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RESEARCH MEMORANDUM

INVESTIGATION OF THE DYNAMIC LATERAL STABILITY AND CONTROL CHARACTERISTICS OF A MODEL OF A FIGHTER AIRPLANE WITHOUT A HORIZONTAL TAIL AND EQUIPPED WITH EITHER SINGLE OR TWIN VERTICAL TAILS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
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INVESTIGATION OF THE DYNAMIC LATERAL STABILITY AND CONTROL CHARACTERISTICS OF A MODEL OF A FIGHTER AIRPLANE WITHOUT A HORIZONTAL TAIL AND EQUIPPED WITH EITHER SINGLE OR TWIN VERTICAL TAILS

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SUMMARY

An investigation has been conducted in the Langley free-flight tunnel to determine the dynamic lateral stability and control characteristics of two configurations of a model of a fighter airplane without a horizontal tail, one with a single vertical tail mounted on the fuselage and the other with twin tails of about the same tail volume mounted on the wing. The results of the investigation indicated generally similar flight characteristics for the two configurations.

INTRODUCTION

Interest has recently been shown by aircraft designers in the relative merit of single and twin vertical-tail configurations on fighter airplanes with sweptback wings and without a horizontal tail. An investigation has therefore been conducted in the Langley free-flight tunnel to compare the dynamic lateral stability and control characteristics of two configurations of a model of such an airplane, one with a single vertical tail mounted on the rear of the fuselage and the other with twin vertical tails located approximately halfway out on the wing semispans. The two tail configurations had about the same tail volume. The model used in the investigation had a wing with 35° sweepback of the quarter-chord line, an aspect ratio of 3, and a taper ratio of 0.65.

The present investigation consisted of force tests to determine the static stability and aileron control characteristics of the model with the two tail configurations and flight tests to determine the dynamic stability and the controllability of the model with the two tail configurations. Flight tests were also made to determine the effect of decreased directional stability on the flying characteristics of the model.

SYMBOLS

All force and moment measurements were referred to the stability axes. A sketch showing the positive directions of the forces, moments, and angles is given in figure 1.

S	wing area, square feet
$\bar{c}$	mean aerodynamic chord, feet
b	wing span, feet
S_t	vertical-tail area, square feet
l_t	tail length (longitudinal distance from center of gravity to $c/4$ of vertical tail), feet
V	airspeed, feet per second
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
ρ	air density, slugs per cubic foot
α	angle of attack of fuselage center line, degrees
β	angle of sideslip, degrees $(-\psi)$
ψ	angle of yaw, degrees
φ	angle of roll, degrees
C_L	lift coefficient $(-Z/qS)$
C_D	drag coefficient $(-X/qS)$
C_m	pitching-moment coefficient $(M/qS\bar{c})$
C_Y	lateral-force coefficient (Y/qS)
C_n	yawing-moment coefficient (N/qSb)

C_l rolling-moment coefficient (L/qSb)

Z normal force, pounds

X longitudinal force, pounds

M pitching moment, foot pounds

Y lateral force, pounds

N yawing moment, foot pounds

L rolling moment, foot pounds

δ_a aileron deflection (perpendicular to hinge line), degrees

C_{Y_β} rate of change of lateral-force coefficient with angle of sideslip in degrees $(\partial C_Y/\partial\beta)$

C_{n_β} rate of change of yawing-moment coefficient with angle of sideslip in degrees $(\partial C_n/\partial\beta)$

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

Subscripts:

r right control surface

l left control surface

APPARATUS AND MODEL

The investigation was conducted in the Langley free-flight tunnel which is designed to test free-flying dynamic models. A description of the tunnel and the testing technique is presented in reference 1. Force tests to determine the static aerodynamic characteristics of the model were made on the Langley free-flight-tunnel six-component balance which is described in reference 2.

Three-view drawings of the model configurations used in the investigation are presented in figures 2 and 3 and photographs are given in figure 4. Table I presents the dimensional and mass characteristics of the design.

The wing of the model had a modified Rhode St. Genese 35 airfoil section. The use of this section is in accordance with the Langley free-flight tunnel practice of using an airfoil that will attain a reasonable maximum lift coefficient at low Reynolds numbers. The wing was set at 0° incidence with respect to the fuselage center line and the control surfaces on the wing were set at an upward deflection to balance out the pitching moment due to camber. The control surfaces were deflected in opposite directions from this trim setting for aileron control and in the same direction for elevator control. The tails were built in several sections, as shown in figures 2 and 3, in order that the directional stability of the model could be easily reduced by removing the various sections.

A comparison of the geometry of the two different tail configurations can be obtained from figures 2 and 3 and from table I. In estimating the tail volume $(S_t l_t)$ of the twin tails, the area of the landing-gear fairings located under the wing was neglected since this area is a low-aspect-ratio, rounded surface which probably contributes very little to the directional stability, except possibly at large yaw angles. On this basis, the total area of the twin tails is about 55 percent greater than that of the single tail. The single tail, however, has a tail length 55 percent greater than that of the twin tails so that its tail volume is about equal to that of the twin tails. The aspect ratio of the single tail was approximately 10 percent greater than that of the twin tails.

TESTS

Force tests were made to determine the static lateral stability characteristics of the model for the single-tail, twin-tail, and tail-off configurations. Rolling and yawing moments produced by aileron deflections and basic longitudinal stability characteristics were also determined for the two tail configurations.

All force tests were run at a dynamic pressure of 3.0 pounds per square foot, which corresponds to an airspeed of about 34 miles per hour at standard sea-level conditions and a Reynolds number of 420,000 based on the mean aerodynamic chord of 1.31 feet. All forces and moments for the model are referred to a center-of-gravity position at 0.20 mean aerodynamic chord and at a vertical position of 0.018 mean aerodynamic chord above the fuselage center line.

Flight tests were made to determine the effect of tail configuration on the dynamic stability and controllability characteristics of the model. The effect of reducing the directional stability was also studied. The flights were made at a lift coefficient of approximately 0.6

and with a static margin ($-\partial C_m/\partial C_L$) of about 0.16. The mass characteristics were approximately as shown in table I. A relatively light wing loading was used to minimize damage to the model in crashes.

