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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 517

# THE AERODYNAMIC FORCES AND MOMENTS ON A SPINNING MODEL OF THE F4B-2 AIRPLANE AS MEASURED BY THE SPINNING BALANCE

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## SUMMARY

The aerodynamic forces and moments on a 1/12-scale model of the F4B-2 airplane were measured with the spinning balance in nine spinning attitudes with three sets of tail surfaces, namely, F4B-2 surfaces; F4B-4 fin and F4B-3 rudder with F4B-2 stabilizer; F4B-4 fin and F4B-3 rudder with rectangular stabilizer; and with all tail surfaces removed. In one of these attitudes ($\alpha = 46^\circ\ 48'$; $\beta = 0^\circ\ 42'$) measurements were made to determine the effect upon the forces and moments of independent and of simultaneous displacements of the rudder and elevator for two of the sets of tail surfaces. Additional measurements were made for a comparison of model and full-scale data for six attitudes that were determined from flight tests with various control settings.

The characteristics were found to vary in the usual manner with angle of attack and sideslip. The F4B-2 surfaces were quite ineffective as a source of yawing moments. The F4B-4 fin and F4B-3 rudder with the F4B-2 stabilizer gave a greater damping yawing moment when controls were against the spin than did the F4B-2 surfaces but otherwise there was little difference. Substitution of a rectangular stabilizer for the F4B-2 stabilizer made no appreciable difference in the coefficients.

Values of rolling- and yawing-moment coefficients as found from model tests were consistently larger in a sense to oppose the spin than are the full-scale values. The average differences were: in rolling-moment coefficient, 0.02; in yawing-moment coefficient (neglecting one case of extreme difference), 0.006. Further comparisons with other airplane types are necessary before final conclusions can be drawn as to the relations between model and full-scale spin measurements.

## INTRODUCTION

The tests described in this report were made as part of an investigation of the spinning characteristics of the F4B-2 airplane conducted at the request of the Bureau of Aeronautics, Navy Department. This airplane had exhibited dangerous spinning characteristics in the hands of service pilots and it was desired to find how this fault could be eliminated.

An extensive program of flight tests was being carried out and it was thought advisable to make tests of a model of the airplane with the spinning balance to supplement the flight data and also to provide further checks between full-scale and model measurements of spins. The present report is confined to the wind-tunnel tests; the flight tests will be reported later. Two modifications to the tail were tested in an endeavor to improve the characteristics without drastic alteration of the airplane. A third modification was considered, i.e., movement of the stabilizer to the top of the fin; for reasons of convenience tests with such an arrangement were made on a different model and have been reported in reference 1.

## APPARATUS AND MODELS

The tests were made with the spinning balance (reference 2) in the N.A.C.A. 5-foot open-throat vertical tunnel (reference 3). The spinning balance measures all six components of the aerodynamic forces and moments upon a model moving with respect to the air as does an airplane when spinning.

The 1/12-scale model of the F4B-2 airplane was furnished by the Navy Department. (See fig. 1.) It was of mahogany and wire construction and was fitted with a clamp for attachment to the spinning balance. The trailing edge of the upper wing was cut away at the center section to permit installation on the balance but it is thought that the cut-out had no appreciable effect upon the characteristics in spinning attitudes.

The model was originally fitted with tail surfaces representing those of the F4B-2 airplane (fig. 2). An extra set of vertical surfaces (fig. 3) was constructed to represent the F4B-4 fin and the F4B-3 rudder and used for one series of tests in place of the surfaces furnished. (The F4B-3 rudder was used because such a rudder was available for flight tests. It differed but slightly from the F4B-4 rudder, as indicated in figure 3, and will be referred to as the "F4B-4 rudder" in the remainder of the text.) In addition, a rectangular stabilizer was built and tested in combination with the F4B-4 fin and rudder (fig. 3). The general dimensional characteristics of the model were:

| | | |
|---|---|---|
| Wing area, upper | 142 | sq.in. |
| Wing area, lower | 93.7 | sq.in. |
| Wing span, upper | 30.0 | in. |
| Wing span, lower | 26.3 | in. |
| Wing chord, upper | 5.0 | in. |
| Wing chord, lower | 3.75 | in. |
| Wing section | Boeing 106 | |
| Gap/chord ratio, (based on the mean aerodynamic chord) | 1.02 | |
| Stagger | 2.67 | in. |
| Decalage | none | |
| Dihedral, upper wing | none | |
| Dihedral, lower wing | 2° | |
| Distance, c.g. to rudder hinge | 12.8 | in. |
| Area, F4B-2 stabilizer | 15.9 | sq.in. |
| Area, rectangular stabilizer | 15.9 | sq.in. |
| Area, elevator | 18.0 | sq.in. |
| Area, F4B-2 fin | 1.8 | sq.in. |
| Area, F4B-2 rudder | 8.2 | sq.in. |
| Area, F4B-4 fin | 5.55 | sq.in. |
| Area, F4B-3 rudder | 8.65 | sq.in. |

## TESTS

Tests were made with various tail combinations in the nine different attitudes given in table I. The case where $\alpha = 46^\circ\ 48'$ and $\beta = 0^\circ\ 42'$ was a flight attitude with the F4B-4 fin and rudder, and the F4B-2 stabilizer. The other eight attitudes were arrived at by calculations of $\Omega/V$ and radius based on the physical characteristics of the airplane and the following assumptions:

$-C_Z = C_R$, when $\beta = 0^\circ$

$C_R$ is constant at its value as given in flight when

$\alpha = 46^\circ\ 48'$ and $\beta = 0^\circ\ 42'$

$$\tfrac{1}{2}\ \rho\ V^2\ S\ C_R\ \sin\alpha = W$$

$$\tfrac{1}{2}\ \rho\ V^2\ S\ C_R\ \cos\alpha = (\Omega^2\ \tfrac{W}{g})\ (\text{radius})$$

$$\tfrac{1}{2}\ \rho\ V^2\ b\ C_m = \Omega^2\ \sin\alpha\ \cos\alpha\ (A-C)$$

$$\frac{d\ C_m}{d\alpha} = -\ 0.0036$$

$C_m$ does not change with sideslip

$C_m$ is independent of $\frac{\Omega b}{2V}$

Change of sideslip at a given angle of attack is accomplished by a single rotation of model about the lift vector.

The foregoing symbols are defined as follows:

$\alpha$, angle of attack at the c.g.

$\beta$, angle of sideslip at the c.g. $(\sin^{-1} \frac{v}{V})$.

$v$, relative velocity of the airplane along its (Y) span axis, positive when toward the right.

$V$, resultant velocity of the c.g.

$\Omega$, resultant angular velocity.

Radius, radius of c.g.

$C_R = \dfrac{R}{\frac{1}{2}\,\rho\,V^2\,S}$, absolute coefficient of resultant force.

R, resultant force.

S, wing area.

W, weight of airplane.

b, span.

$C_m = \dfrac{M}{\frac{1}{2}\,\rho\,V^2\,S\,b}$, absolute coefficient of pitching moment.

A, moment of inertia about (X) thrust axis.

C, moment of inertia about (Z) normal axis.

The tail combinations tested in these attitudes were: all tail surfaces removed; F4B-2 surfaces, rudder and elevator with the spin and neutral; F4B-4 fin and rudder with F4B-2 stabilizer, rudder and elevator with the spin and neutral; and F4B-4 fin and rudder with the rectangular stabilizer, rudder, and elevator with the spin and neutral.

