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THE EFFECT OF LATERAL AREA ON THE LATERAL STABILITY AND CONTROL CHARACTERISTICS OF AN AIRPLANE AS DETERMINED BY TESTS OF A MODEL IN THE LANGLEY FREE-FLIGHT TUNNEL

By Hubert M. Drake

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

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THE EFFECT OF LATERAL AREA ON THE LATERAL STABILITY AND CONTROL CHARACTERISTICS OF AN AIRPLANE AS DETERMINED BY TESTS OF A MODEL IN THE LANGLEY FREE-FLIGHT TUNNEL

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SUMMARY

The effects of large variations of lateral area on the lateral stability and control characteristics of a free-flying model when ailerons are used as the principal control have been determined by flight tests in the Langley free-flight tunnel. The effects of the lateral-force parameter C_{Y_β} (rate of change of lateral-force coefficient with angle of sideslip) were investigated for a wide range of values of the directional-stability parameter C_{n_β} (rate of change of yawing-moment coefficient with angle of sideslip) and the rotary-damping-in-yaw parameter C_{n_r} (rate of change of yawing-moment coefficient with yawing angular velocity).

Although large values of C_{Y_β} were found to increase the lateral stability, a definitely undesirable effect was obtained with large values of this parameter when ailerons were used to raise a low wing or to make a banked turn. With large amounts of lateral area the adverse yaw accompanying aileron rolls created adverse side forces of sufficient magnitude to interfere with the aileron control. This action was particularly objectionable for low values of C_{n_β} and C_{n_r}. It is indicated that decreasing C_{Y_β} will improve the over-all lateral flight behavior.

INTRODUCTION

Theoretical considerations (reference 1) have indicated that the stability of an airplane is affected by the lateral-force parameter C_{Y_β} (rate of change of lateral-force coefficient with angle of sideslip). This parameter has been given little consideration in the past but, with the recent trend toward cleaner airplanes with small lateral area, particularly tailless airplanes, interest in the effects of lateral area has increased.

In order to determine some of the over-all effects of changes in lateral area on lateral stability and control, an investigation with a free-flying dynamic model has been made in the Langley free-flight tunnel. It was already known that increases in lateral area would increase the ease with which flat turns could be made by use of the rudder and no attempt was consequently made to measure this effect; rather, the interest was centered upon the behavior of the model in maneuvers either with ailerons alone or rudder coordinated with ailerons.

SYMBOLS AND COEFFICIENTS

The forces and coefficients are measured with reference to the stability axes. The stability system of axes is defined as an orthogonal system of axes having their origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry. A diagram of these axes showing the positive directions of forces and moments is presented as figure 1.

C_L lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$

C_l rolling-moment coefficient $\left(\frac{\text{Rolling moment}}{qSb}\right)$

C_n yawing-moment coefficient $\left(\frac{\text{Yawing moment}}{qSb}\right)$

C_Y lateral-force coefficient $\left(\frac{\text{Lateral force}}{qS}\right)$

S wing area, square feet

b wing span, feet

q dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

V airspeed, feet per second

ρ mass density of air, slugs per cubic foot

β angle of sideslip, degrees

ψ angle of yaw, degrees (for force-test data, $\psi = -\beta$)

L rolling moment, about X-axis

N yawing moment, about Z-axis

M pitching moment, about Y-axis

δ_r rudder deflection

δ_e elevator deflection

α angle of attack

$T_{1/2}$ time for oscillation to damp to one-half amplitude

P period of lateral oscillation, seconds

k_X radius of gyration about X-axis, feet

k_Y radius of gyration about Y-axis, feet

$pb/2V$ helix angle generated by wing tip in roll, radians

p rolling angular velocity, radians per second

r yawing angular velocity, radians per second

C_{l_β} rate of change of rolling-moment coefficient with angle of sideslip, per degree $(\partial C_l/\partial\beta)$

C_{n_β} directional-stability parameter, that is, rate of change in yawing-moment coefficient with angle of sideslip, per degree $(\partial C_n/\partial\beta)$

C_{n_r} rotary-damping-in-yaw parameter, that is, rate of change of yawing-moment coefficient with yawing angular velocity, per radian $\left[\partial C_n/\partial\left(\frac{rb}{2V}\right)\right]$

C_{Y_β} lateral-force parameter, that is, rate of change of lateral-force coefficient with angle of sideslip, per degree $(\partial C_Y/\partial\beta)$

APPARATUS

The investigation was conducted in the Langley free-flight tunnel, a complete description of which is given in reference 2. A photograph of the test section of the tunnel with the model in flight is given as figure 2. Force tests to determine the static stability characteristics of the model were made on the free-flight-tunnel six-component balance (described in reference 3), which measures moments and forces about the stability axes.

The free-oscillation method employed in reference 4 was used to determine experimentally the values of the rotary-damping-in-yaw parameter C_{n_r}. These values were derived from damping measurements of the model mounted on a strut that permitted freedom in yaw.

A three-view sketch of the model used in the tests is shown as figure 3 and a photograph of the model is shown as figure 4. The test model was so designed that vertical tails of different size (fig. 3) could be mounted at various locations along the fuselage, both ahead of and behind the center of gravity. Ten vertical tails were used during the tests. Eight of these tails, two each of tails 1 to 4 (fig. 3), were geometrically similar. Of the other two tails, one was extremely large (tail 5) and the other was of low aspect ratio (tail 6).

A photograph of the model with tail 5 in place is presented as figure 5. The dimensional and mass characteristics of the model used in the tests are given in table I.

TESTS

Test Conditions

The flight tests of the model were made for a wide range of values of the lateral-force parameter C_{Y_β} over a range of values of the directional-stability parameter C_{n_β} and the rotary-damping-in-yaw parameter C_{n_r}. Changes in these parameters were obtained by various combinations of vertical-surface area and tail lengths so that the lateral-force parameter could be varied while the directional-stability and rotary-damping-in-yaw parameters were held constant. The dihedral was zero for most of the tests.