RESULTS AND DISCUSSION

Force Tests

The results of force tests made to determine the static longitudinal and lateral stability characteristics of the model are presented in figure 5 to 7. The differential setting of the ailerons indicated on the figures corresponded to the flight-test trim conditions which were necessary because of asymmetry of the model due to warping and deformation resulting from crashes.

The data presented in figure 5 show that the model had about the same drag and longitudinal stability characteristics with either tail configuration but that the lift coefficient was generally slightly higher for the single-tail configuration. This can probably be accounted for by the difference in the interference effects on the wing for the two configurations.

The variation of the lateral coefficients with angle of yaw (fig. 6) is essentially linear over a range of yaw angles from 20° to -20° for either the twin or single tails or tail off at $\alpha = 12^\circ$, which corresponds approximately to the angle of attack of the model in the flight tests. The variation of the lateral-stability parameters $-C_{l_\beta}$, C_{n_β}, and $-C_{Y_\beta}$ with lift coefficient for the model with tails on and off is presented in figure 7. These parameters were obtained from force tests made at 5° and -5° yaw. The values of C_{n_β} were larger for the single tail than for the twin tails. Inasmuch as the tail volumes of the two configurations were about the same, this difference is probably due to the fact that the aspect ratio of the single tail was greater than that of the twin tail. With the tails removed the model had a small positive value of directional stability at the higher lift coefficients. The effective-dihedral parameter $-C_{l_\beta}$ was about the same for both configurations over the lift-coefficient range.

The results of aileron effectiveness tests made at $\alpha = 12^{o}$ with 15^{o} deflection of each aileron (which corresponds to the deflections used in the flight tests) are presented in the following table:

Configuration	C_l	C_n
Single tail	0.028	0.0045
Twin tails	.021	.0040

These data show that the aileron rolling moment was somewhat lower for the twin tails than for the single tail. The aileron yawing moment was small and favorable for each tail configuration, apparently because of the initial upward setting of the surfaces, and was relatively unaffected by tail configuration.

Flight Tests

The results of the flight tests showed that the vertical-tail configuration had very little effect on the general flying characteristics of the model. With either the twin-tail or single-tail arrangement the model was easy to fly. Oscillations resulting from normal control or gust disturbances were small and well damped. The model could be controlled as well with ailerons alone as with coordinated aileron and rudder control except in cases where the model was rather violently disturbed either inadvertently or intentionally. In these cases, recovery was effected more easily when the rudder was used in conjunction with the ailerons.

The flights made with the directional-stability parameter C_{n_β} reduced progressively from a large positive value to a small negative value, by removal of tail sections, indicated that the directional stability could be reduced considerably before any effect was noted. (See fig. 8.) With fairly small positive values of C_{n_β} the model was more easily disturbed in yaw and was more difficult to control once it was disturbed. Even with the tails removed, however, fairly good flights were obtained and it was difficult to disturb the model sufficiently by abrupt aileron deflection to cause the model to become uncontrollable.

The flying characteristics of a model with such low directional stability are usually unsatisfactory because of large-amplitude yawing motions which are excited by the adverse aileron yawing moment and the yawing moment due to rolling velocity. When the effective dihedral ($-C_{l_\beta}$) is moderate or large, this adverse yawing produces large rolling moments which tend to counteract the aileron rolling moments and thereby make the flying characteristics even more unsatisfactory. In the present investigation, however, flights were obtained with approximately zero directional stability and a moderately large value of $-C_{l_\beta}$ (0.0015) apparently because the disturbing yawing moments due to aileron deflection and rolling velocity were very small. The force-test results of figure 7 indicate that with tail off the model had negative C_{n_β} at the flight lift coefficient (0.6), but fairly satisfactory flights were obtained. Although these results might appear to be in disagreement, it is theoretically possible for no directional divergence to exist even when C_{n_β} is slightly negative, especially if the effective dihedral $-C_{l_\beta}$ has a moderately large positive value as it has in the present case.

During the tail-off flight tests the lift coefficient was reduced from about 0.6 to 0.5 and it became impossible to fly the model because of directional instability. This result substantiated the force-test results which showed a decrease in directional stability with decreasing lift coefficient.

CONCLUDING REMARKS

The results of the investigation to determine the dynamic lateral stability and control characteristics of a model without a horizontal tail and equipped either with a single vertical tail mounted on the fuselage or with twin tails of about the same tail volume mounted on the wing indicated generally similar flight behavior for the two configurations.

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REFERENCES

1. Shortal, Joseph A., and Osterhout, Clayton J.: Preliminary Stability and Control Tests in the NACA Free-Flight Wind Tunnel and Correlation with Full-Scale Flight Tests. NACA TN 810, 1941.

2. Shortal, Joseph A., and Draper, John W.: Free-Flight-Tunnel Investigation of the Effect of the Fuselage Length and the Aspect Ratio and Size of the Vertical Tail on Lateral Stability and Control. NACA ARR 3D17, 1943.

TABLE I

DIMENSIONAL AND MASS CHARACTERISTICS OF FIGHTER AIRPLANE

RESEARCH MODEL TESTED IN LANGLEY FREE-FLIGHT TUNNEL

Weight, W, lb	9.1
Wing loading, W/S, lb/sq ft	1.83
Relative-density factor, (Mass/ρSb)	6.78
Center-of-gravity location, percent M.A.C.	20
Moments of inertia (approx.)	
About X-axis, slug-ft^2	0.13
About Y-axis, slug-ft^2	.18
About Z-axis, slug-ft^2	.29
Ratio of radius of gyration to wing span (approx.)	
X-axis	0.19
Y-axis	.22
Z-axis	.29
Wing	
Airfoil section	Modified Rhode St. Genese 35
Area, sq ft	4.96
Span, ft	3.88
Aspect ratio	3.00
Sweepback of quarter-chord line, deg	35
Incidence, deg	0
Dihedral, deg	0
Taper ratio	0.65
Washout, deg	0
M.A.C., ft	1.31
Longitudinal distance between leading edge M.A.C. and leading edge root chord, ft	0.696
Root chord, ft	1.60
Tip chord, ft	0.967
Distance from nose to leading-edge root chord, ft	0.946
Elevators and ailerons	
Area, percent wing area (one)	9.7
Span, percent wing semispan (one)	43
Chord, percent wing chord (inboard end)	22.9
Chord, percent wing chord (outboard end)	29.2
Vertical tails (twin)	
Area, sq ft (total, neglecting landing-gear-fairing area under wing)	0.99
Area, sq ft (total, including landing-gear-fairing area under wing)	1.16
Tail span, ft	0.75
Aspect ratio	1.13
Tail length, ft (center of gravity to tail $\bar{c}/4$)	1.09
Tail volume ($S_t l_t$) (area above wing only)	1.08
Vertical tail (single)	
Area, sq ft	0.64
Tail span, ft	1.20
Aspect ratic	0.875
Tail length, ft (center of gravity to tail $\bar{c}/4$)	1.69
Tail volume ($S_t l_t$)	1.08