In the above-mentioned flight spinning attitude ($\alpha = 46^\circ\ 48'$, $\beta = 0^\circ\ 42'$) wind-tunnel tests were made with the elevator up, neutral, and down when the rudder was in each of the positions: full with the spin, neutral, and full against the spin. Two sets of tail surfaces were tested with these control positions: (1) the F4B-2 surfaces, and (2) the F4B-4 fin and rudder with the F4B-2 stabilizer. Aileron and fin settings were 0° and the stabilizer chord was parallel to the thrust line in all cases.

Six additional tests were made with the control settings and the attitudes given in table II. These attitudes were obtained in flight with the corresponding control settings.

All tests were made at a tunnel air speed ($w''$) of 65 feet per second, giving a Reynolds Number of 147,000 based on the mean chord.

The results, except $C_m$, are given in the form of absolute coefficients referred to airplane axes.

$$C_X = \frac{X}{\frac{1}{2}\rho V^2 S} \qquad C_Y = \frac{Y}{\frac{1}{2}\rho V^2 S}$$

$$C_Z = \frac{Z}{\frac{1}{2}\rho V^2 S} \qquad C_l = \frac{L}{\frac{1}{2}\rho V^2 S b}$$

$$C_m = \frac{M}{\frac{1}{2}\rho V^2 S b} \qquad C_n = \frac{N}{\frac{1}{2}\rho V^2 S b}$$

where

X, force along thrust axis, positive forward.

Y, force along span axis, positive to right.

Z, force along normal axis, positive downward.

L, moment about thrust axis, positive when it tends to lower right wing.

M, moment about span axis, positive when it tends to raise nose of fuselage.

N, moment about normal axis, positive when it tends to cause nose of fuselage to go to the right.

Pitching-moment coefficient is based on the span rather than on the chord to make it more readily comparable with the other coefficients. Conversion may be made to standard form by use of the ratio $\frac{b}{c} = 6.86$. Data are given with the proper signs for right spins in all cases.

Values of the coefficients of all six force and moment components for the F4B-2 with controls with the spin, controls neutral, and tail surfaces removed are plotted against $\alpha$ and $\beta$ in figures 4 to 9, inclusive.

Values of $C_m$ and $C_n$ against elevator movement and against rudder movement are plotted for the case where $\alpha = 46^\circ\ 48'$ and $\beta = 0^\circ\ 42'$ for the F4B-2 surfaces in figure 10 and for the F4B-4 fin and rudder combined with the F4B-2 stabilizer in figure 11.

Table III gives a comparison between full-scale and model values of $C_R$, $C_l$, $C_m$, and $C_n$. All of the flight spins that have been tested on the balance are included. Two of the comparisons are for the NY-1 airplane model tests reported in reference 2.

The discrepancies between flight and wind-tunnel data are revealed in table III and will be considered in the discussion. Individual experimental values obtained with the spinning balance are believed to be accurate within the following limits:

| | |
|---|---|
| $C_X$ | ±0.05 |
| $C_Y$ | ±.05 |
| $C_Z$ | ±.1 |
| $C_l$ | ±.005 |
| $C_m$ | ±.01 |
| $C_n$ | ±.005 |

The plotted data (figs. 4 to 11, inclusive), which are faired as smooth curves through selected points, are believed to be more accurate than the individual experimental limits because the points were chosen after careful consideration of similarity between curves and after check tests had been made in cases of uncertainty.

## DISCUSSION

The curves of variations of the various coefficients with $\alpha$ and $\beta$ are quite normal and require no special discussion. All models that have been tested with the spinning balance have shown increases of $C_Z$ and $C_m$ in the negative sense, increases of $C_n$ in a sense to oppose the spin with increase of angle of attack, and no consistent changes in $C_X$, $C_Y$, and $C_l$ with the same independent variable. Similarly, the models have, in general, shown increases of $C_Y$ and $C_n$ in a sense to oppose the spin and an increase of $C_l$ in a sense to aid the spin with change of sideslip from inward to outward. The coefficients $C_X$, $C_Z$, and $C_m$ have shown no consistent variation with $\beta$.

Comparison of the values of $C_n$ with the tail surfaces removed with those obtained with the surfaces in place reveals that the F4B-2 fin and rudder were quite ineffective as sources of yawing moment in most of the attitudes tested. The same was found to be true of the F4B-4 fin and rudder with both the F4B-2 and the rectangular stabilizers. The curves of variations with $\alpha$ and $\beta$ for the F4B-4 fin and rudder are not included as they differ but slightly from those for the F4B-2 surfaces.

The curves showing variation of $C_m$ and $C_n$ with elevator and rudder movements are of some interest. The diving moment increased in a normal manner as the elevator was moved down. In the case of the F4B-2 surfaces, movement of the rudder from with the spin to against the spin also produced considerable increase in diving moment. Yawing moments were greatest with the elevator neutral, except when the rudder was with the spin, for both sets of surfaces. The only striking feature of the yawing-moment curves was that movement of the F4B-2 rudder from neutral to against the spin resulted in a reduction of the yawing moment; whereas the opposite was true for the F4B-3.

Table III is included for a comparison between the wind-tunnel results and the flight results soon to be published. As soon as feasible, additional measurements are to be made comparing model and full-scale data for spins of the XN2Y-1 and of other airplanes.

It is interesting to note that the model rolling- and yawing-moment coefficients are consistently greater in a sense to oppose the spin than are the full-scale values. It appears that the full-scale values can be estimated with fair accuracy by adding 0.02 to the rolling-moment coefficients and 0.006 to the yawing-moment coefficients obtained for the models. Values of the pitching moments for the model are neither consistently greater nor less than the full-scale values, although individual differences are in several cases rather large. Resultant-force coefficients given by the models are less than the full-scale values with one exception. If one case of extreme difference be neglected, the average difference between model and full-scale results is 0.075.

## CONCLUSIONS

1. The vertical surfaces of the F4B-2 are quite ineffective in spinning attitudes.

2. Substitution of the F4B-4 fin and F4B-3 rudder for the F4B-2 surfaces should make little difference in the spin. Recovery will be more positive when the controls are against the spin than it will with the F4B-2 surfaces.

3. Changing the plan form of the stabilizer to rectangular will give no improvement of spinning characteristics of the F4B-2 airplane.

4. Indications are that full-scale values of rolling and yawing moments may be estimated by adding constant correction factors to the model values. This conclusion is tentative and needs further confirmation.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 29, 1934.

## REFERENCES

1. Bamber, M. J., and Zimmerman, C. H.: Effect of Stabilizer Location upon Pitching and Yawing Moments in Spins as Shown by Tests with the Spinning Balance. T.N. No. 474, N.A.C.A., 1933.

2. Bamber, M. J., and Zimmerman, C. H.: The Aerodynamic Forces and Moments Exerted on a Spinning Model of the "NY-1" Airplane as Measured by the Spinning Balance. T.R. No. 456, N.A.C.A., 1933.

3. Wenzinger, Carl J., and Harris, Thomas A.: The Vertical Wind Tunnel of the National Advisory Committee for Aeronautics. T.R. No. 387, N.A.C.A., 1931.

