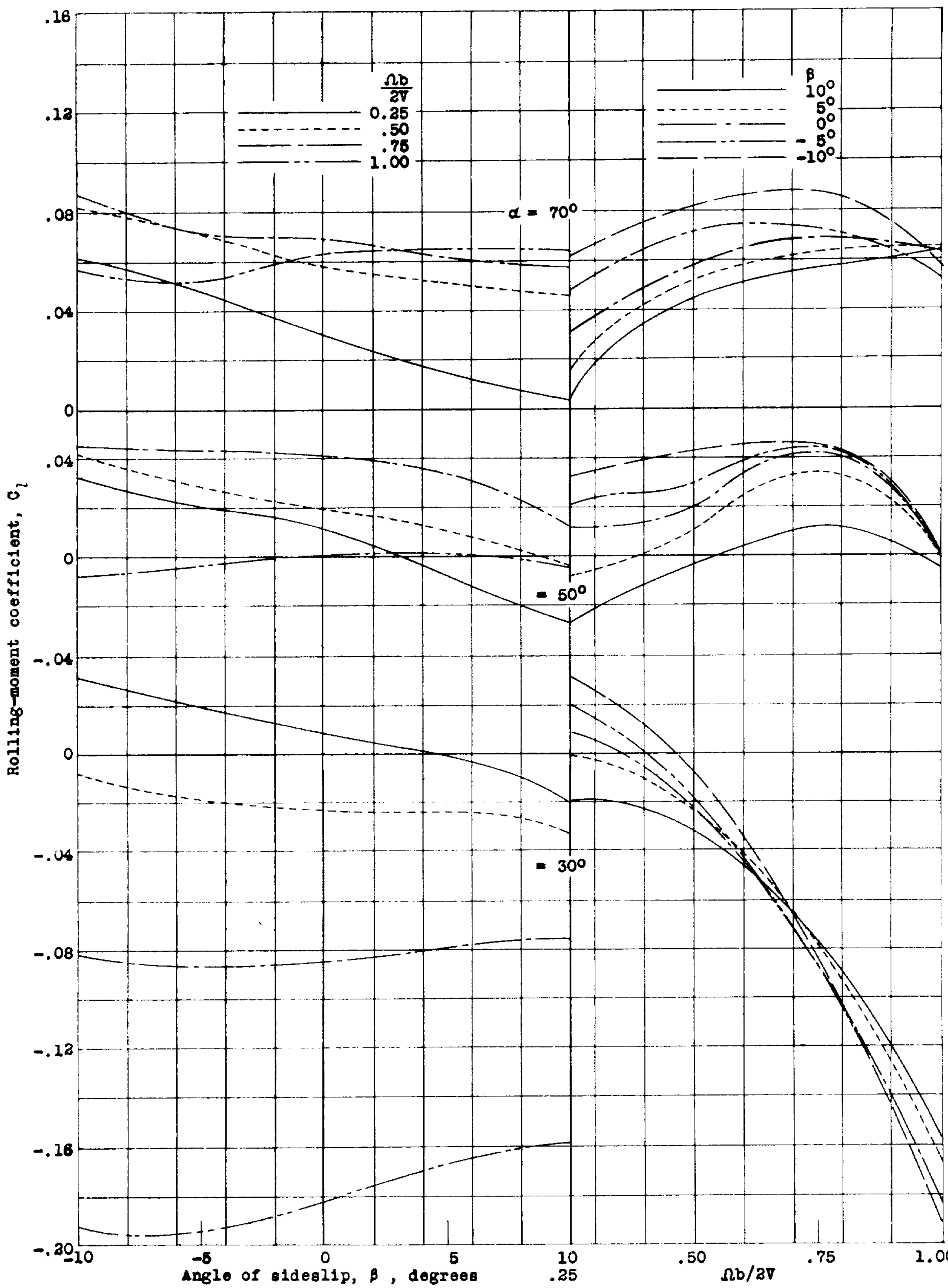


Figure 9.- Variation of rolling-moment coefficient C_l (body axes) with angle of sideslip and with $\Omega b/2V$. Signs for right spine.