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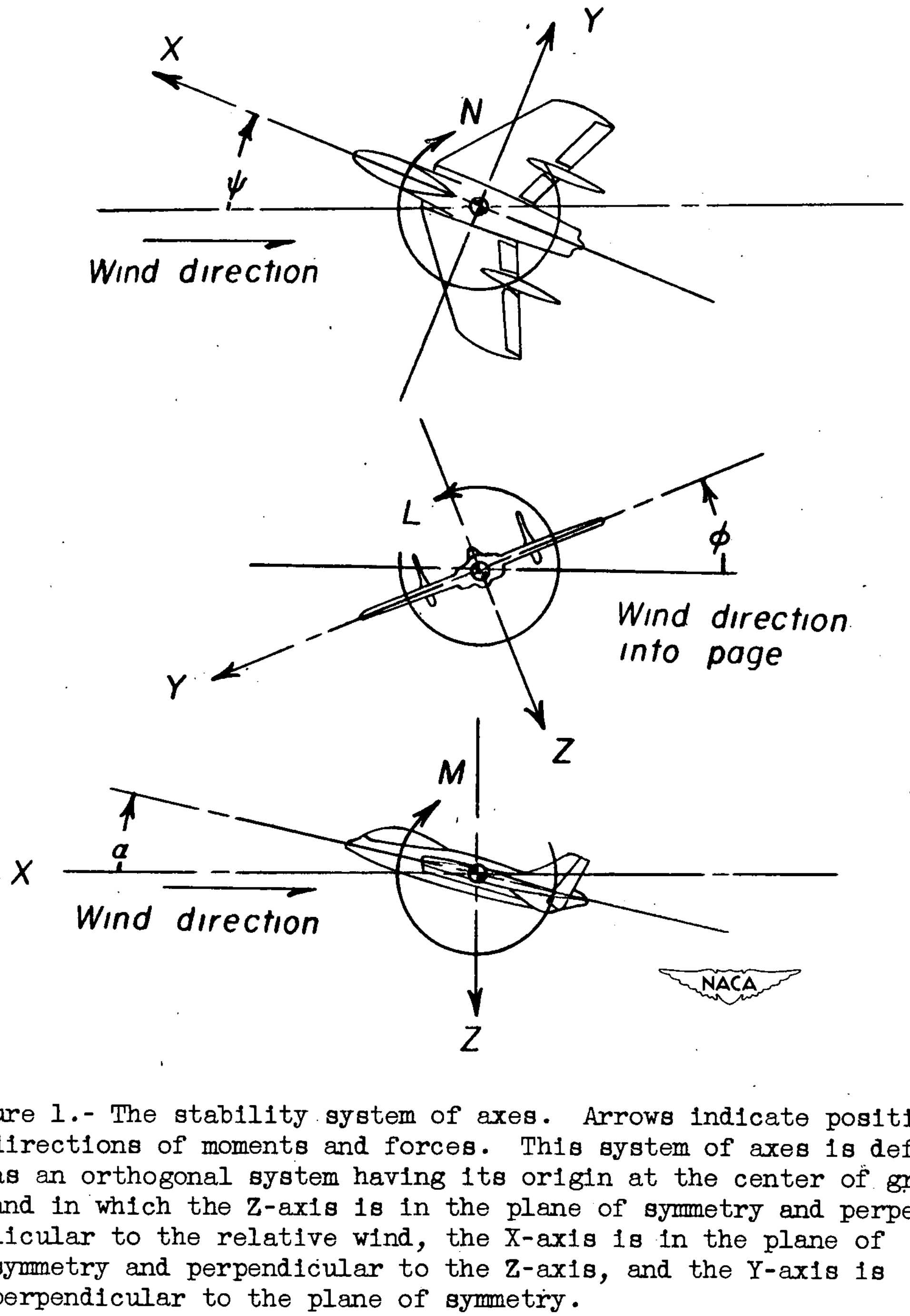


Figure 1.- The stability system of axes. Arrows indicate positive directions of moments and forces. This system of axes is defined as an orthogonal system having its origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.