## TABLE I

### Calculated Spinning Attitudes

| $\alpha$ | $\beta$ | Radius | $\frac{\Omega}{w''}$ | $\frac{p}{\Omega}$ | $\frac{q}{\Omega}$ | $\frac{r}{\Omega}$ |
|---|---|---|---|---|---|---|
| | | inches | | | | |
| 40° | 7° 30° | 7.41 | 0.2002 | 0.7334 | 0.2515 | 0.6305 |
| 40° | 0° | 7.41 | .2002 | .7522 | .1230 | .6473 |
| 40° | -10° | 7.41 | .2002 | .7567 | -.0512 | .6518 |
| 46° 48' | 10° 42' | 3.00 | .2910 | .6537 | .2549 | .7126 |
| [1]46° 48' | 0° 42' | 3.00 | .2910 | .6739 | .0828 | .7342 |
| 46° 48' | -9° 18' | 3.00 | .2910 | .6734 | -.0915 | .7336 |
| 60° | 10° | .99 | .4435 | .4871 | .2093 | .8478 |
| 60° | 0° | .99 | .4435 | .4977 | .0364 | .8665 |
| 60° | -10° | .99 | .4435 | .4935 | -.1377 | .8588 |

[1] Flight attitude

## TABLE II

### Flight Spinning Attitudes

| $\alpha$ | $\beta$ | Radius | $\frac{\Omega}{w''}$ | $\frac{p}{\Omega}$ | $\frac{q}{\Omega}$ | $\frac{r}{\Omega}$ | $\delta_a$ | $\delta_e$ | $\delta_r$ |
|---|---|---|---|---|---|---|---|---|---|
| | | inches | | | | | | | |
| 49° 15' | -3° 02' | 3.37 | 0.306 | 0.6492 | 0.0323 | 0.7600 | 0° | $27\frac{1}{4}$° U[2] | 29° W |
| 53° 19' | -4° 35' | 1.84 | .463 | .5956 | -.0090 | .8032 | 0° | $20\frac{1}{4}$° D | 29° W |
| 47° 43' | 7° 55' | 2.77 | .344 | .6489 | .2150 | .7299 | R $23\frac{1}{2}$° U<br>L $15\frac{1}{2}$° D | $27\frac{1}{4}$° U | 29° W |
| [1]43° 1' | -2° 26' | 2.99 | .409 | .7272 | .0589 | .6839 | 0° | 7° U | 0° |
| 49° 7' | -7° 19' | 3.42 | .335 | .6537 | -.0323 | .7561 | R $8\frac{3}{4}$° D<br>L $16\frac{3}{4}$° U | $27\frac{1}{4}$° U | 29° W |
| 37° 4' | 17° 03' | 3.18 | .361 | .7319 | .3827 | .5639 | 0° | $27\frac{1}{4}$° U | 29° A |

[1] This test made with F4B-2 tail
All others made with F4B-4 fin, F4B-3 rudder, and F4B-2 stabilizer.

[2] U, up
D, down
R, right
L, left
W, with
A, against

## TABLE III

### Comparison Between Full-Scale and Model Results

| TYPE | $\alpha$ | $\beta$ | $\delta_a$ | $\delta_e$ | $\delta_r$ | $C_R$ | | $C_l$ | | $C_m$ | | $C_n$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | F[1] | M[2] | F | M | F | M | F | M |
| F4B | 46° 48' | 0° 42' | 0° | 27-1/4°U | 29°W | 1.41 | 1.25 | 0.002 | -0.018 | -0.042 | -0.047 | 0.003 | -0.003 |
| F4B | 49° 15' | -3° 2' | 0° | 27-1/4°U | 29°W | 1.18 | 1.22 | .001 | -.011 | -.048 | -.061 | .001 | -.003 |
| F4B | 53° 19' | -4° 35' | 0° | 20-1/4°D | 39°W | 1.56 | 1.52 | -.001 | -.011 | -.105 | -.118 | -.001 | -.005 |
| F4B | 47° 43' | 7° 55' | R 23-1/2°U<br>L 15-1/2°D | 27-1/4°U | 29°W | 1.23 | 1.17 | .009 | -.007 | -.064 | -.051 | .011 | .006 |
| F4B | 43° 1' | -2° 26' | 0° | 7°U | 0° | 1.62 | 1.21 | .003 | -.037 | -.091 | -.058 | .004 | -.006 |
| F4B | 49° 7' | -7° 19' | R 8-3/4°D<br>L 16-3/4°U | 27-1/4°U | 29°W | 1.38 | 1.28 | -.001 | -.026 | -.063 | -.077 | -.002 | -.008 |
| F4B | 37° 4' | 17° 3' | 0° | 27-1/4°U | 29°A | 1.23 | 1.12 | .013 | -.020 | -.060 | -.055 | .024 | .004 |
| NY-1 | 46° 20' | -1° 43' | 0° | 33°U | 31.5°W | 1.47 | 1.30 | .006 | -.012 | -.070 | -.045 | .006 | -.010 |
| NY-1 | 50° 0' | 0° 30' | 0° | 33°U | 31.5°W | 1.41 | 1.41 | .012 | -.013 | -.078 | -.076 | .003 | -.006 |