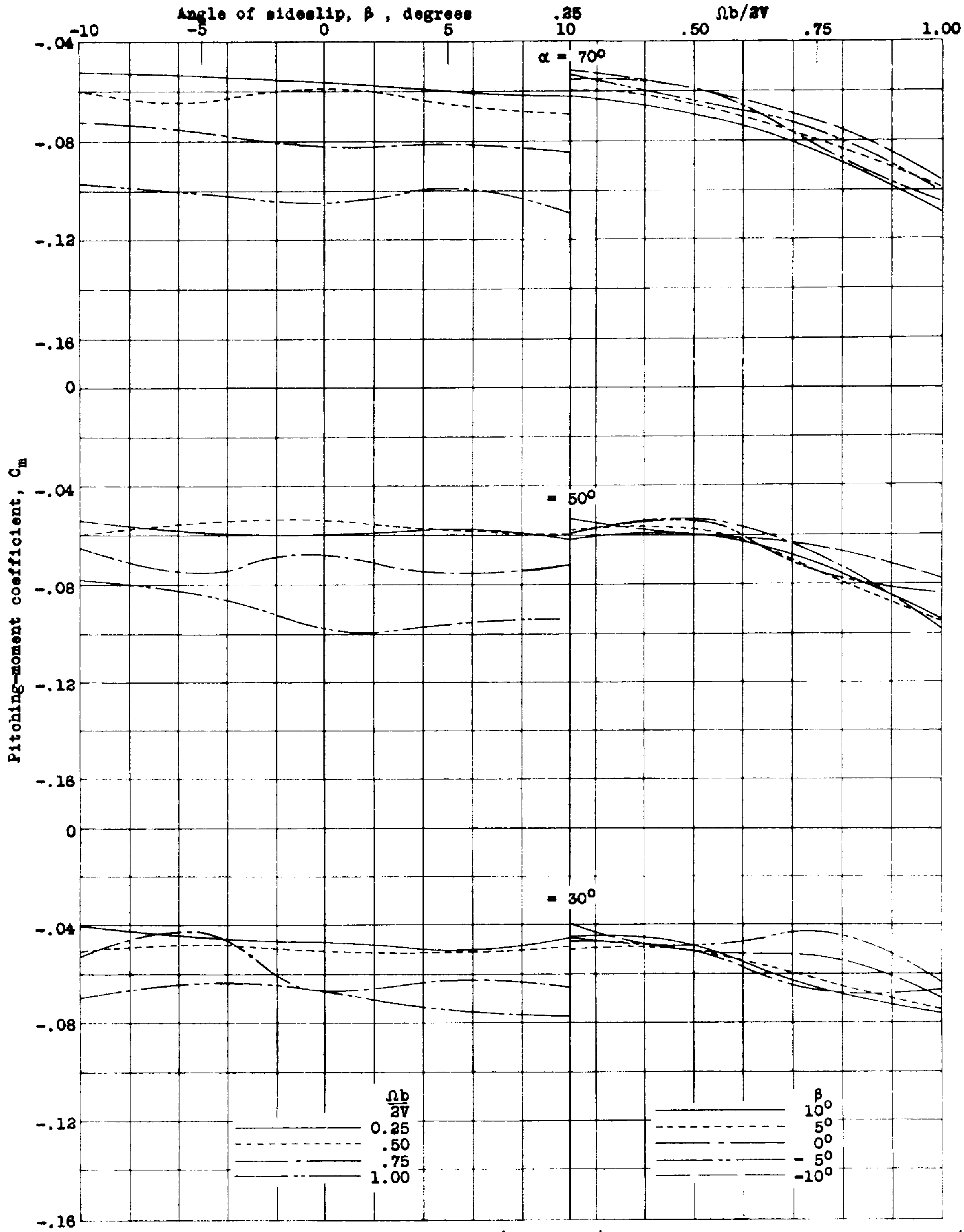


Fig. 10.-Variation of pitching-moment coefficient C_m(body axes) with angle of sideslip and with Ωb/2V.

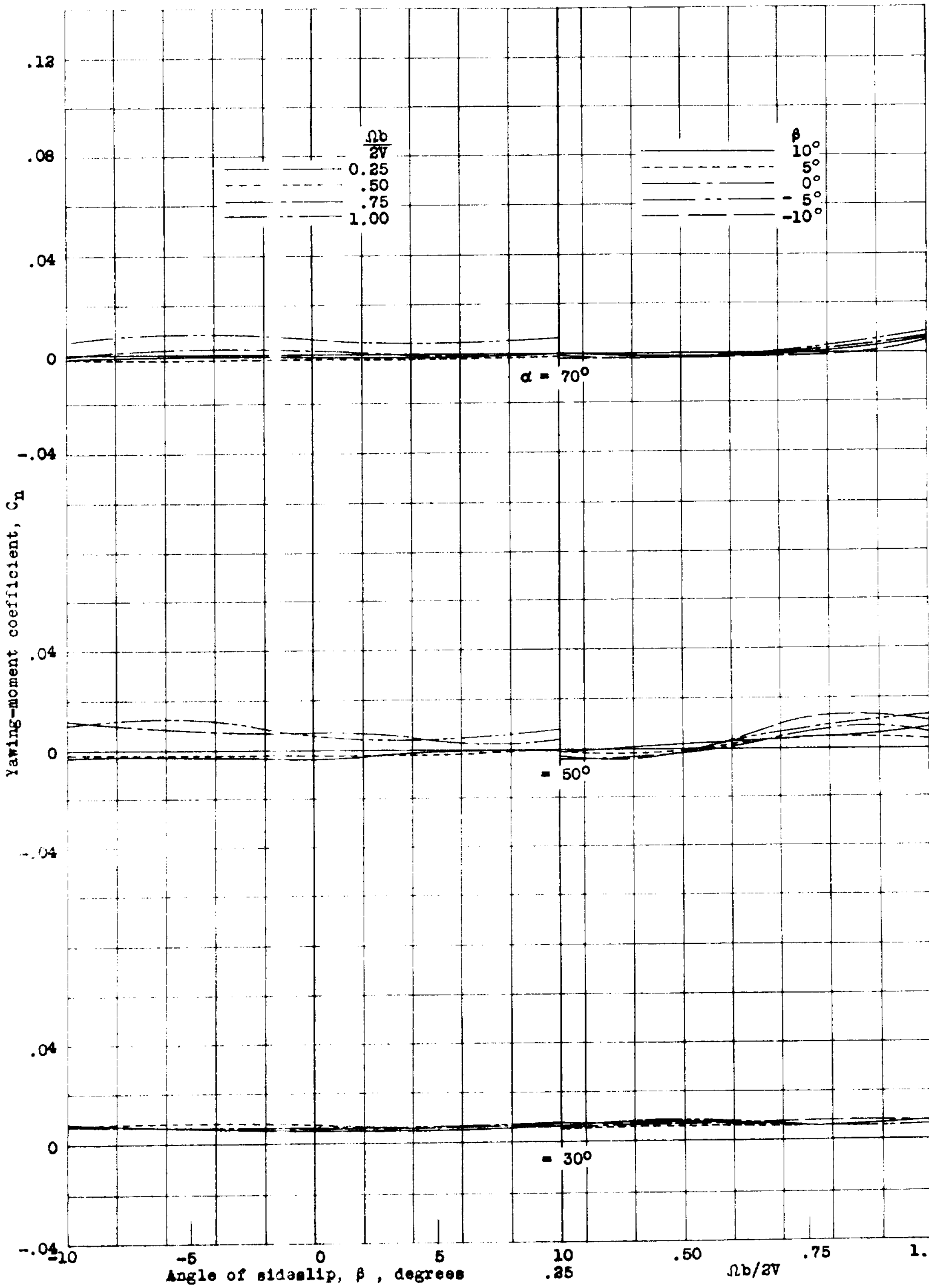


Figure 11.- Variation of yawing-moment coefficient C_n (body axes) with angle of sideslip and with $\Omega b/2V$. Signs for right spins.