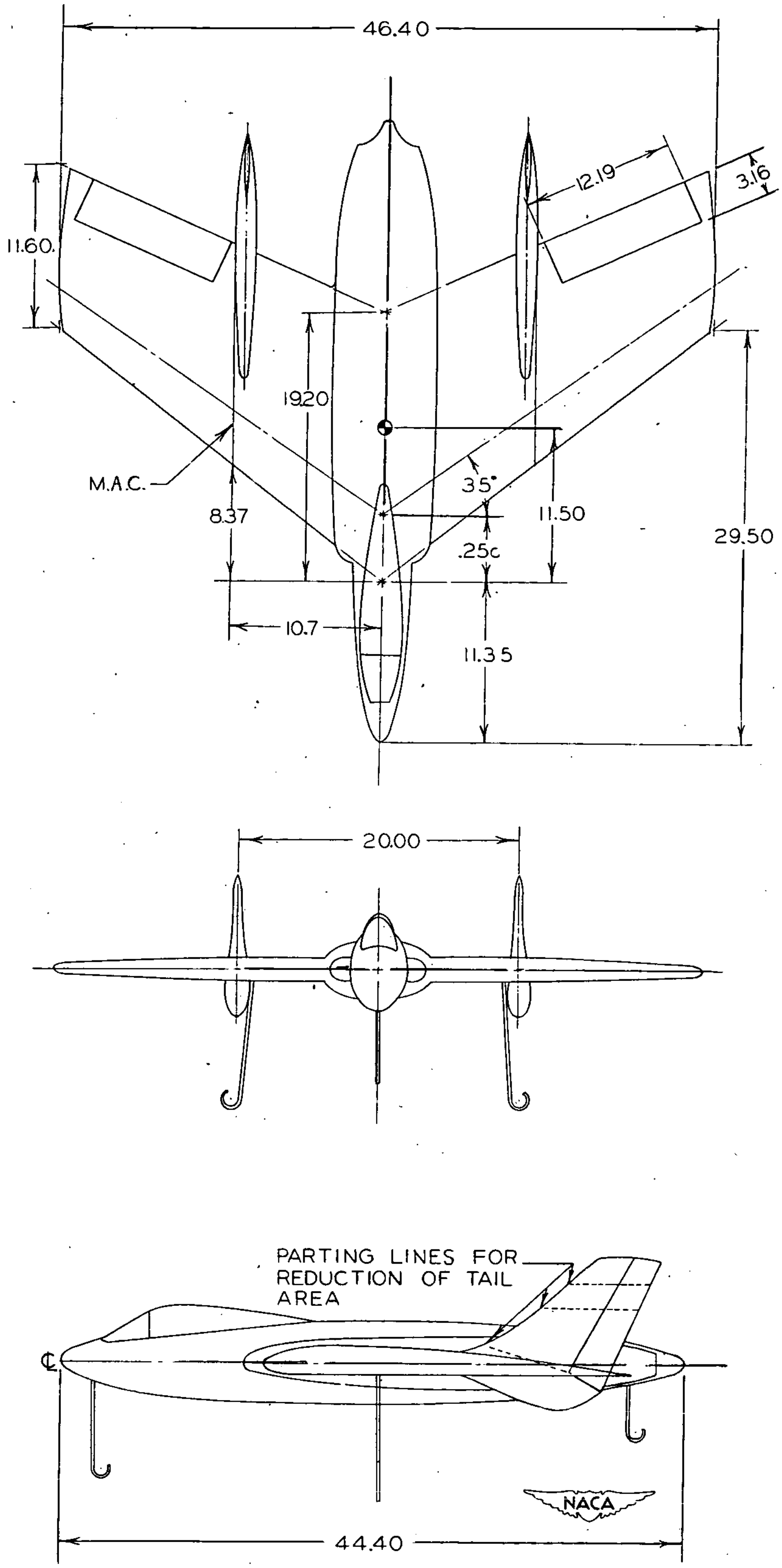


Figure 2.- Twin-tail configuration of fighter airplane model. (All dimensions are in inches unless otherwise noted.)