The range of test conditions covered in the investigation is shown in figure 6 in the form of slope values obtained from the force tests and the free-oscillation tests of the various configurations. For most of the tests, the values of C_{Y_β}, C_{n_β}, and C_{n_r} were varied, respectively, from -0.0014 to -0.0201, from -0.00004 to 0.00260, and from -0.011 to -0.158. The ratio between $-C_{n_r}$ and C_{n_β} was held at a convenient normal value of about 60:1 for most tests, but no attempt was made to maintain an exactly constant value of this ratio. In addition, the model was tested with two configurations having a very high value of C_{Y_β} (-0.0600) for two large values of C_{n_β} and C_{n_r}. For some tests the vertical tail was removed and the minimum value of C_{n_r} occurred in this condition rather than at the negative value of C_{n_β} because, in order to obtain negative C_{n_β}, a vertical tail had to be added ahead of the center of gravity.

Flight tests were arbitrarily made at a lift coefficient of 0.5 for each of the conditions represented by the test points shown in figure 6. In order to determine the effect of lift coefficient, some tests were also made at a lift coefficient of 1.0. Flights were made for each test arrangement by use of ailerons alone or rudder coordinated with ailerons for control.

The total aileron deflection used in the tests was 30°. This deflection gave a value of $pb/2V$ of about 0.07 as measured in rolls from level flight with rudder fixed. For most of the tests the ailerons were rigged up 10° in order to minimize the adverse aileron yawing.

Flight tests were made at approximately 0° effective dihedral angle as indicated by force tests. The vertical tails were added above or below the fuselage in order to maintain the effective dihedral angle as near 0° as possible. One exception was the test with tail 5, which gave approximately 24° effective dihedral angle.

Throughout the tests, the mass characteristics were maintained constant at the values given in table I.

Flight Ratings

The model was flown at each of the test conditions represented by the parameter values in figure 6. Graduated ratings on stability, control, and general flight characteristics were assigned each test condition from pilot's observations of the model in flight. The stability and control ratings used were as follows:

Rating	Stability or control
A	Good
B	Fair
C	Poor
D	Very poor
E	Divergent

Plus or minus ratings were assigned to indicate slight but perceptible changes in the rating. Motion-picture records of some flights were made to permit more careful study of the flight behavior and thereby to aid observers in making more accurate flight ratings.

The stability rating of a free-flying model in a stable condition is generally determined in the free-flight tunnel from the steadiness of flight in the rather gusty air of the tunnel. A very stable model returns to its original flight path more rapidly after receiving a gust disturbance and generally does not tend to move as far from its original flight path as one with less stability. Greater stability is thus indicated by greater steadiness. For unstable conditions, however, the stability is judged from the rate at which the model deviates from straight and level flight and from the frequency of control application required to maintain steady flight.

The control rating is determined from the ease with which straight and level flight is maintained and from the response of the model to control applications designed to perform maneuvers. Any unnatural lag or motion in the wrong direction is judged as poor control.

The general flight ratings are based on the over-all flying characteristics of the model. The ratings indicate the ease with which the model can be flown, both for straight and level flight and for performance of the mild maneuvers possible in the Langley free-flight tunnel. Any abnormal characteristics of the model are generally judged as poor general flight behavior, inasmuch as they are disconcerting to the free-flight-tunnel pilots.

RESULTS AND DISCUSSION

The results of the investigation are summarized in figure 7, which presents pilot's ratings for the stability, control, and general flight characteristics. The stability and control ratings are substituted for the test point values of figure 6 and are therefore representative of various configurations. It should be remembered that these results were obtained at a dihedral angle of 0° ($C_{l_\beta} = 0$), except for tail 5, and are strictly true only for this dihedral angle; however, the qualitative effects of C_{Y_β} are believed to be unaffected by dihedral. The general effects of dihedral have been reported in references 5 and 6.

Effect of C_{Y_β} on Stability

The stability ratings of figure 7 show that increasing C_{Y_β} while maintaining C_{n_β} and C_{n_r} constant slightly increased the stability. The results of stability calculations, made by the method of reference 7, are presented in figure 8. The lateral-force parameter is given as a function of the period of the lateral oscillation (P) and as a function of the time required for the oscillation to damp to one-half amplitude $(T_{1/2})$. The results shown in figure 8 show the same trend noted in the results of figure 7. The increase in stability with increased C_{Y_β} is greatest for the smallest values of C_{n_β} and C_{n_r}. The calculations also show that C_{Y_β} has very little effect on the period of the lateral oscillation.

Effect of C_{Y_β} on Control by Use of Ailerons

The results of figure 7 show that increasing C_{Y_β} generally decreased the ease with which the model could be controlled with ailerons alone or rudder coordinated with ailerons. The deterioration in control was much greater for the low values of C_{n_β} and C_{n_r} than for the large values of these derivatives. The reduction in control with increased C_{Y_β} is explained as follows: When the model received a gust disturbance in yaw causing it to sideslip, the pilot gave corrective aileron control to bring the model back on course. As a result of this control application, the model rolled but the large side force opposed the lateral component of lift that tended to bring the model back to its original location in the tunnel. The return to the original flight path was thus abnormally slow. As C_{Y_β} and, hence, the opposing side force was increased, the aileron control became less effective in restoring the model to its original lateral position in the tunnel. For another case, if the model was in straight level flight and the pilot applied aileron control to perform a maneuver, the adverse yawing caused by the aileron deflection and rolling introduced a side force in such a direction as to oppose the side force produced by the angle of bank. This effect caused the model to hesitate or move first in the wrong direction and was therefore considered undesirable.