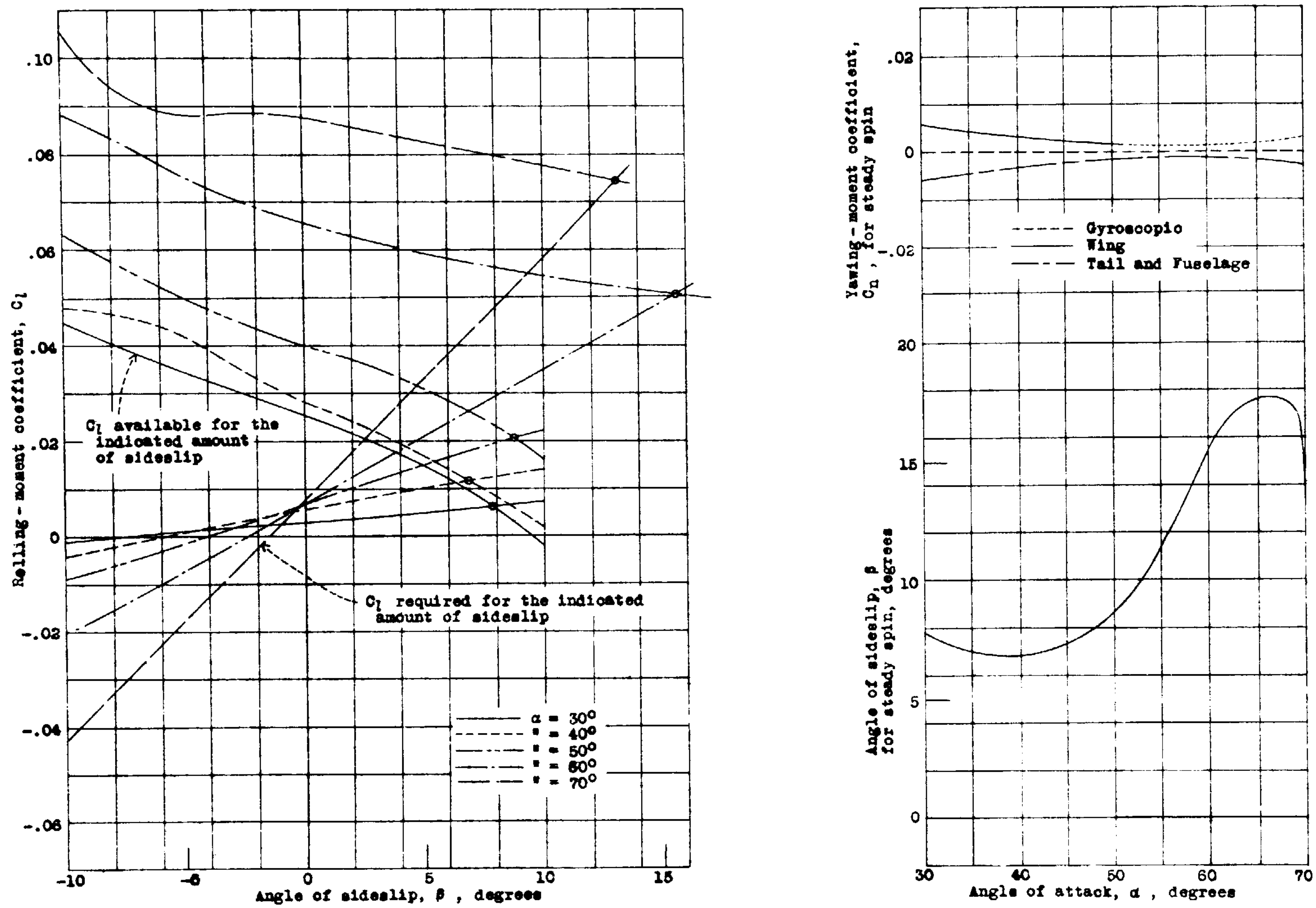


Figure 12.- Sample chart illustrating method of determining angle of sideslip and tail and fuselage yawing-moment coefficients necessary for equilibrium in right spins with $k_X^2 = k_Y^2$, $C_m = 0.0020(\alpha - 20°)$, $\mu = 5$, $C_L = C_X$,

$$\frac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2} = 1 \qquad \frac{b^2}{k_Z^2 - k_X^2} = 80$$