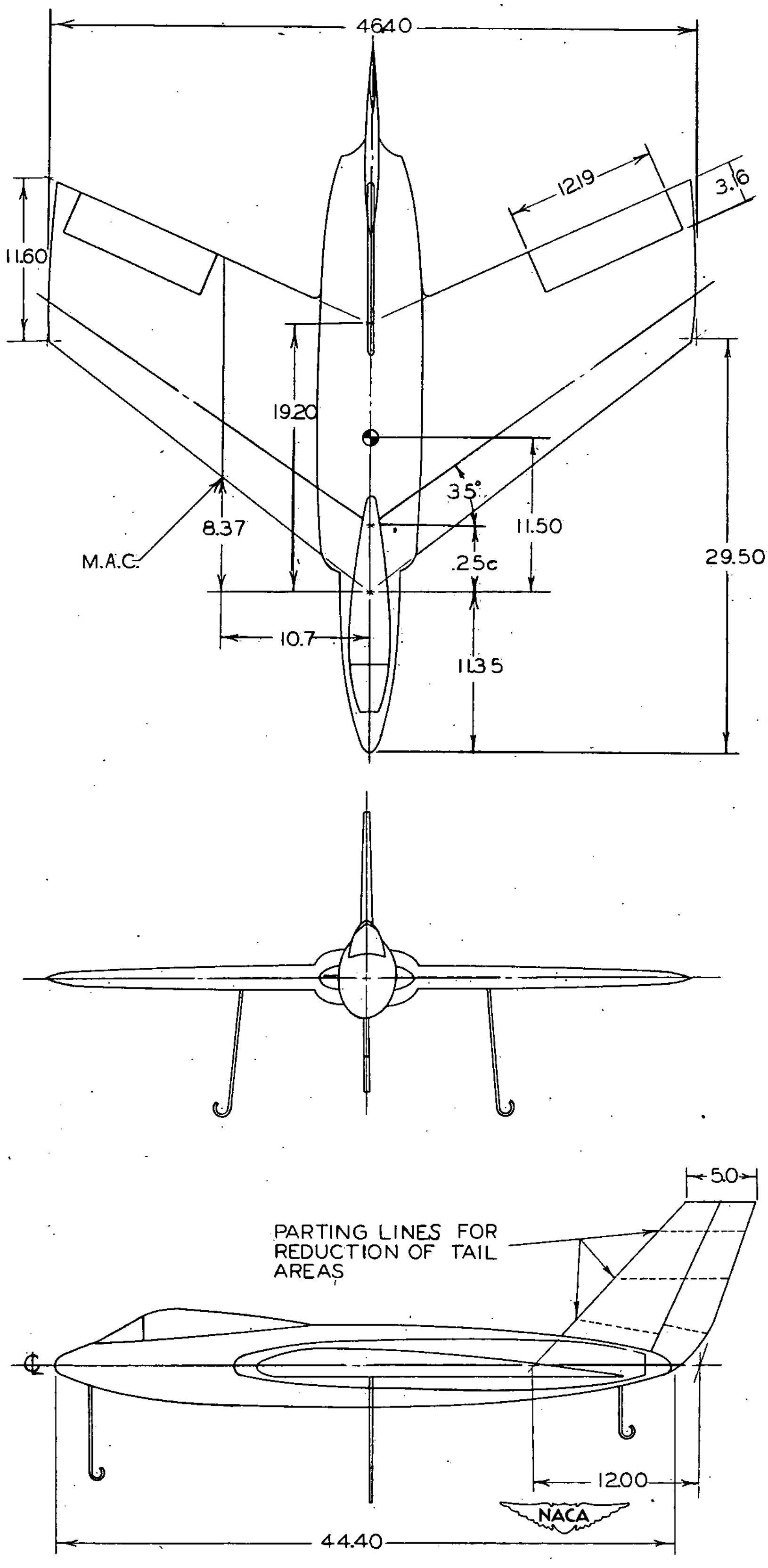
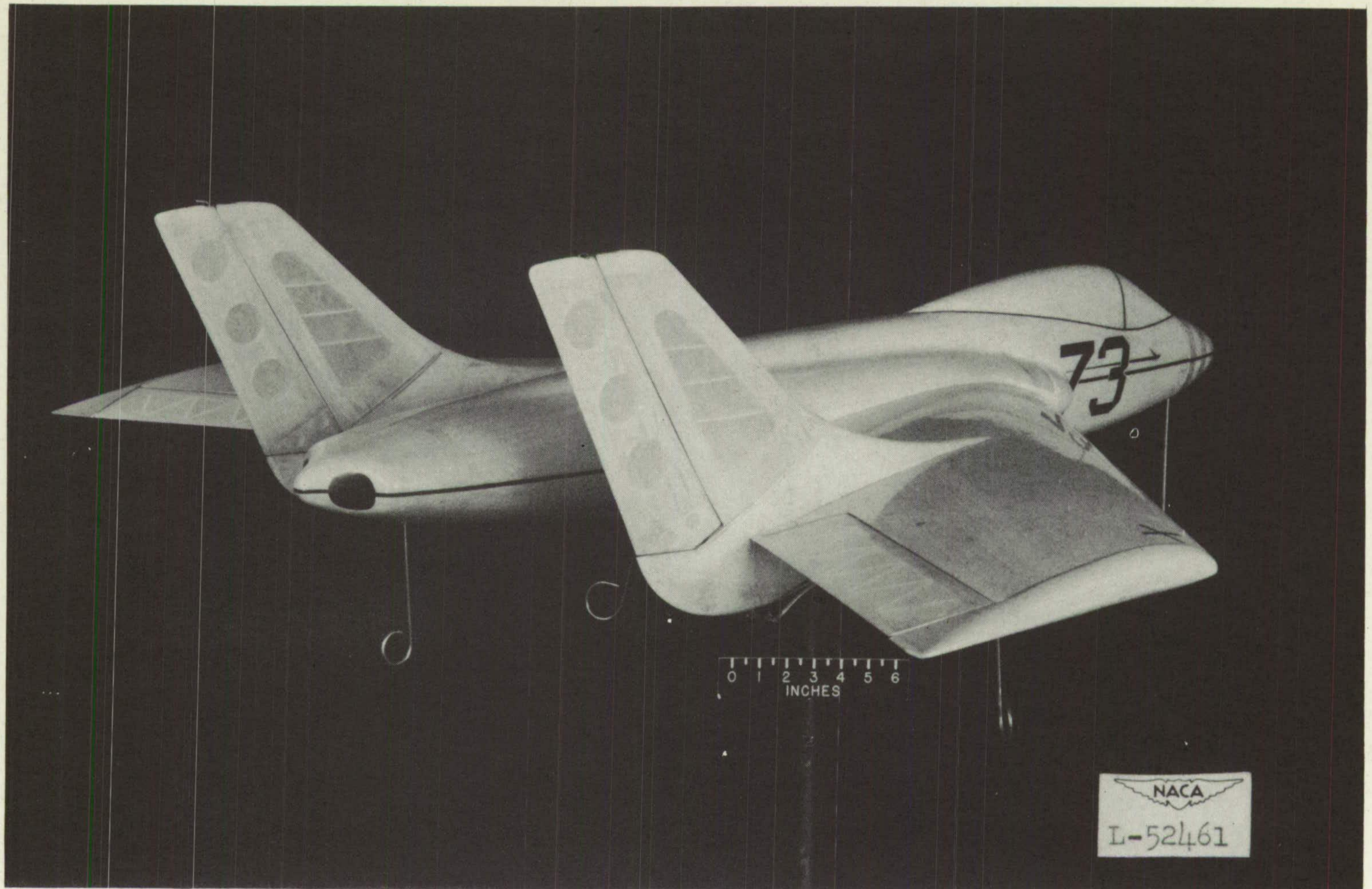
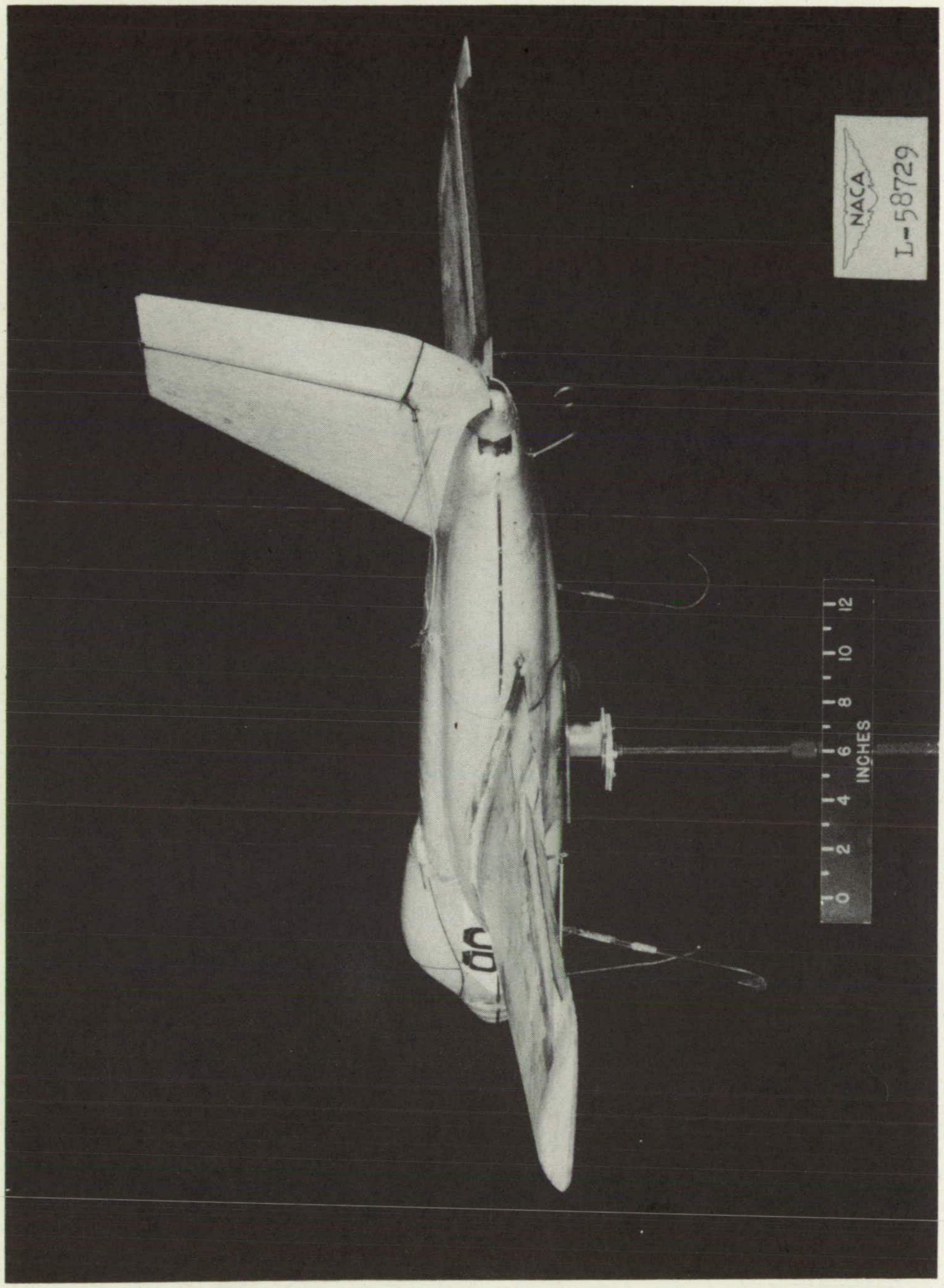