[1] F, full scale

[2] M, model

Fig. 1

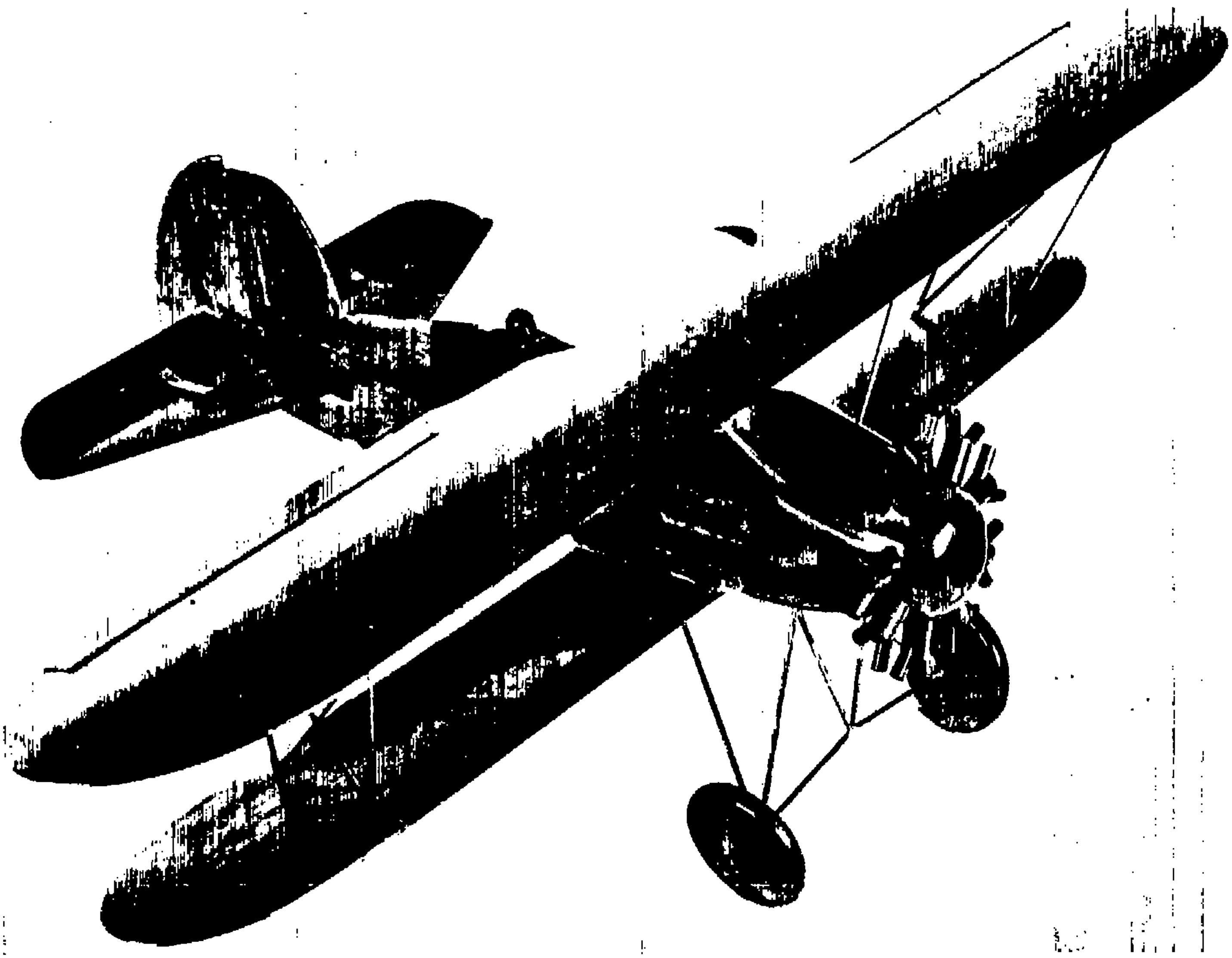

Figure 1.- The 1/12-scale model of the F4B-2 airplane with F4B-4 fin and F4B-3 rudder.

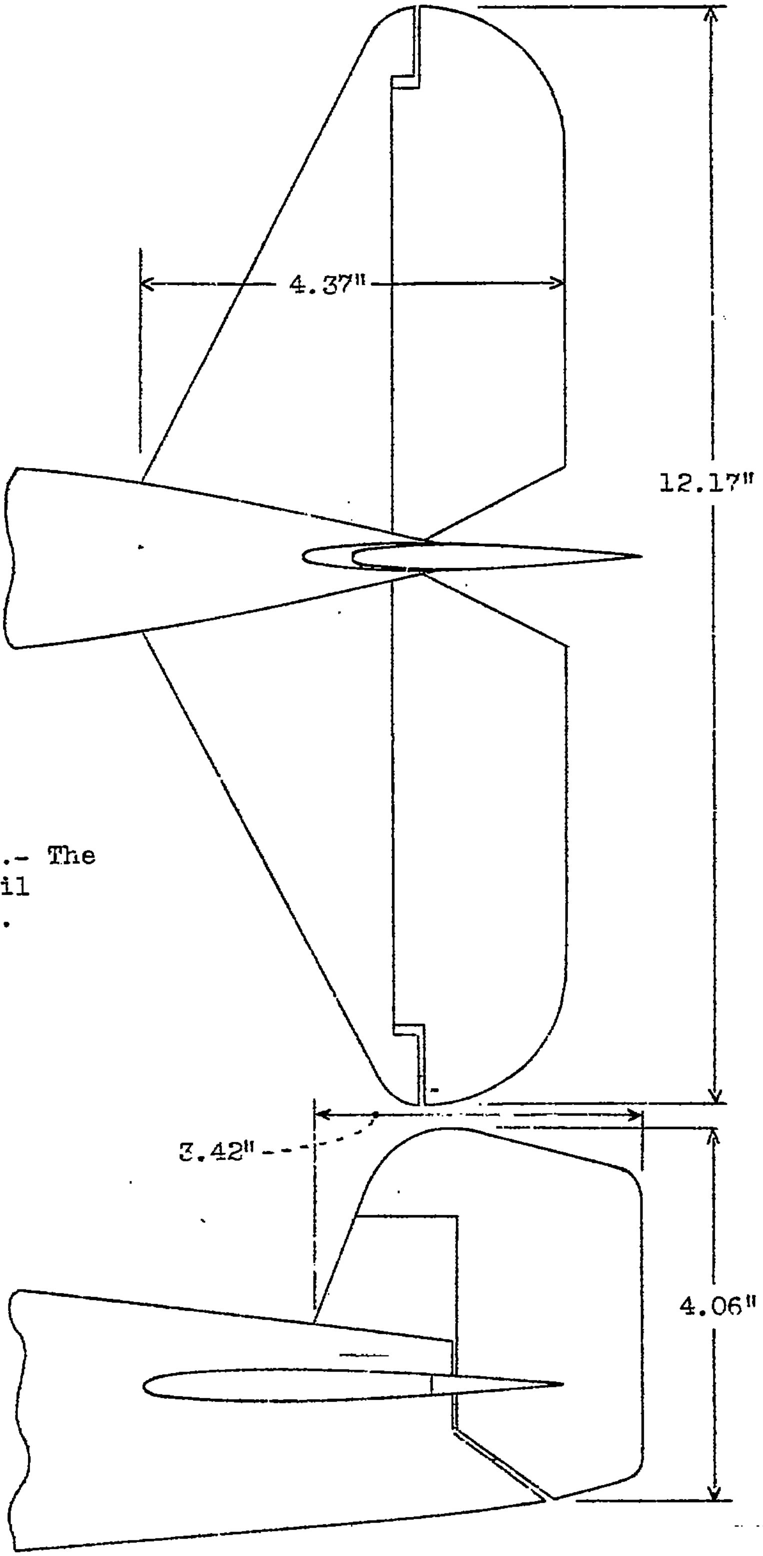

Figure 2.- The F4B-2 tail surfaces.