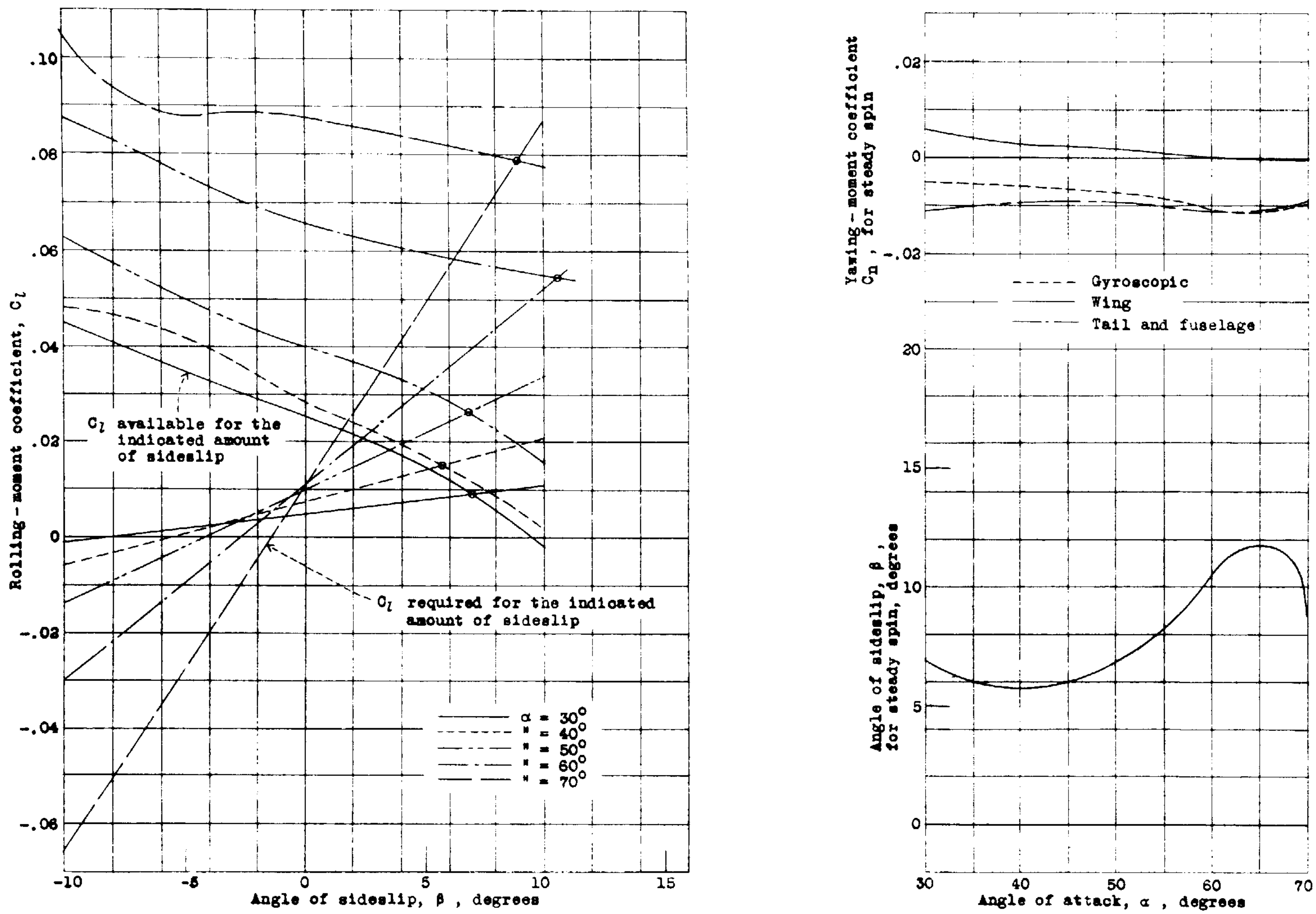


Figure 13.- Sample chart illustrating method of determining angle of sideslip and tail and fuselage yawing-moment coefficients necessary for equilibrium in right spins with $k_X{}^2 > k_Y{}^2$. $C_m = 0.0020(\alpha - 20°)$, $\mu = 5$,

$$\frac{k_Z{}^2 - k_Y{}^2}{k_Z{}^2 - k_X{}^2} = 1.5 \qquad \frac{b^2}{k_Z{}^2 - k_X{}^2} = 80$$

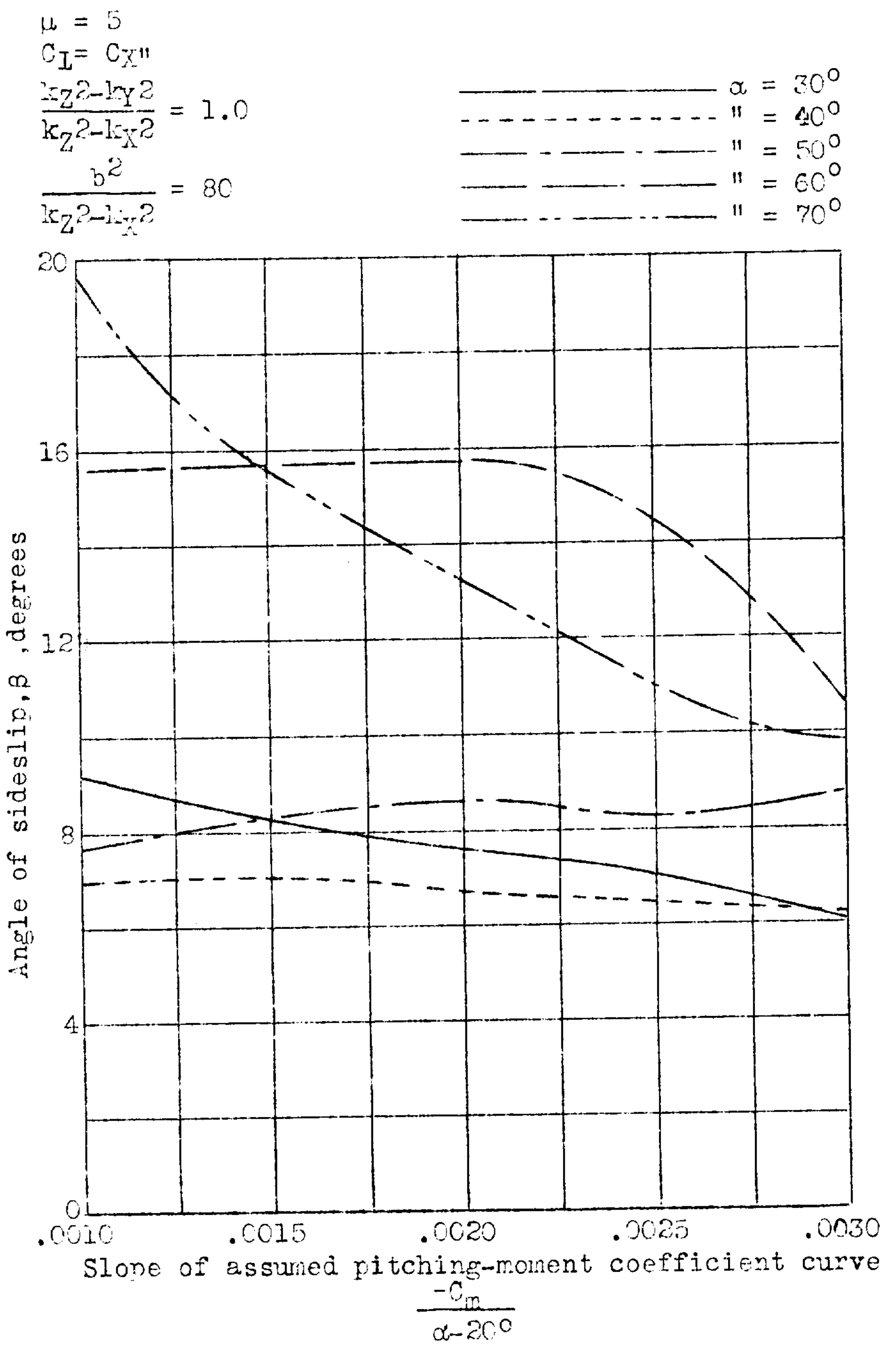


Figure 14.-Effect of pitching-moment coefficient upon sideslip necessary for equilibrium in a spin.