Figure 3.- Single-tail configuration of fighter airplane model. (All dimensions are in inches unless otherwise noted.)



(a) Twin-tail configuration.

Figure 4.- Model used for investigation conducted in the Langley free-flight tunnel.



(b) Single-tail configuration.

Figure 4.- Concluded.

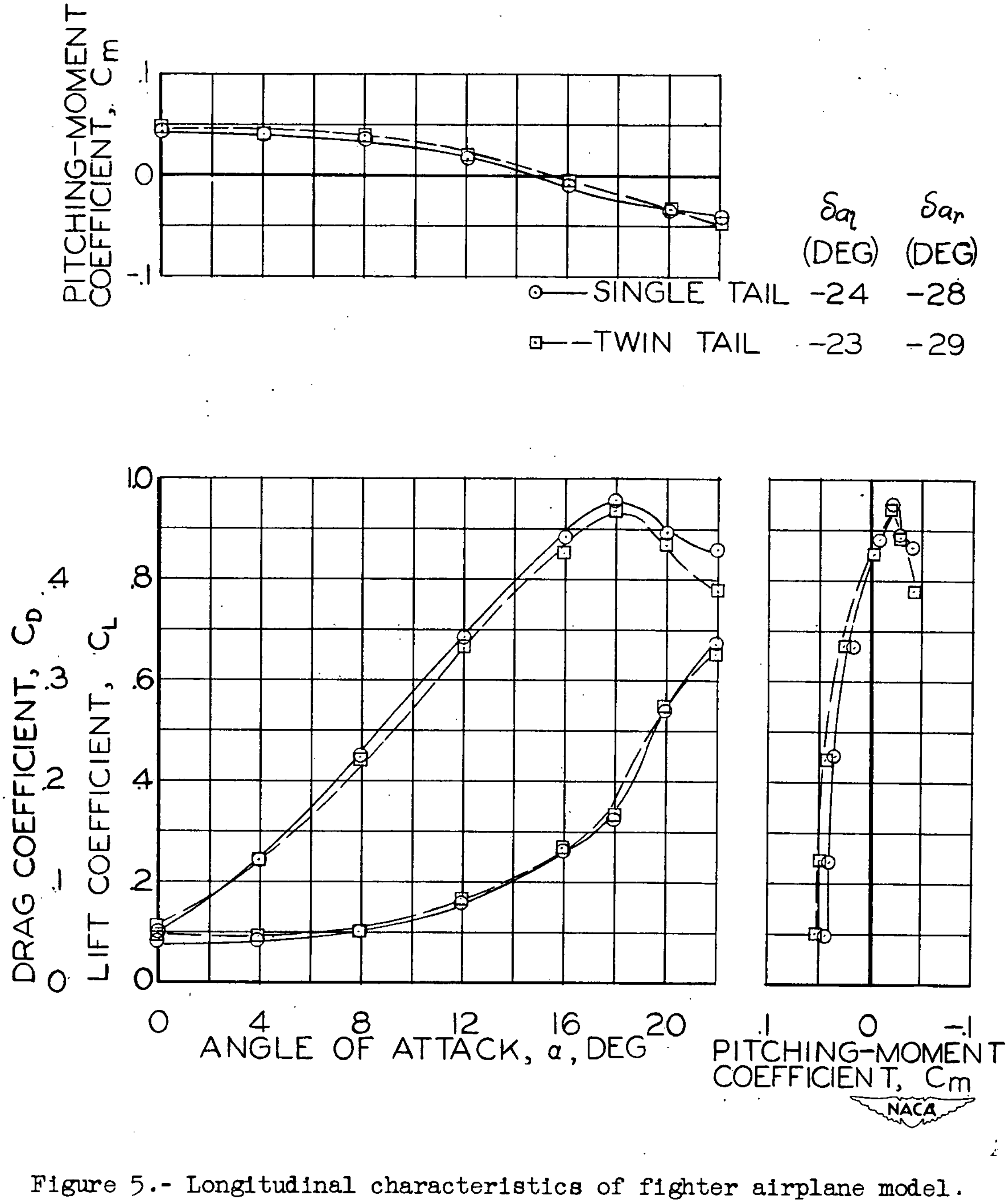


Figure 5.- Longitudinal characteristics of fighter airplane model.