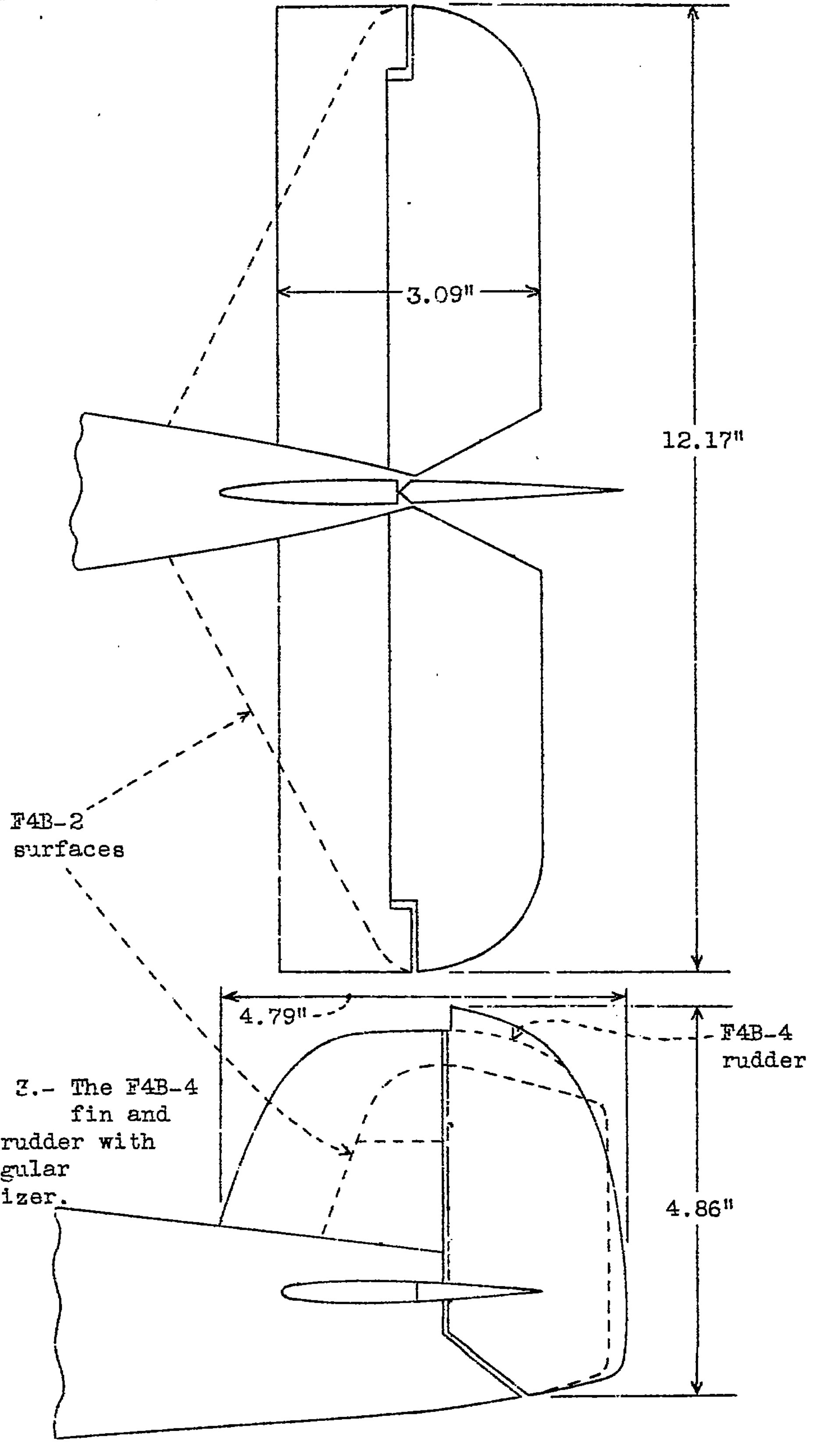

Figure 3.- The F4B-4 fin and F4B-3 rudder with rectangular stabilizer.

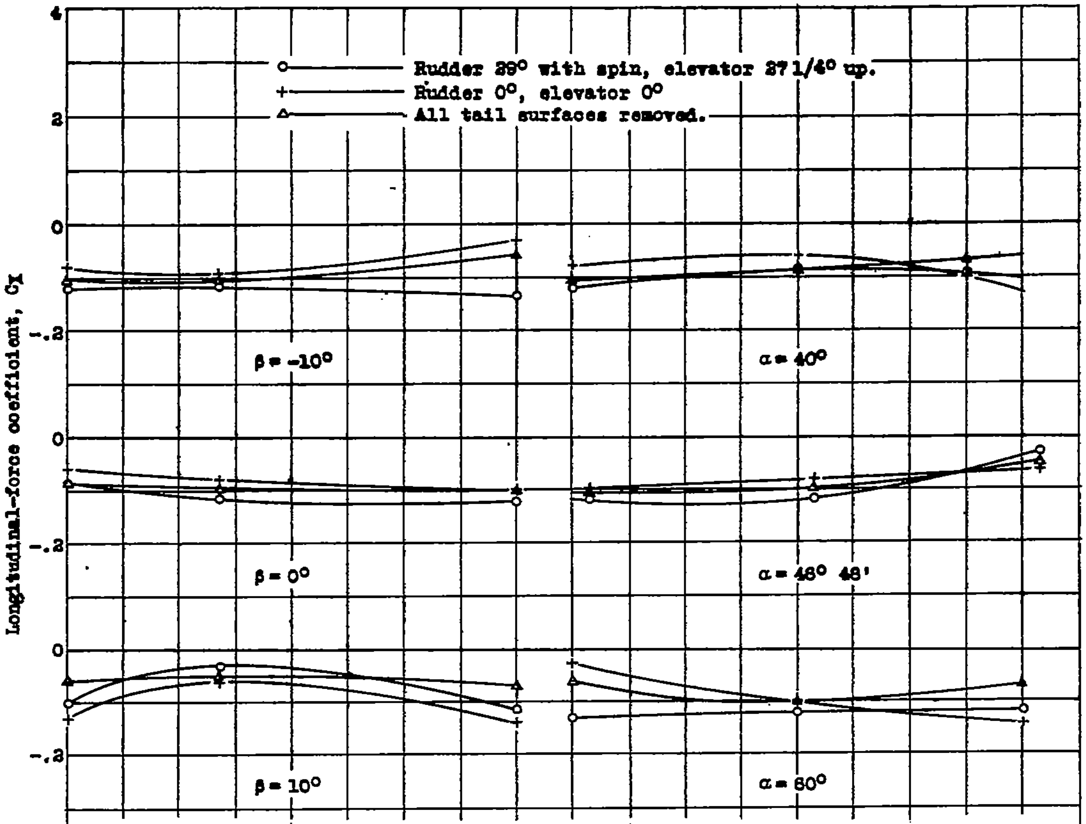

Figure 4.- Variation of $C_X$ with α and β. F4B-2 tail surfaces.

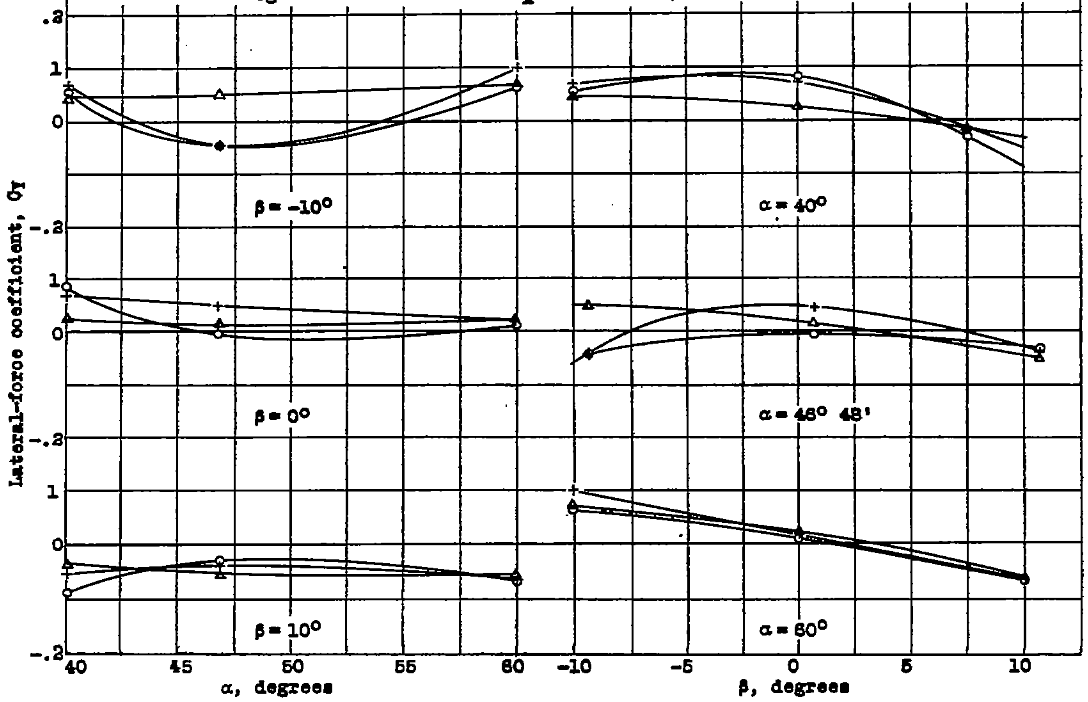

Figure 5.- Variation of $C_Y$ with α and β. F4B-2 tail surfaces.