Effect of C_{Y_β} on General Flight Characreristics

The pilot's ratings for general flight characteristics are presented in figure 7 together with those for stability and control. These ratings are shown by the separated regions of figure 7(b) and indicate that the pilot preferred the ease of control obtained with low values of C_{Y_β} to the slight increase in stability resulting from increased C_{Y_β}. Obviously, the ideal configuration would be one that was both very stable and easily controlled. If low stability characteristics necessitated a compromise, the pilot's rating indicated a preference for ease of control rather than a slight increase in stability. The tests showed that the quantitative effect of varying C_{Y_β} was dependent upon the accompanying values of C_{n_β} and C_{n_r}.

Large values of C_{n_β} and C_{n_r}.- At extremely large values of C_{n_β} and C_{n_r}, such as are shown in the flying-bomb region in figure 6, all flights were given an excellent rating by the pilot despite the fact that two of the configurations tested had extremely large values of C_{Y_β}. For conditions in this region, the large amount of directional stability limited to small values the side-slipping due to adverse aileron yaw. As a result, the side force created by the large values of C_{Y_β} was not large enough to affect the aileron control appreciably.

Moderate values of C_{n_β} and C_{n_r}.- When C_{n_β} and C_{n_r} were reduced to values corresponding to those of the ordinary conventional airplane, large variations of C_{Y_β} appreciably affected the control of the model. For values of C_{n_β} corresponding to a conventional airplane with a rather large tail $\left(C_{n_\beta} = 0.00200\right)$, increasing C_{Y_β} from small to large values caused a corresponding reduction in general flight ratings from excellent to good. With smaller values of C_{n_β} and C_{n_r} $(C_{n_\beta} = 0.00140)$ in the conventional-airplane range the change in flight characteristics with large increases in C_{Y_β} was more pronounced (excellent to fair).

Small values of C_{n_β} and C_{n_r}.- Flights made in the tailless-airplane region $(C_{n_\beta} = 0.00014$ to $0.00080)$ were satisfactory only for the smallest values of C_{Y_β}. Increasing C_{Y_β} to larger values in this region resulted in very poor flight behavior.

Flights made at the lowest value of C_{n_β} $(C_{n_\beta} = 0.00014)$ in the tailless region, although very controllable (control rating, A-) were given a general flight rating of only fair. This rating was given because, although the model was stable in this configuration, it had a long-period large-amplitude yawing oscillation that was objectionable to the pilot. The model flew very steadily, however, because of the long period of the oscillation. This flight behavior has been previously reported for other tailless designs (model and full scale) and was similarly objectionable both to free-flight-tunnel and airplane pilots. Increasing C_{n_β} to a value of 0.00080 reduced the yawing oscillation to a great extent and resulted in satisfactory flights.

The model was directionally divergent in flights made with a negative value of C_{n_β} for values of C_{Y_β} equal to -0.0030 and -0.0105 and thus could not be given a control rating, but was however given a general flight rating of very poor. The directional divergence at both values of C_{Y_β} was very slow and the pilot felt that the divergence could have been prevented with independent rudder control had this control been available. In any case, the condition would have been given a general flight rating of very poor because of the unnatural control required.

Effect of lift coefficient.- Flights made at a lift coefficient of 1.0 showed a negligible change in flight behavior from corresponding flights made at a lift coefficient of 0.5 and consequently no data are presented for these tests.

CONCLUDING REMARKS

In tests, made in the Langley free-flight tunnel, in which ailerons were used as the principal control, it was found that, although large values of the lateral-force parameter C_{Y_β} (rate of change of lateral-force coefficient with angle of sideslip) increased the lateral stability, a definitely undesirable effect was obtained when ailerons were used to raise a low wing or to make a banked turn. This effect was particularly objectionable for small values of the directional-stability parameter C_{n_β} (rate of change of yawing-moment coefficient with angle of sideslip) and the rotary-damping-in-yaw parameter C_{n_r} (rate of change of yawing-moment coefficient with yawing angular velocity). For such conditions the adverse yaw accompanying aileron deflection created adverse side forces sufficient to interfere with the aileron control. The over-all flight behavior of the model was considered best with small values of C_{Y_β}.

For any value of C_{Y_β} the over-all flight characteristics were improved by increasing C_{n_β} and C_{n_r}. Increasing C_{n_β} and C_{n_r} was most effective at the smallest values of C_{Y_β}.

Little change in the flight characteristics was caused by a change in lift coefficient from 0.5 to 1.0.

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

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TABLE I

MASS AND DIMENSIONAL CHARACTERISTICS OF THE MODEL

Weight, lb	5.03
Wing:	
Area, sq ft	2.67
Span, ft	4.0
Aspect ratio	6.0
M.A.C., ft	0.70
Sweepback of 50-percent-chord line, deg	0
Dihedral, deg	0
Taper ratio (ratio of tip chord to root chord)	0.50
Root chord, ft	0.90
Tip chord, ft	0.45
Loading, lb per sq ft	1.89
Radii of gyration:	
k_X, ft	0.625
k_Z, ft	0.844
Ailerons:	
Type	Plain
Area, percent S	7
Span, percent b	46.2