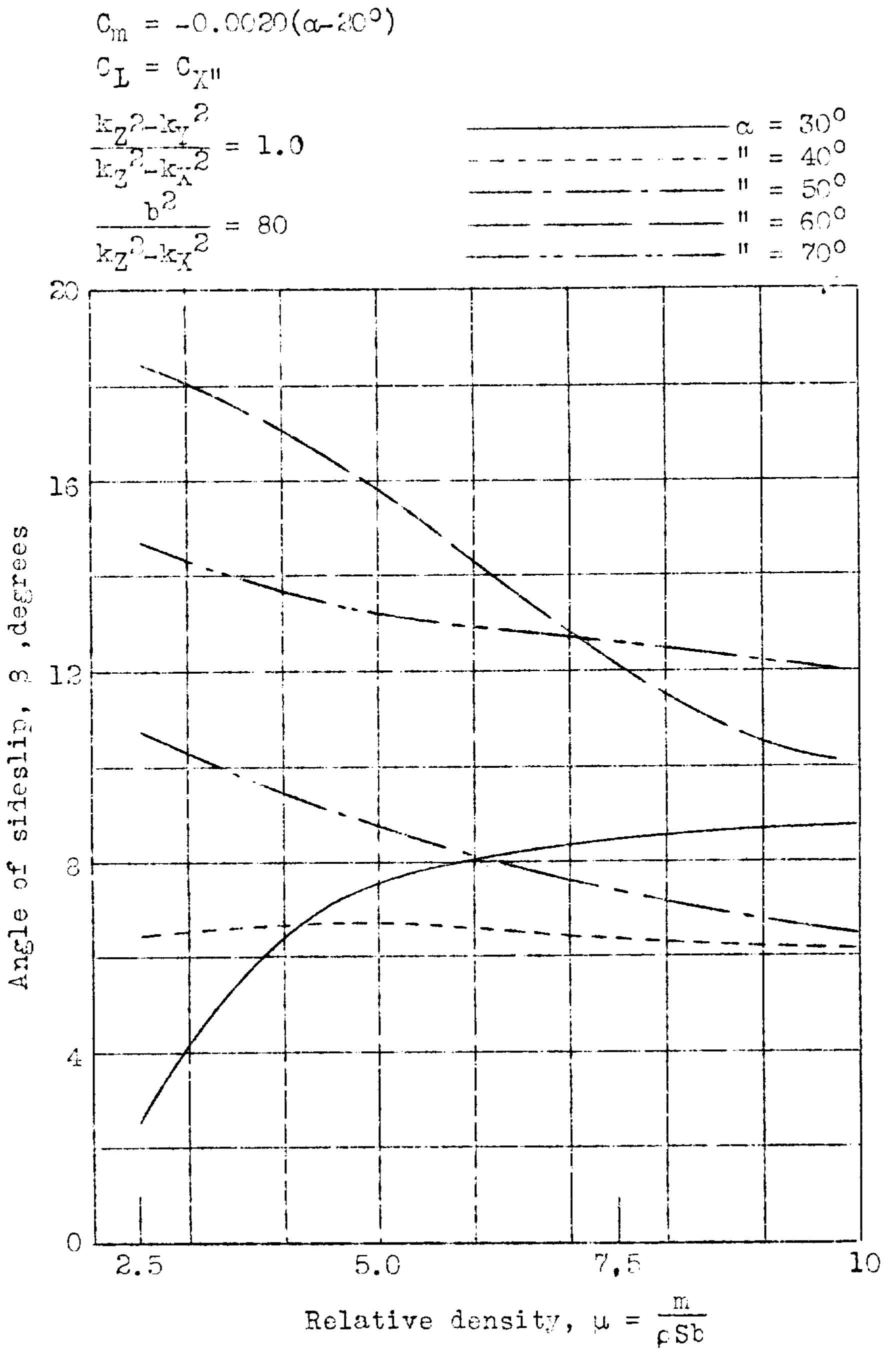


Figure 15.-Effect of relative density of airplane upon sideslip necessary for equilibrium in a spin.

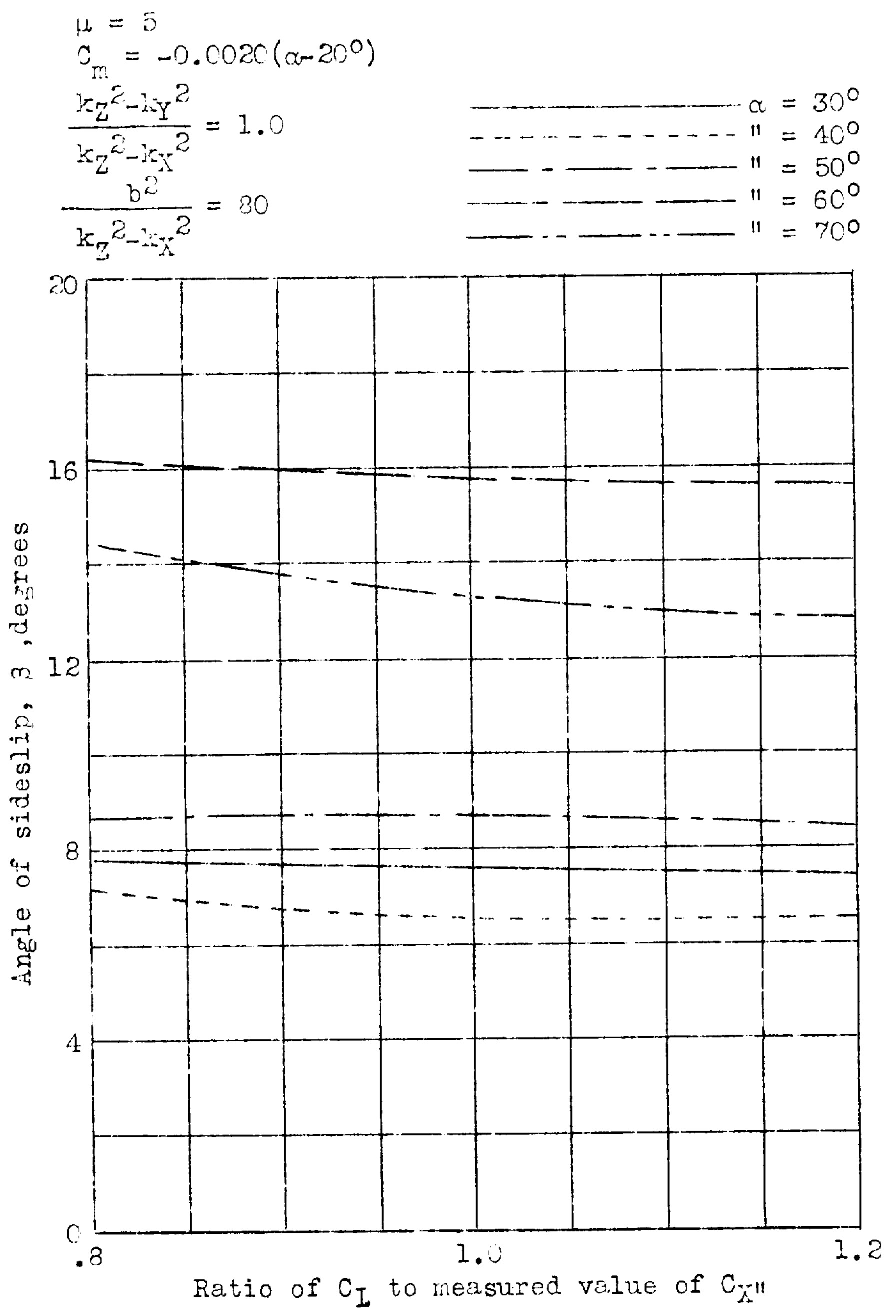


Figure 16.-Effect of lift coefficient upon sideslip necessary for equilibrium in a spin.