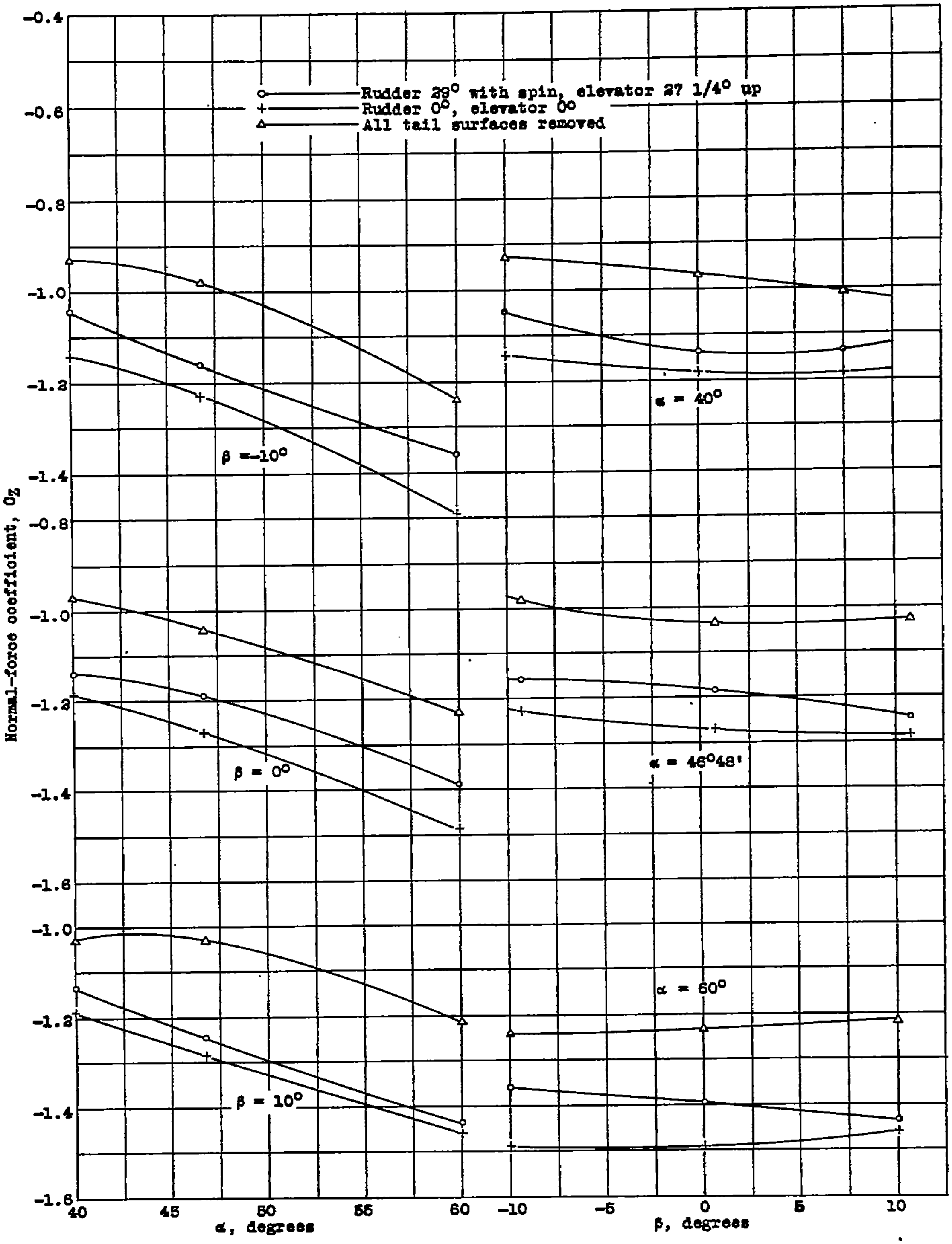

Figure 6.-Variation of $C_Z$ with α and β. F4B-2 tail surfaces.

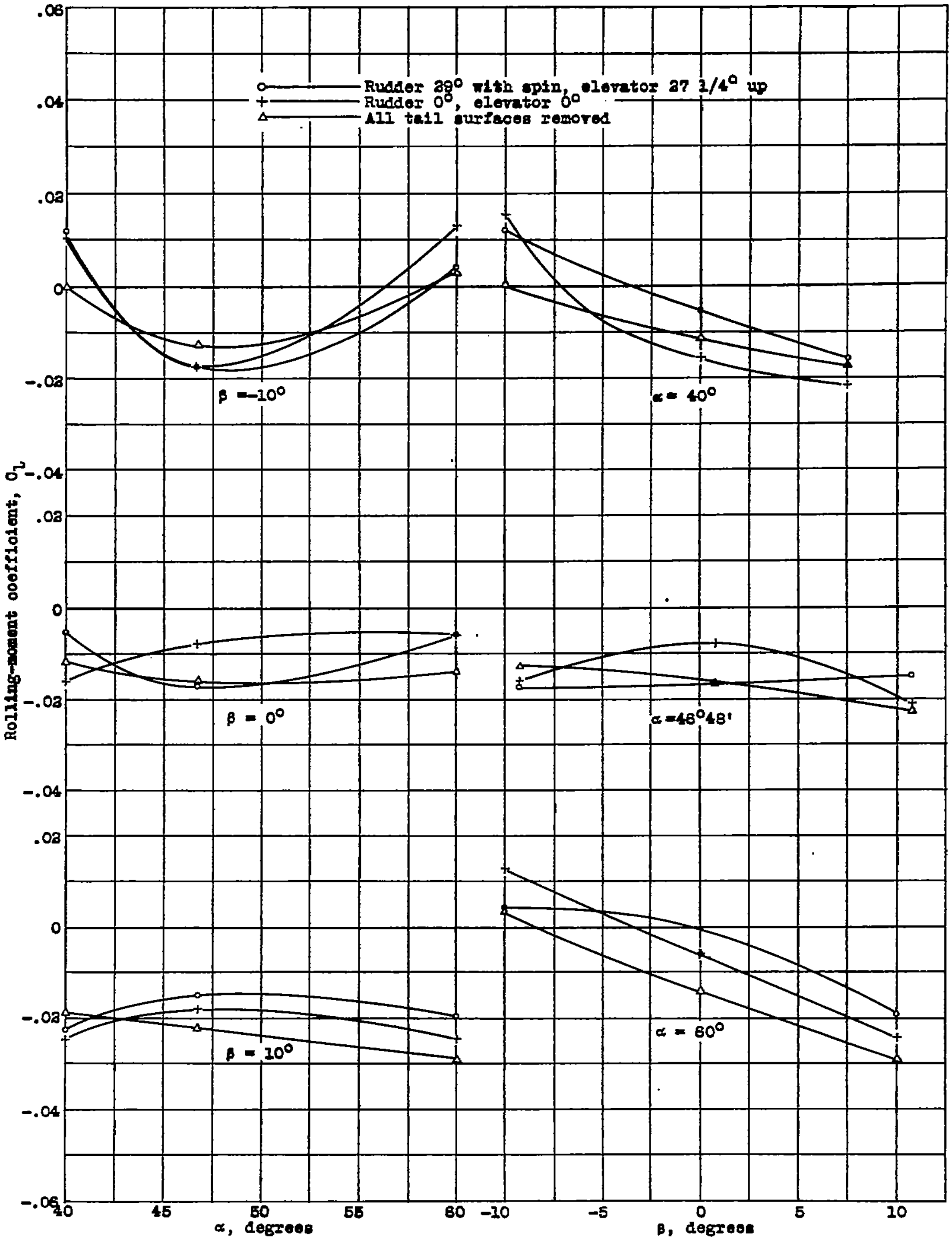

Figure 7.-Variation of $C_l$ with α and β. F4B-2 tail surfaces.