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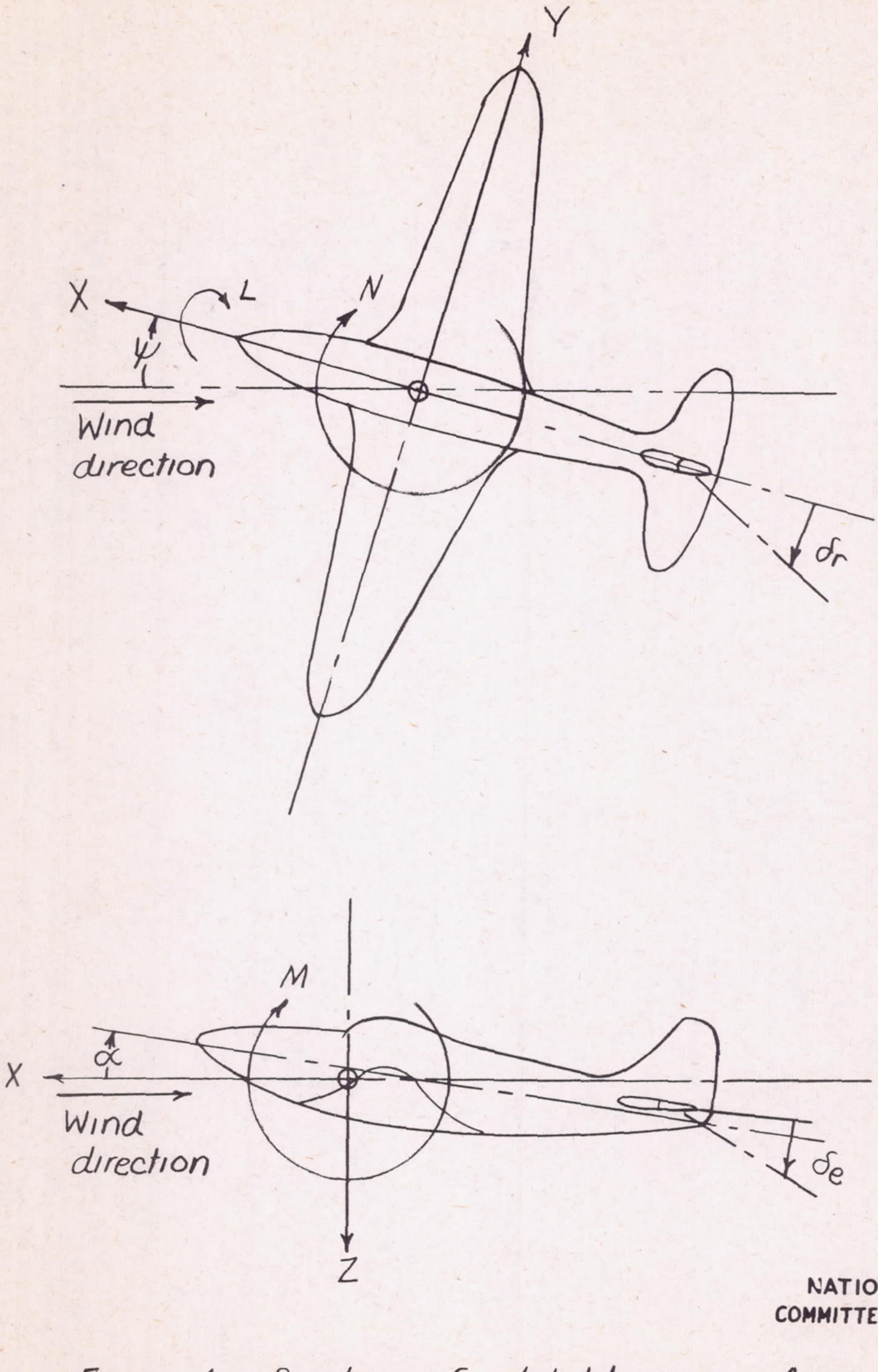

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Figure 1.- System of stability axes. Arrows indicate positive directions of moments, forces, and control-surface deflections.