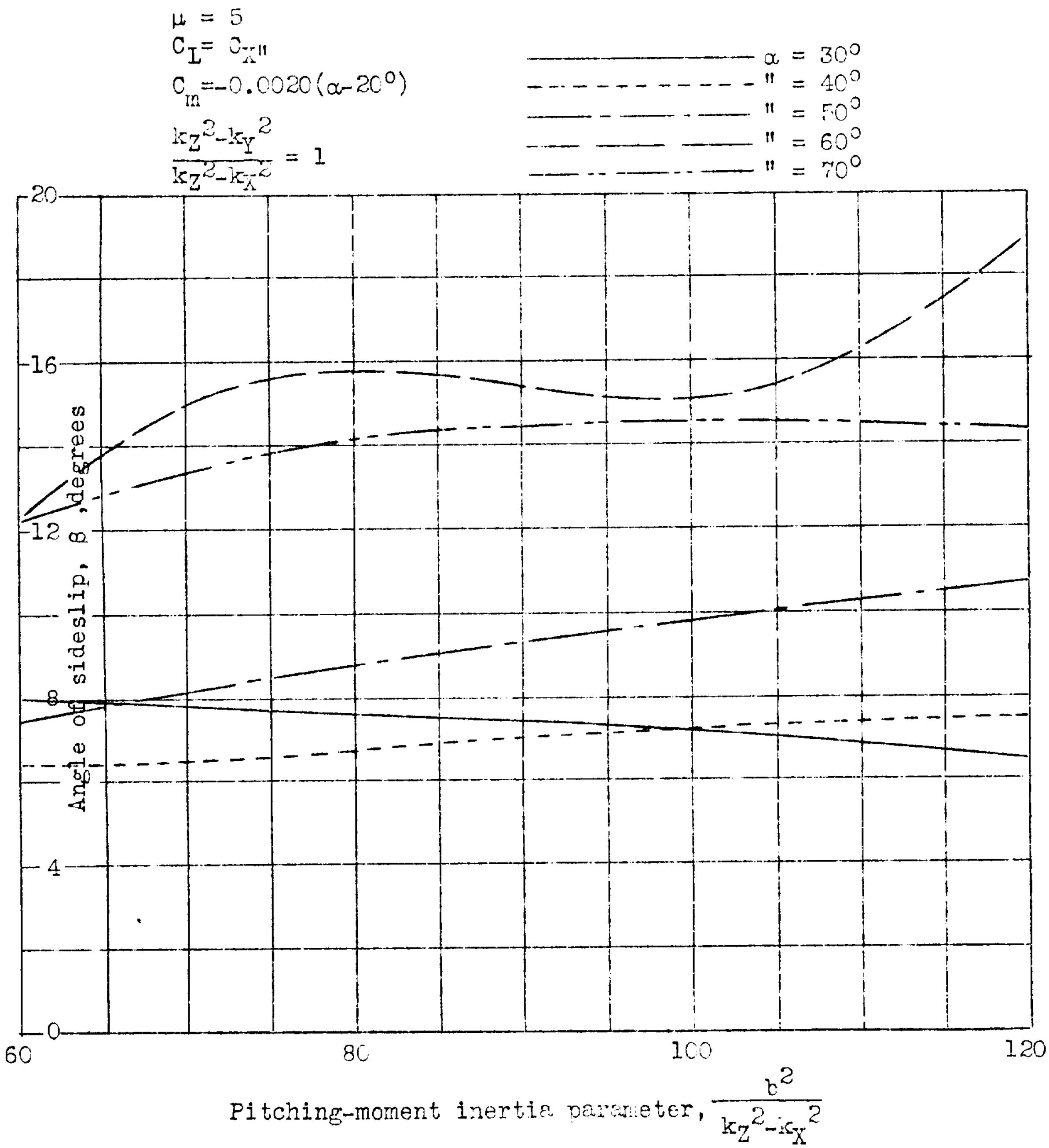


Figure 17.-Effect of pitching-moment inertia parameter upon sideslip necessary for equilibrium in a spin.