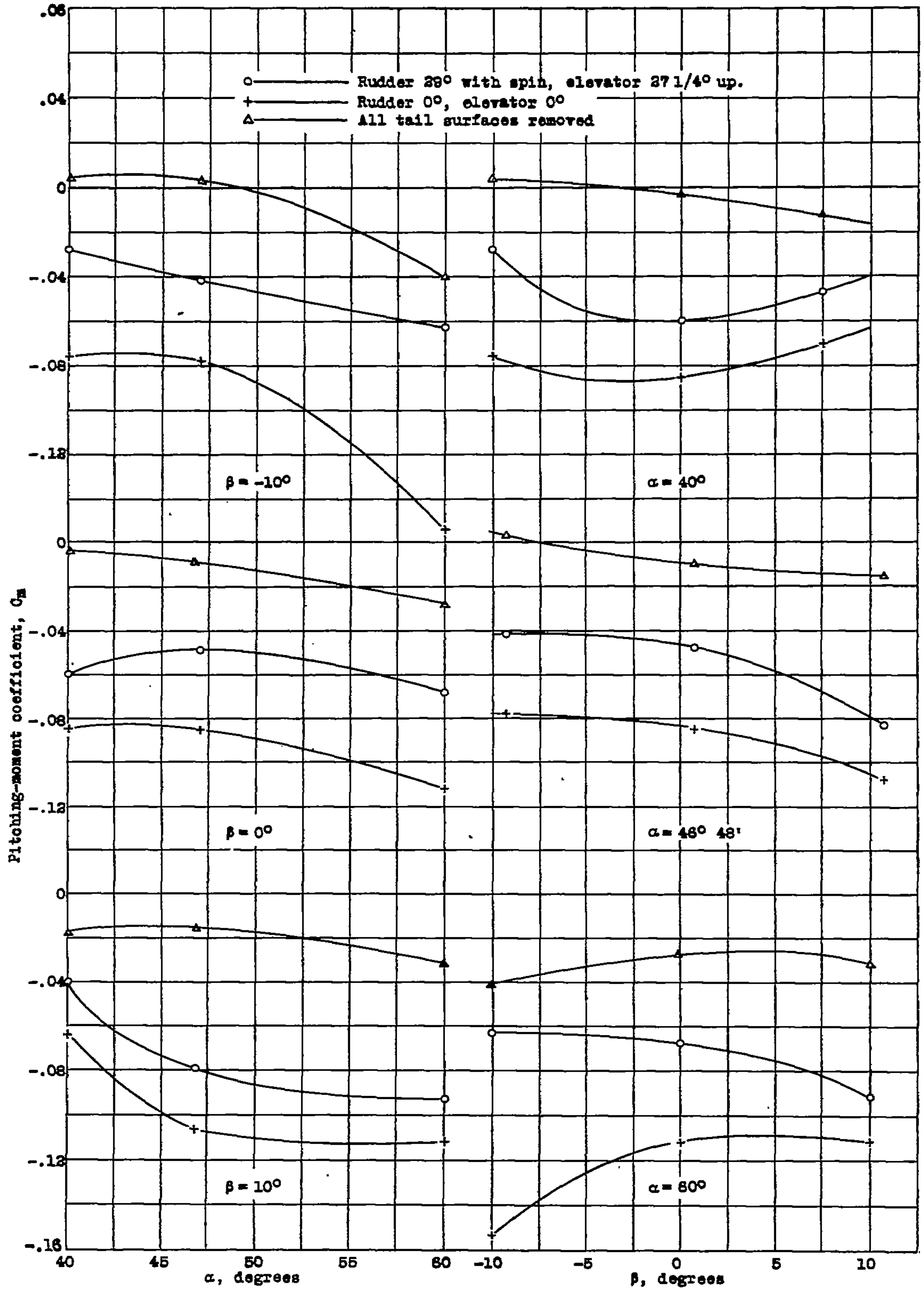

Figure 8.- Variation of $C_m$ with α and β. F4B-2 tail surfaces.