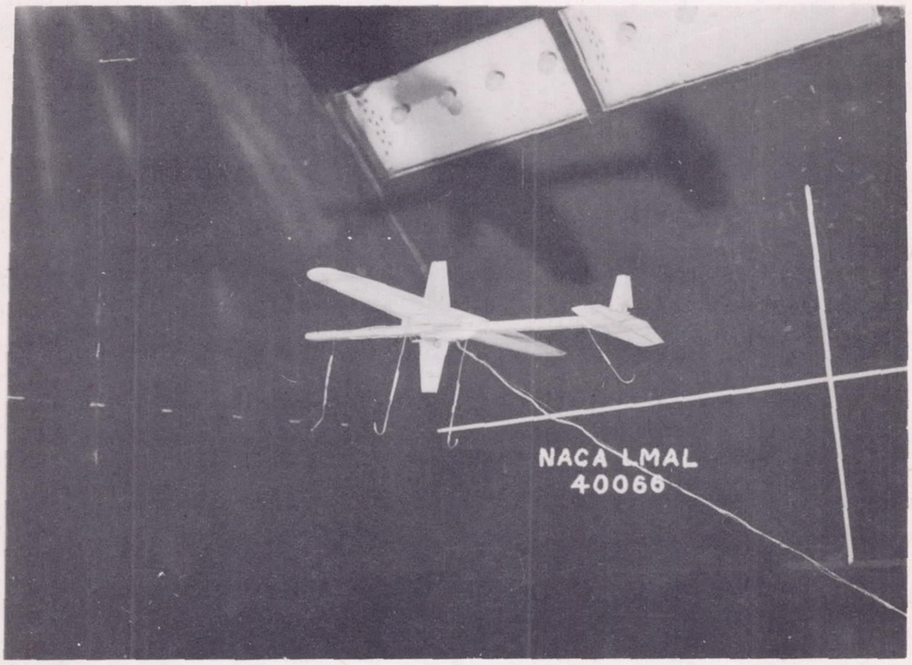
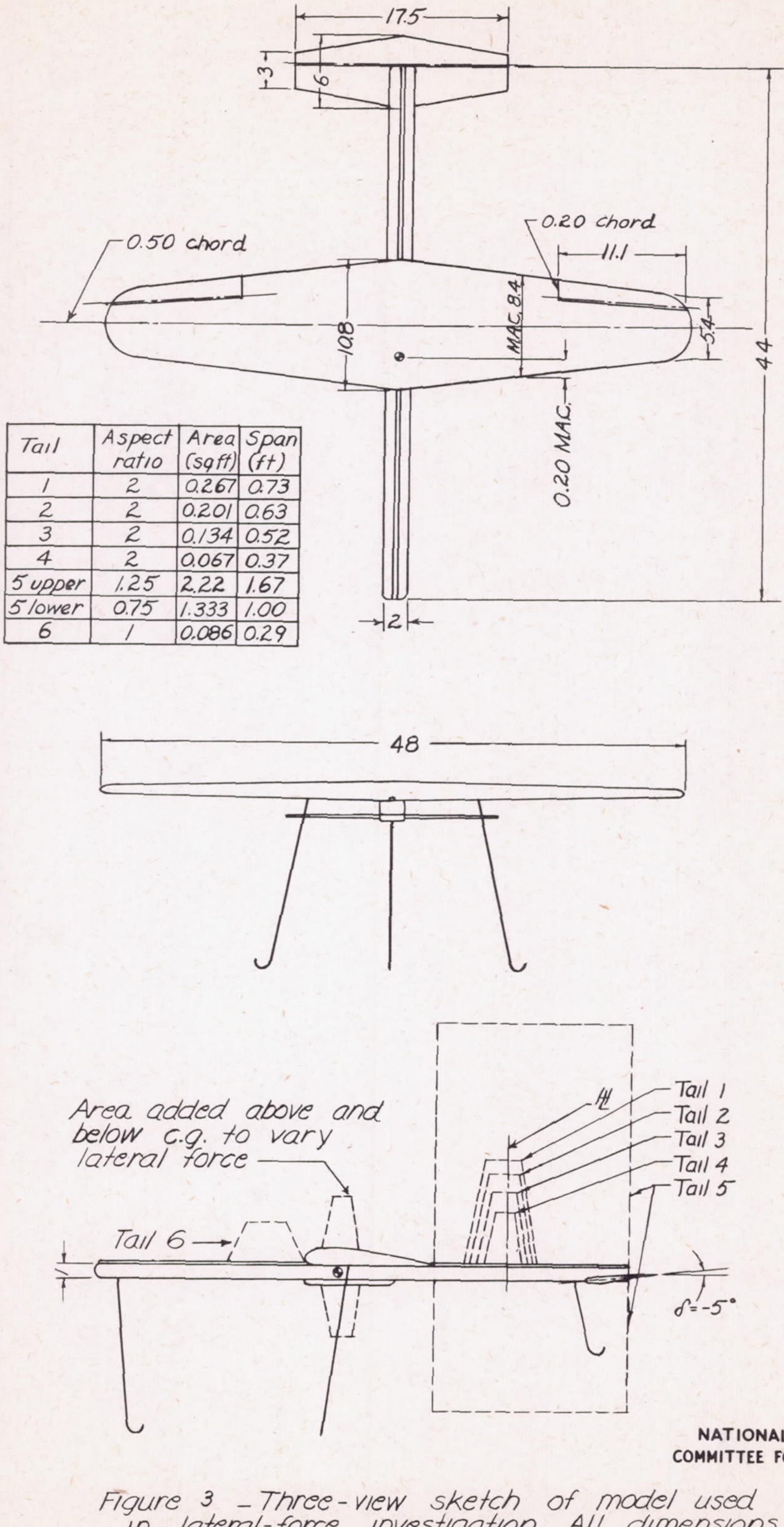


Figure 2.- Test section of Langley free-flight tunnel with model in flight. $C_{Y_\beta} = -0.0160$; $C_{n_\beta} = 0.00080$; $C_{n_r} = -0.064$; $C_L = 0.5$.



Tail	Aspect ratio	Area (sq ft)	Span (ft)
1	2	0.267	0.73
2	2	0.201	0.63
3	2	0.134	0.52
4	2	0.067	0.37
5 upper	1.25	2.22	1.67
5 lower	0.75	1.333	1.00
6	1	0.086	0.29

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Figure 3 – Three-view sketch of model used in lateral-force investigation. All dimensions in inches.