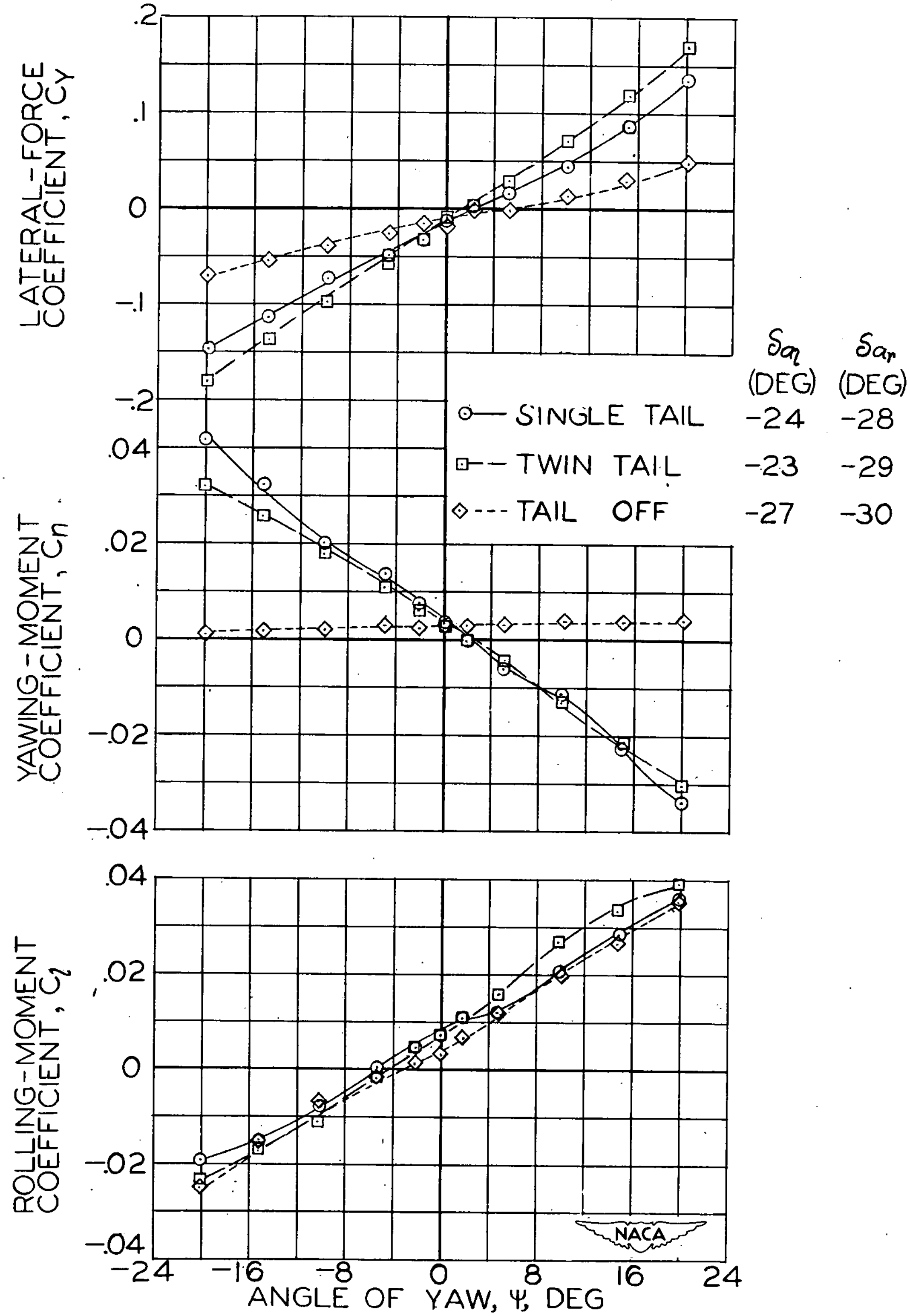


Figure 6.- Lateral characteristics of fighter airplane model. $\alpha = 12^{\circ}$.