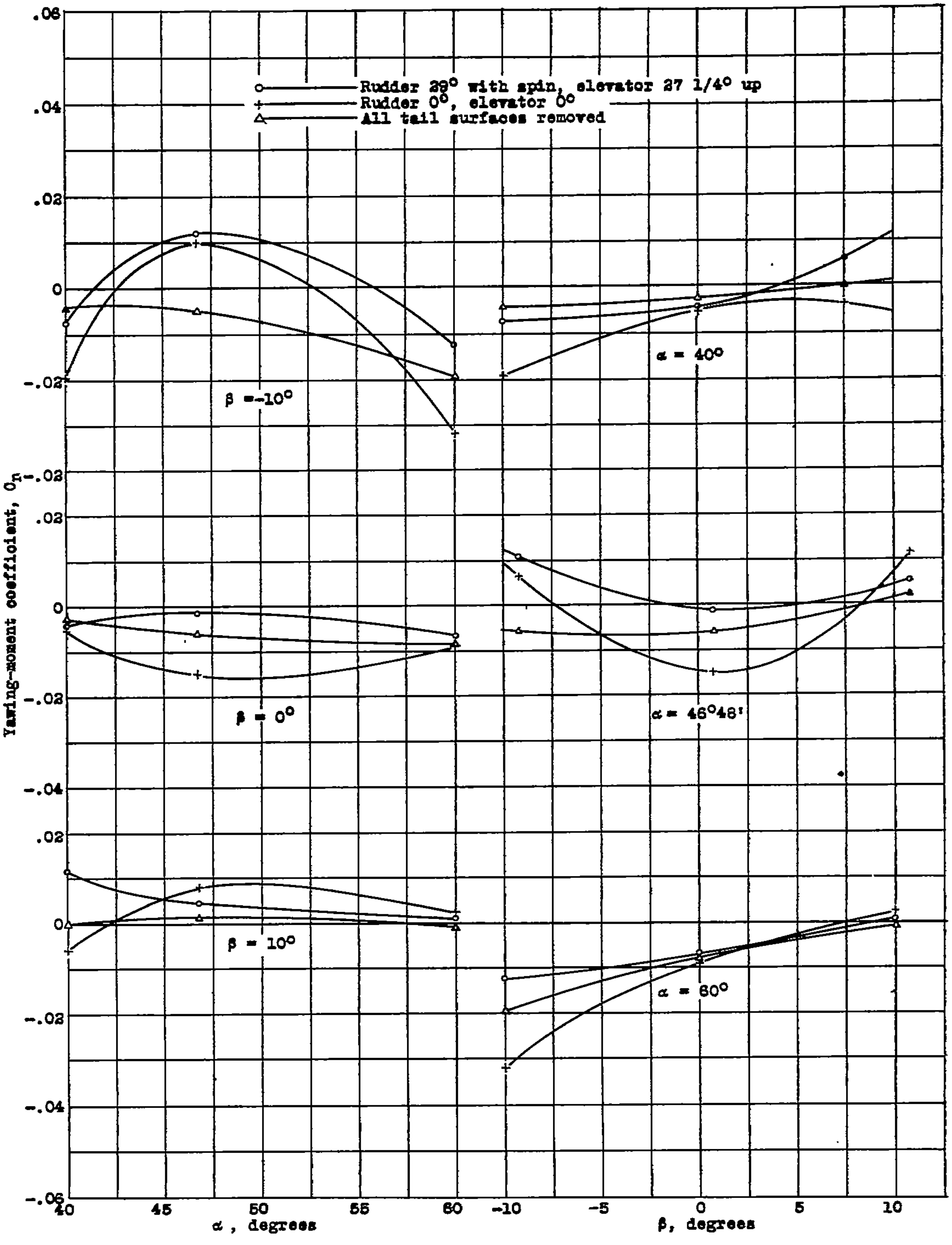

Figure 9.-Variation of $C_n$ with α and β. F4B-2 tail surfaces.

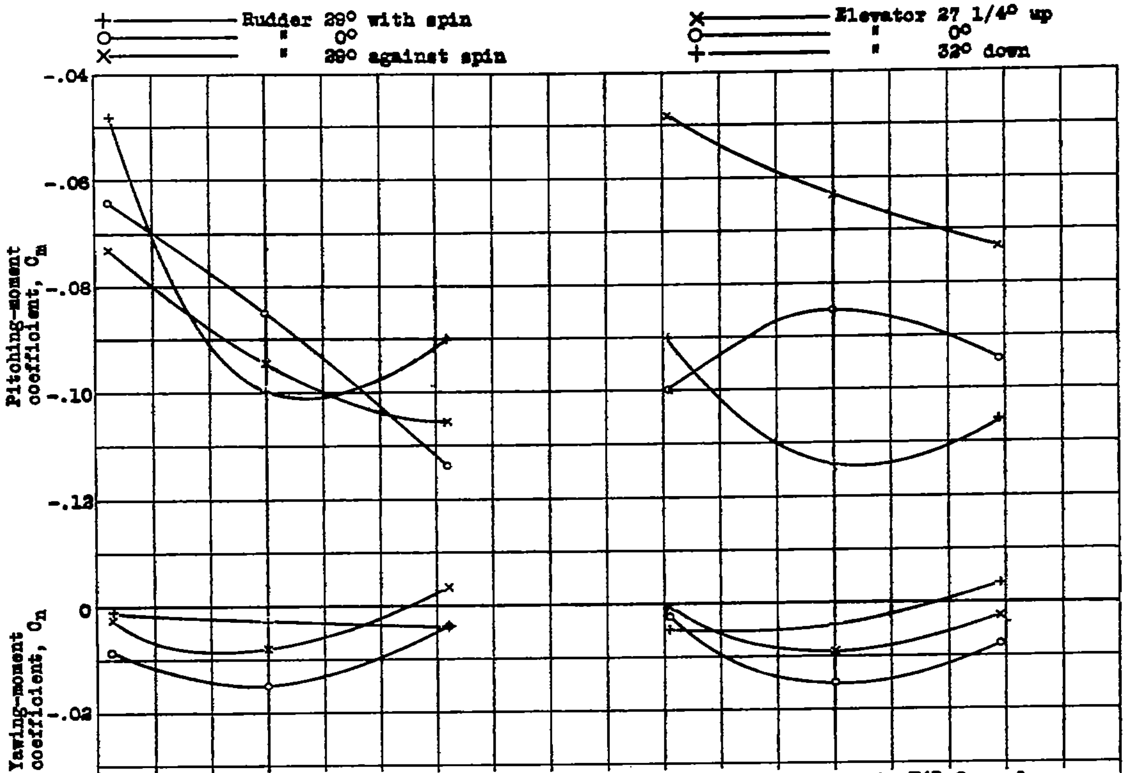

Figure 10.- Variation of $C_m$ and $C_n$ with rudder and elevator movement. F4B-2 surfaces, $\alpha$ = 46° 48' and $\beta$ = 0° 42'.

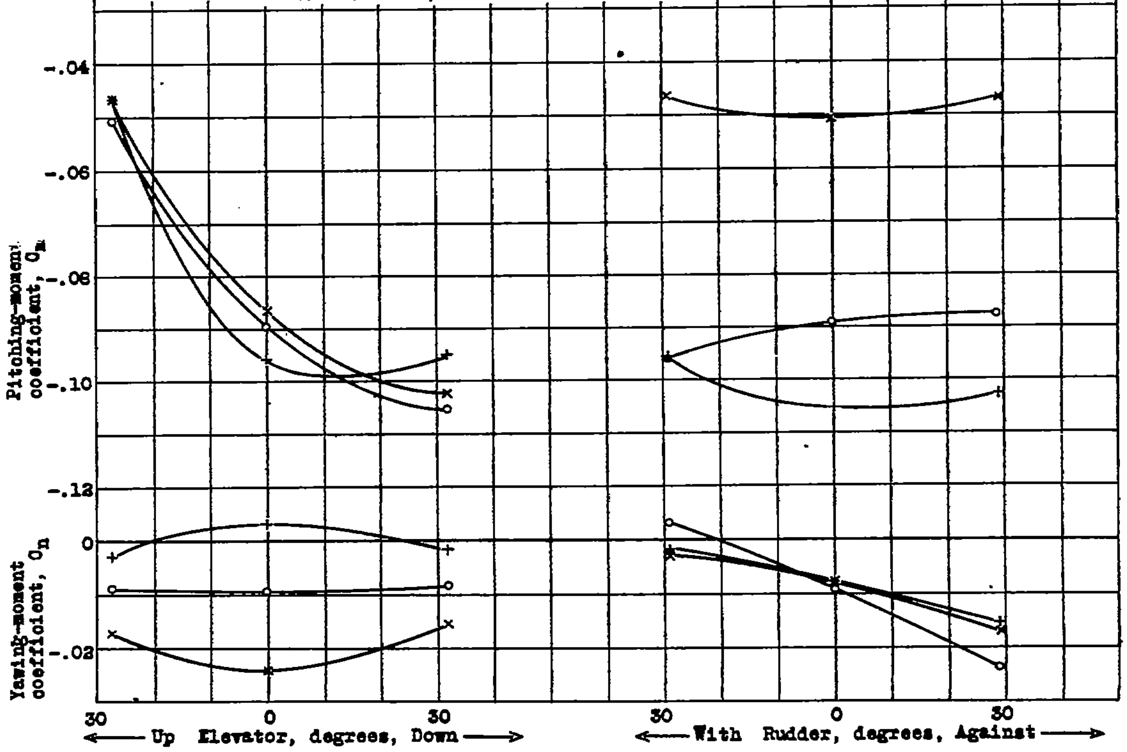

Figure 11.- Variation of $C_m$ and $C_n$ with rudder and elevator movement. F4B-4 fin and F4B-3 rudder with F4B-2 stabilizer, $\alpha$ = 46° 48' and $\beta$ = 0° 42'.