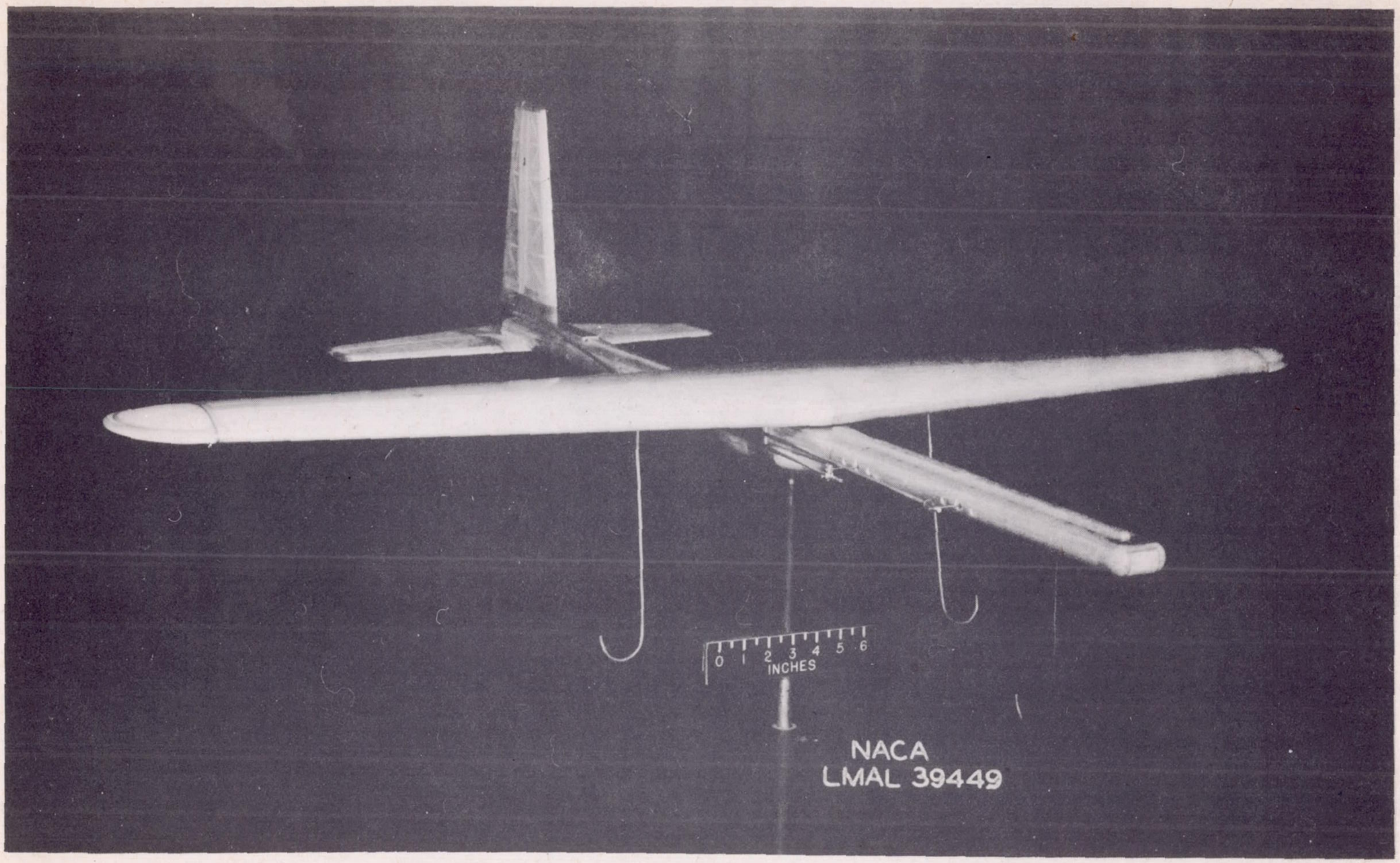

Figure 4.- Three-quarter front view of model used in lateral-force investigation in Langley free-flight tunnel showing tail 1 installed.

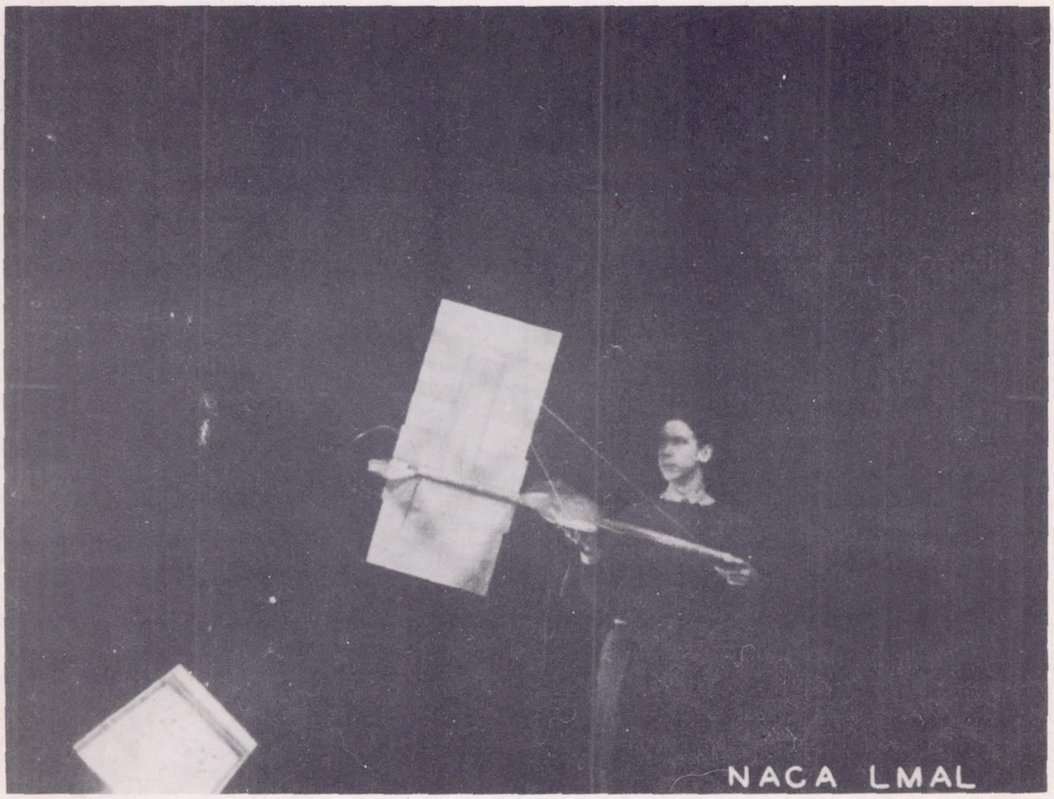

Figure 5.- Side view of model used in lateral-force investigation in Langley free-flight tunnel showing tail 5 mounted on model.