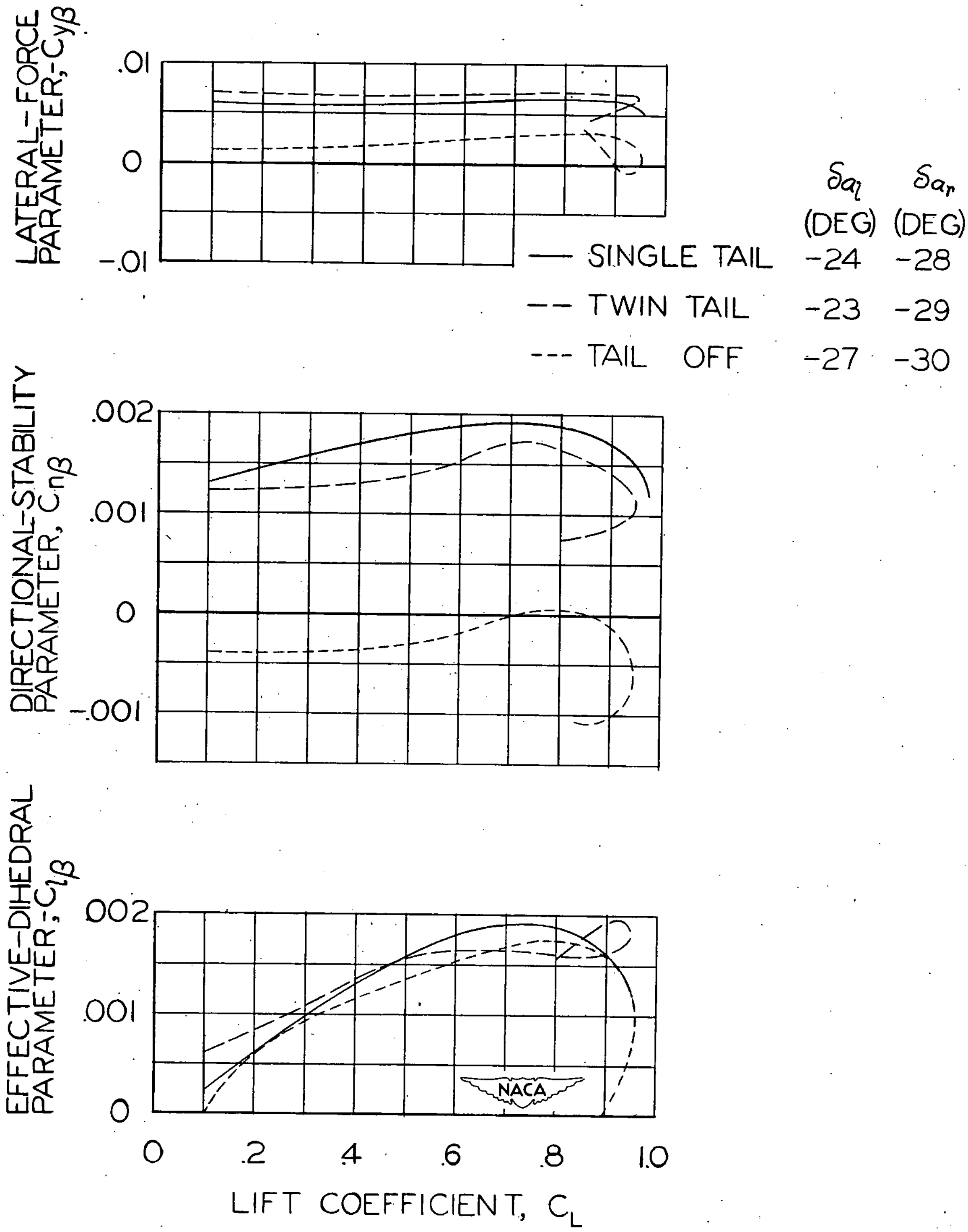


Figure 7.- Static lateral stability characteristics of fighter airplane model.

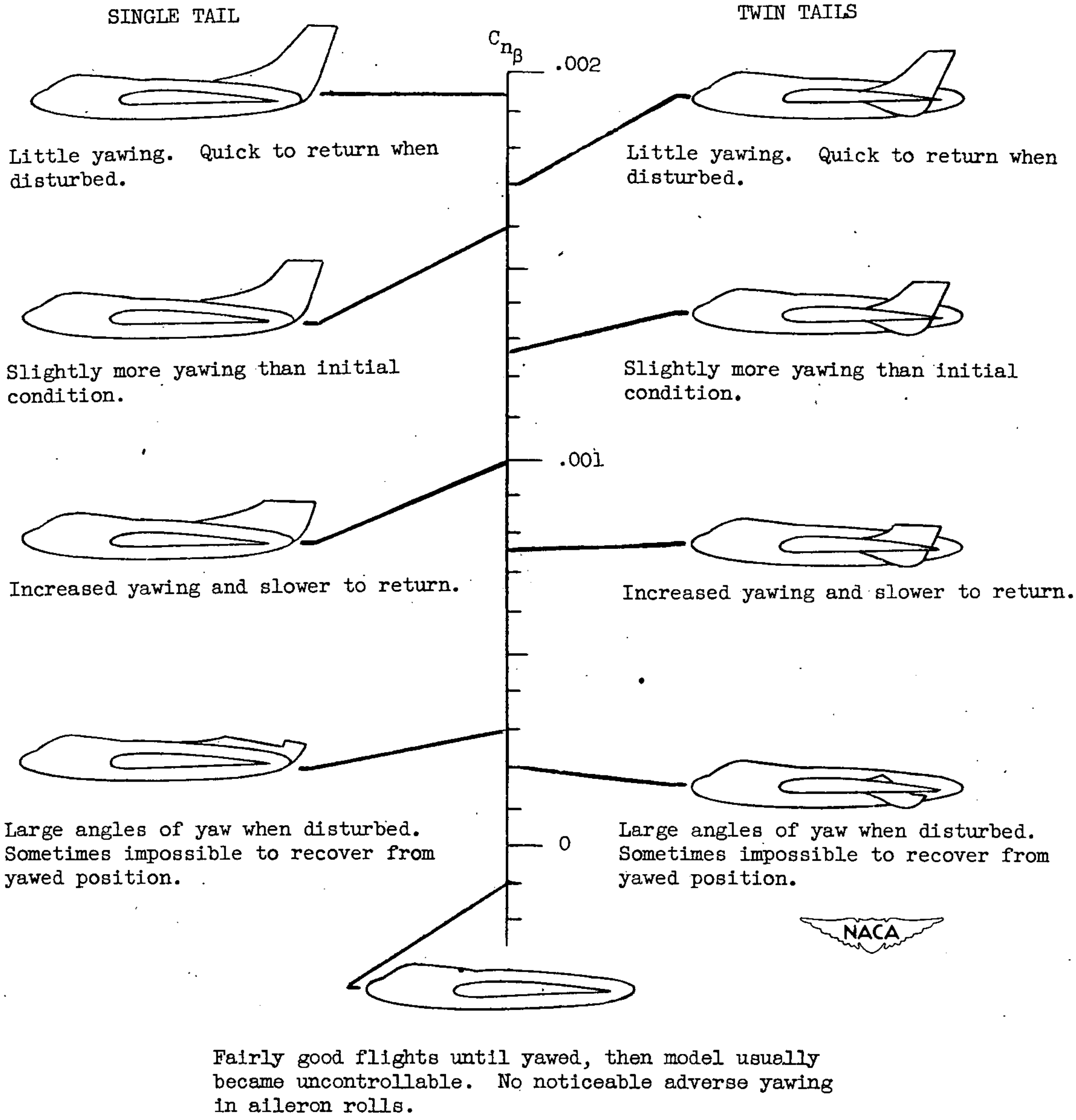


Figure 8.- Effect on flight characteristics of progressively reducing the directional stability for both configurations.