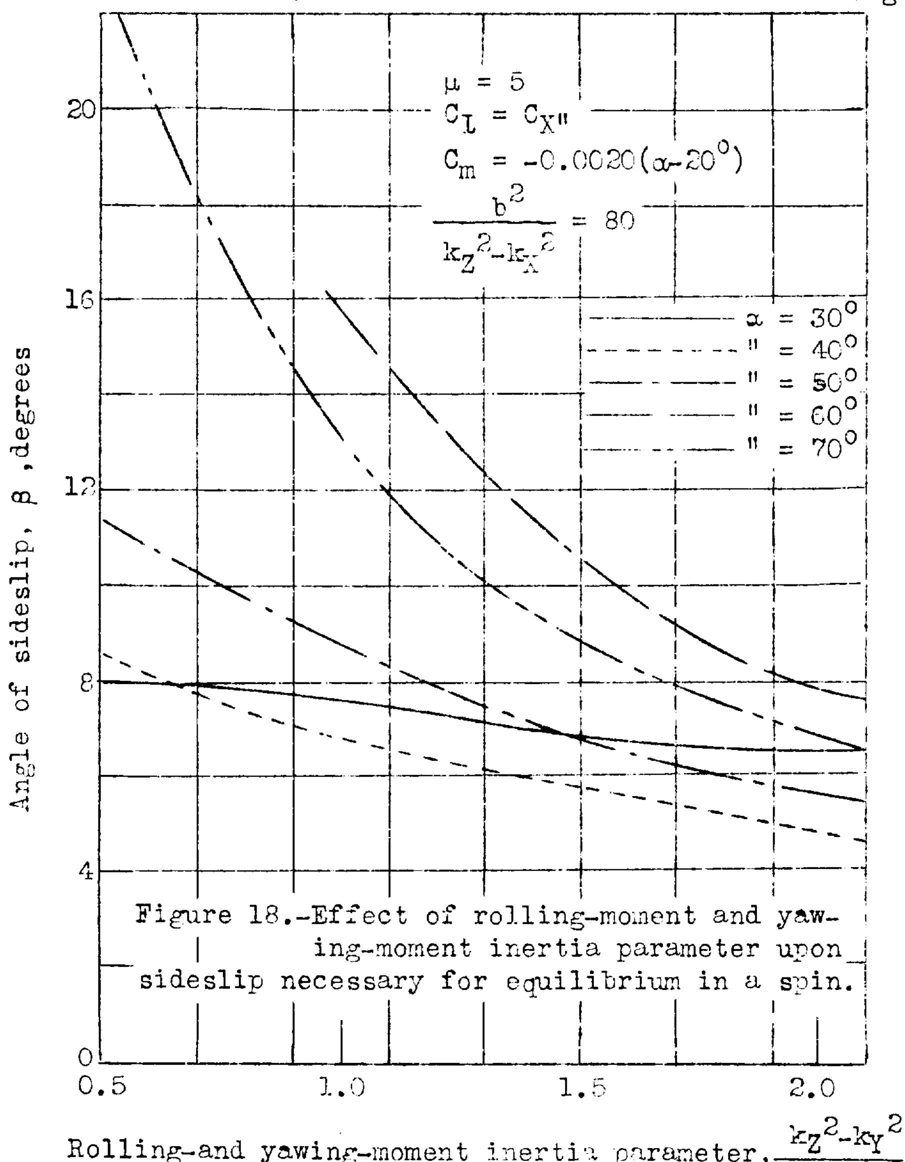


Figure 18.-Effect of rolling-moment and yawing-moment inertia parameter upon sideslip necessary for equilibrium in a spin.

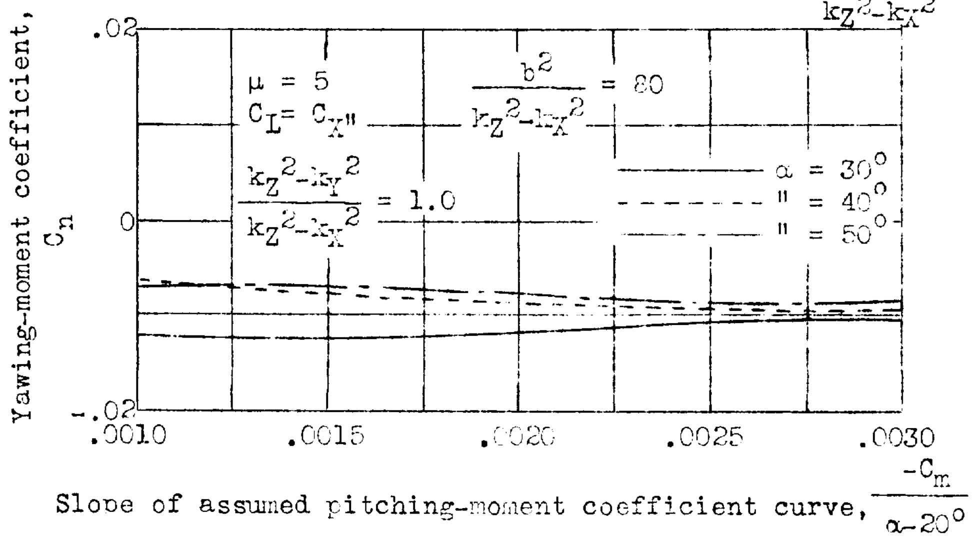
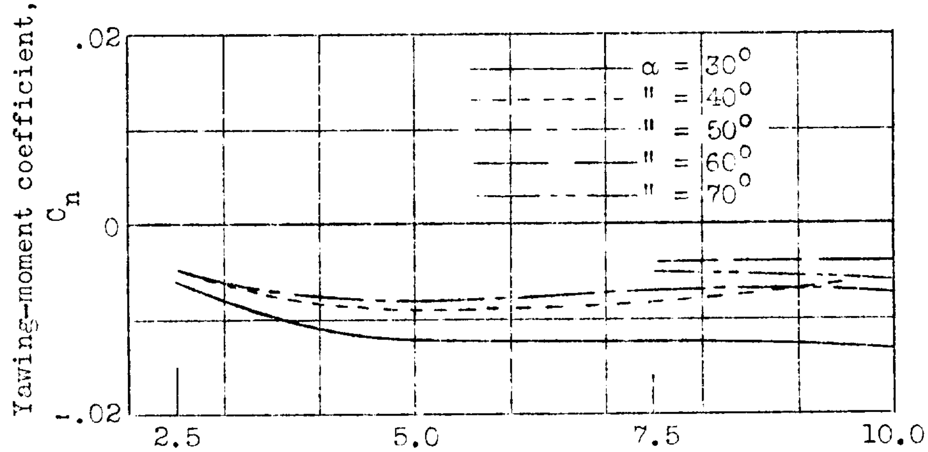


Figure 19.-Effect of pitching-moment coefficient upon yawing-moment coefficient that must be supplied by parts other than the wing for equilibrium in a spin.

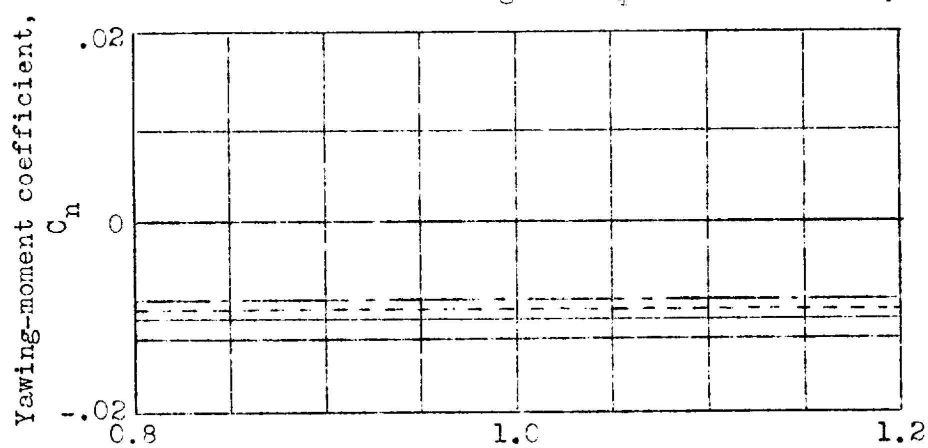


$C_m = -0.0020(\alpha-20°)$ $\frac{b^2}{k_Z{}^2-k_X{}^2} = 80$

$C_L = C_{X''}$

$\frac{k_Z{}^2-k_Y{}^2}{k_Z{}^2-k_X{}^2} = 1.0$

Figure 20.-Effect of relative density of airplane upon yawing-moment coefficient that must be supplied by parts other than the wing for equilibrium in a spin.