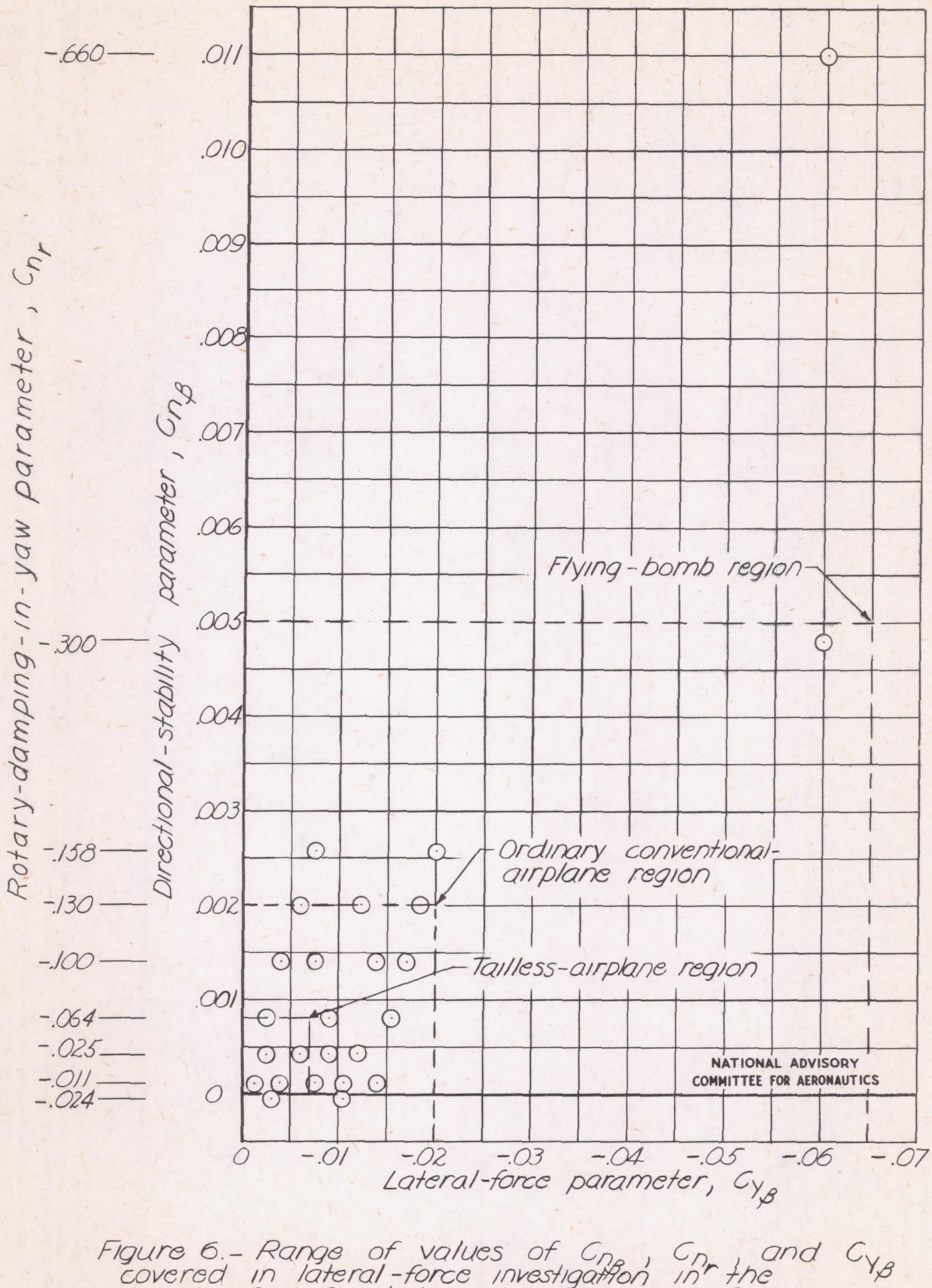

Figure 6.- Range of values of C_{n_β}, C_{n_r}, and C_{Y_β} covered in lateral-force investigation in the Langley free-flight tunnel and range of values for different types of aircraft. $C_L = 0.5$.