$\mu = 5$

$C_m = -0.0020(\alpha-20°)$

$\frac{k_Z{}^2-k_Y{}^2}{k_Z{}^2-k_X{}^2} = 1.0$

$\frac{b^2}{k_Z{}^2-k_X{}^2} = 80$

α = 30°
" = 40°
" = 50°

Figure 21.-Effect of lift coefficient upon yawing-moment coefficient that must be supplied by parts other than the wing for equilibrium in a spin.

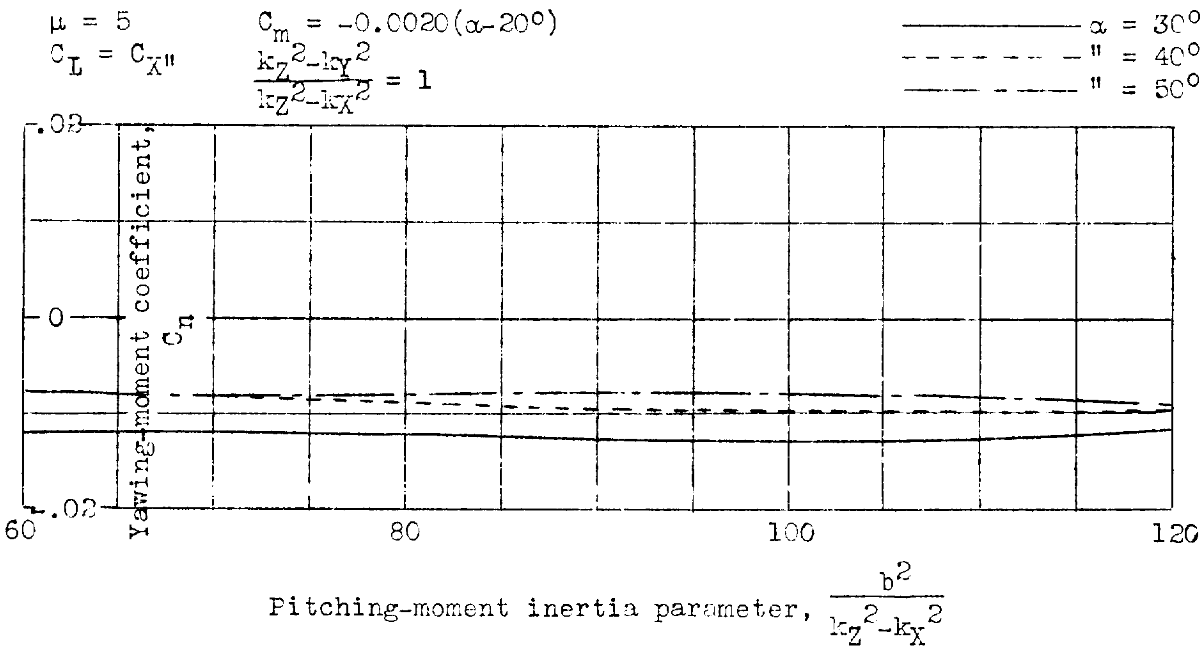


Figure 22.-Effect of pitching-moment inertia parameter upon yawing-moment coefficient that must be supplied by parts other than the wing for equilibrium in a spin.

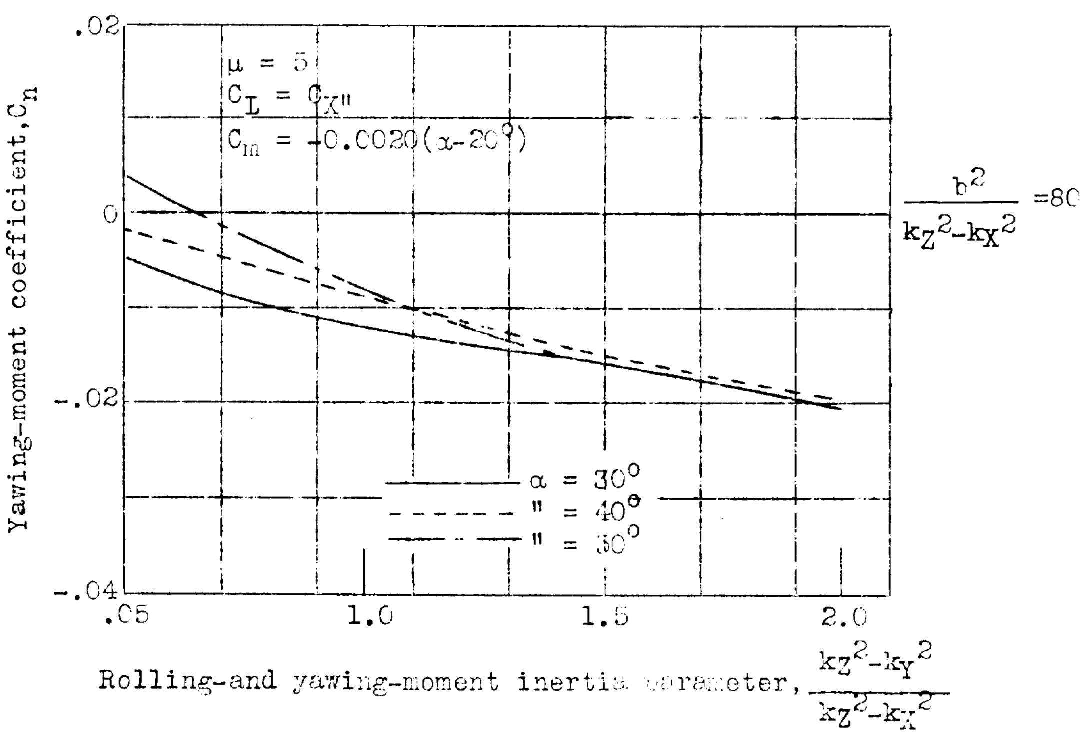


Figure 23.-Effect of rolling-moment and yawing-moment inertia parameter upon yawing-moment coefficient that must be supplied by parts other than the wing for equilibrium in a spin.