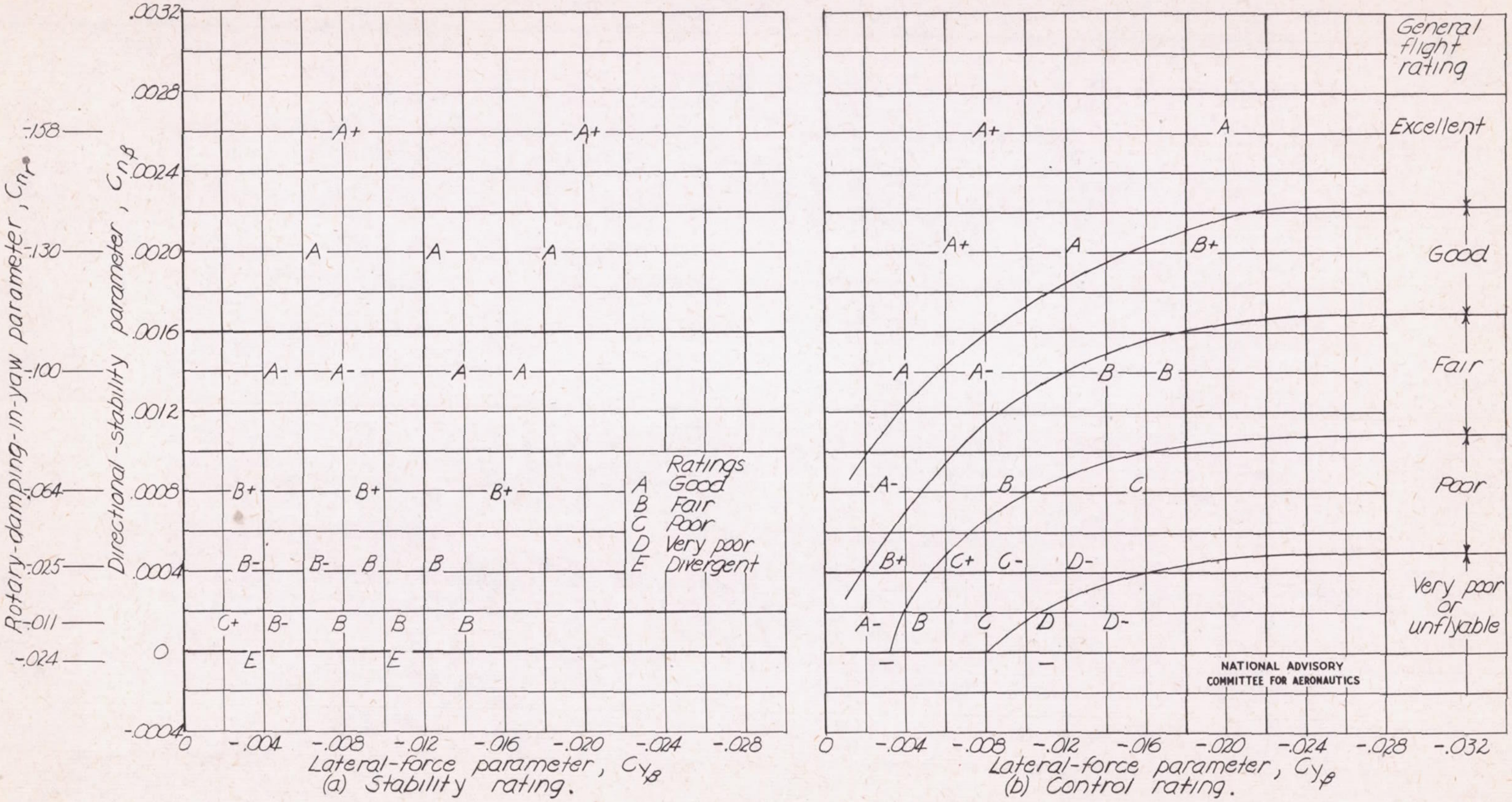

Figure 7.- Pilot's stability, control, and general flight ratings as determined in Langley free-flight tunnel. $C_L=0.5$; $C_{l_\beta}=0$.

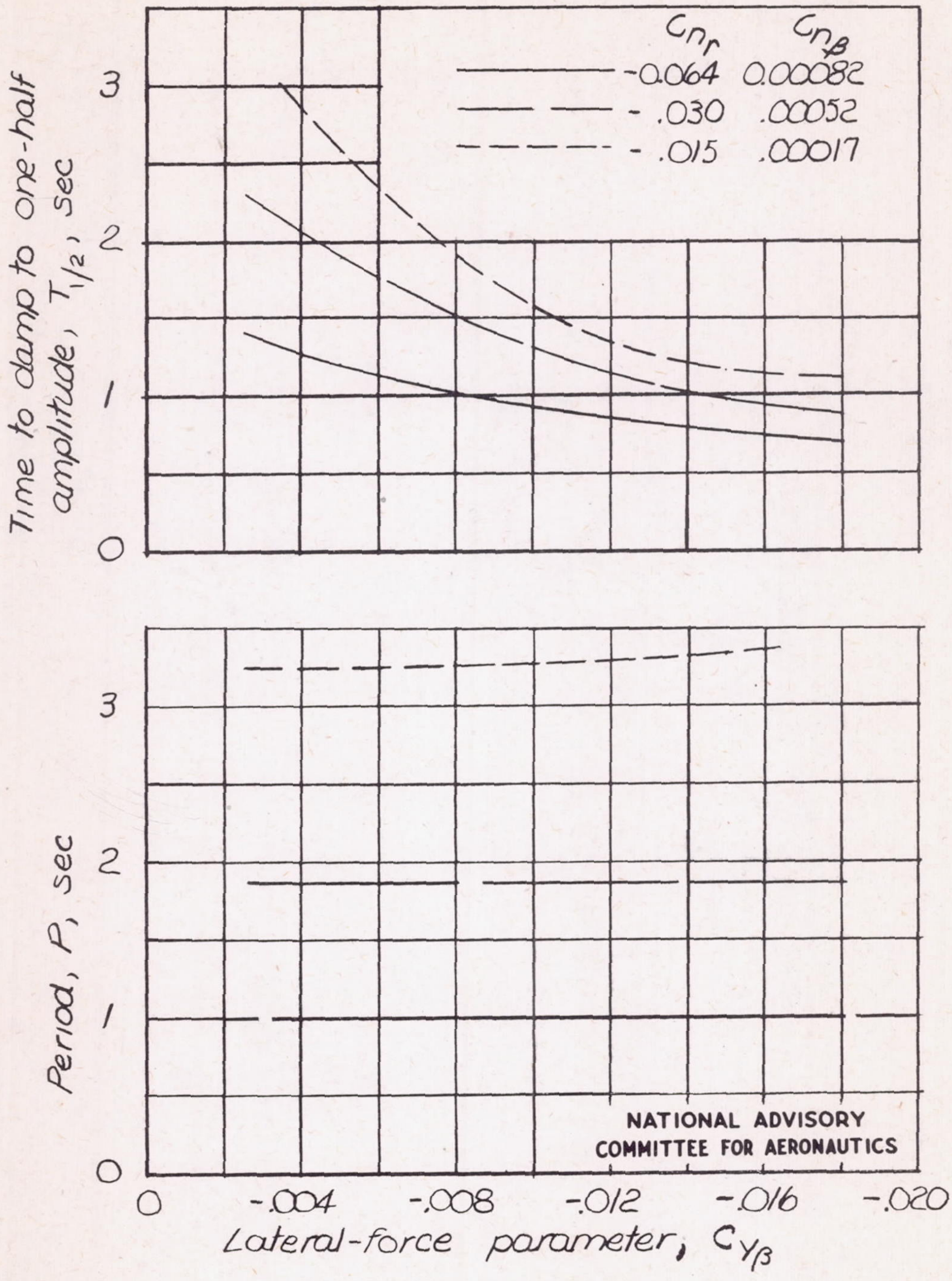

Figure 8.- Calculated characteristics of the lateral oscillation of the model used in the lateral-force investigation in the Langley free-flight tunnel. $C_L = 0.5$.